ORIGINAL ARTICLE

Low-Frequency Electric Muscle Stimulation Combined With Physical Therapy After Total Hip Arthroplasty for Hip Osteoarthritis in Elderly Patients: A Randomized Controlled Trial

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ABSTRACT. Gremeaux V, Renault J, Pardon L, Deley G, Lepers R, Casillas J-M. Low-frequency electric muscle stimulation combined with physical therapy after total hip arthroplasty for hip osteoarthritis in elderly patients: a randomized controlled trial. Arch Phys Med Rehabil 2008;89:2265-73.

Objective: To assess the effects of low-frequency electric muscle stimulation associated with usual physiotherapy on functional outcome after total hip arthroplasty (THA) for hip osteoarthritis (OA) in elderly subjects.

Design: Randomized controlled trial; pre- and posttreatment measurements.

Setting: Hospital rehabilitation department.

Participants: Subjects (N=29) referred to the rehabilitation department after THA for hip OA.

Interventions: The intervention group (n=16; 78±8y) received simultaneous low-frequency electric muscle stimulation of bilateral quadriceps and calf muscles (highest tolerated intensity, 1h session, 5 d/wk, for 5 weeks) associated with conventional physical therapy including resistance training. The control group (n=13; 76±10y) received conventional physical therapy alone (25 sessions).

Main Outcome Measures: Maximal isometric strength of knee extensors, FIM instrument, before and after; a six-minute walk test and a 200m fast walk test, after; length of stay (LOS).

Results: Low-frequency electric muscle stimulation was well tolerated. It resulted in a greater improvement in strength of knee extensors on the operated side (77% vs 23%; $P<.01$), leading to a better balance of muscle strength between the operated and nonoperated limb. The low-frequency electric muscle stimulation group also showed a greater improvement in FIM scores, though improvements in the walk tests were similar for the 2 groups, as was LOS.

Conclusions: Low-frequency electric muscle stimulation is a safe, well-tolerated therapy after THA for hip OA. It improves knee extensor strength, which is one of the factors leading to greater functional independence after THA.

Key Words: Aged; Electric stimulation therapy; Osteoarthritis, hip; Rehabilitation.

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GIVEN THE GOOD FUNCTIONAL results and the aging population, THA is becoming more and more frequent in the treatment of hip OA. Indeed, THA improves function and quality of life in such patients, in particular, those above 75 years of age.[1,2] In France, it is estimated that of 100,000 inhabitants, 135 undergo total hip replacement every year. This is relatively high when compared with the United States, where the rate is estimated at 53 of 100,000 inhabitants per year.[3] However, the number in the United States is increasing, especially among the individuals over age 65.[4]

Although rapid recovery of functional capacity in these often elderly patients is an essential requirement from a medical and financial point of view, the factors that determine the outcome after THA for hip OA need further investigation. The role of functional deterioration because of hip OA before the operation is controversial. In some instances, deterioration is a predictor of poor outcome,[5] whereas in others it is the most disabled patients who reap the greatest benefit in terms of functional improvement.[6] In the immediate postoperative period, minimally invasive hip arthroplasty is associated with lower levels of pain, reduced dependence on walking aids, and a faster return home. However, in the longer-term, the results in terms of functional improvement are identical to the conventional method.[7-9] The conditions of an aesthesia and intensive pain management also have an impact on outcome.[10]

The criteria that underlie the choice to send patients home or refer them to a rehabilitation center during the postoperative period also remain unclear. Senescence seems to be an important criterion.[11] Other parameters that influence the decision include social conditions and the family situation as well as the existence of comorbidities, particularly cognitive troubles.[12,13] One subjective aspect, the patient's preference, also appears to have an impact on decisions to discharge patients.[14] Variations in these parameters lead to major differences between coun-

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List of Abbreviations

ANOVA	analysis of variance
LOS	length of stay
OA	osteoarthritis
PT	physical therapy
ROM	range of motion
200mFWT	200-meter fast walk test
6MWT	six-minute walk test
THA	total hip arthroplasty

tries. For example, in France, 33% of patients are transferred to a rehabilitation center,[15] whereas in England it is 6%.[16] LOS in a rehabilitation center also varies; it seems to be determined particularly by senescence, and it is most frequently associated with comorbidities.[17] With regard to sex, women seem to suffer from greater deconditioning before surgery,[18] and this factor is also associated with a longer stay.[19]

The influence of physical parameters (eg, muscle strength) on functional outcomes and LOS have rarely been studied.[20] Muscular atrophy and the loss of muscle strength that accompany hip OA both limit functional recovery after this operation.[21] This atrophy is particularly marked in the gluteus medius muscle[22] and in the ipsilateral quadriceps,[23] in which it persists for at least 5 months after the operation despite rehabilitation.[24] The resulting loss of strength has an impact on the independence of patients with hip OA, both before and after arthroplasty,[25] and on hospital LOS.[21] Muscle aging is an aggravating factor in the loss of strength in the knee extensors,[26] and it leads to reduced walking autonomy in the elderly.[27,28] A deficit in knee extensor strength on the operated side after hip fracture has also been shown to be correlated with diminished walking performance in elderly women.[29] Because older patients suffering from hip OA often have decreased physical activity because of pain and joint stiffness, they often suffer from serious weakness of the knee extensors.[30,31] Thus, knee extensor strengthening seems to be of primary importance after THA.

Electric muscle stimulation has been known for a number of years for its efficacy in increasing the strength of healthy quadriceps.[32] Low-frequency electric muscle stimulation has been shown to be well tolerated and effective in increasing muscle strength and function in chronic diseases associated with severe muscle deconditioning, such as heart failure and respiratory insufficiency[33-36] and can reduce amyotrophy after arthroplasty of the knee.[37]

Very few studies have evaluated the effects of electric muscle stimulation after hip surgery in the elderly. Two controlled randomized studies investigated the effect of electric muscle stimulation of the quadriceps associated with routine physical therapy after surgical repair of hip or proximal femoral fracture,[38,39] and another prospective study evaluated recovery after THA for hip OA in subjects aged 60 years or more.[40] In these studies, moderate stimulation frequencies were used. The results of these studies are equivocal, and the functional effects were not always reported.

The aim of this study was to evaluate the feasibility and effects of low-frequency electric muscle stimulation when used in association with usual rehabilitation exercises on muscular and functional recovery and on independence in patients over 65 years of age who had undergone THA for hip OA.

METHODS

Study Design

This study was a prospective randomized study conducted in Dijon University Hospital's rehabilitation unit.

Eligibility. Patients 70 years of age or older living in their own home before surgery who had had unilateral THA for hip OA less than 2 weeks before admission to the rehabilitation department were eligible. Patients were not included if they had a history of stroke, Parkinson disease, neurologic gait disorders, neuromuscular disease that precluded the use of low-frequency electric muscle stimulation, postoperative complications such as infection or luxation, clinical depression or mental illness, or a foot pressure ulcer making walking impossible. Potential participants with cardiopulmonary contraindications for exercise training were also excluded from the study. Patients showing painful intolerance to low-frequency electric muscle stimulation were excluded after the first session. Anti-inflammatory medications and analgesics were not exclusion criteria.

Participants. Twenty-nine patients were recruited from the orthopedic rehabilitation unit. They were consecutively admitted after unilateral THA performed because of hip OA. A random number table was prepared in advance to randomly assign patients to the low-frequency electric muscle stimulation group that received low-frequency electric muscle stimulation and conventional physiotherapy or to a control group that received conventional physiotherapy alone. All gave their written consent after being clearly advised about the protocol, which was approved by the institutional ethics committee and conformed to the principles outlined in the Declaration of Helsinki.

Intervention

Low-frequency electric muscle stimulation. Low-frequency electric muscle stimulation consisted of the transcutaneous stimulation of both the quadriceps and calf muscles bilaterally by using 2 portable dual-channel stimulators.[a] Each delivered a 10-Hz biphasic current, with a pulse width of 200ms. Each cycle was alternatively on and off for 20 seconds. During stimulation, the legs were positioned without hip or knee flexion. Rectangular electrodes (80 × 100mm) were positioned on the thighs 3cm distal to the inguinal fold and 2cm proximal to the superior border of the patella. On the calves, they were placed just distal to the knee joint and at the point in which the soleus muscle ends and the tendo calcaneous begins. We chose to stimulate the quadriceps because it has a major role in preserving walking autonomy in the elderly[27,28] and the triceps surae because it has been shown that the strength of the ankle plantar flexor muscles is particularly affected by aging.[41] Moreover, stimulating larger muscle masses is more effective in improving functional capacity.[33]

The stimulation intensity applied to each muscle was increased throughout the training program to the maximum value tolerated by the patient. The maximum output intensity of the apparatus was blocked to avoid accidents. All patients received 1-hour sessions of low-frequency electric muscle stimulation training 5 days a week for 5 weeks in addition to the 2 hours of conventional physical therapy treatment. This protocol had already been validated in the treatment of amyotrophy associated with chronic heart failure.[33,34]

After every 5 sessions of low-frequency electric muscle stimulation, the degree of pain related to the stimulation was assessed by using a 6-level verbal scale relating to mean pain (0=no pain, 1=brief slight pain [<1h], 2=persistent slight pain [>1h], 3=brief moderate pain [<1h], 4=persistent moderate pain [>1h], 5=brief intense pain [<1h], 6=persistent intense pain [>1h]). A score higher than 3 was an exclusion criterion during the protocol.

The physiotherapy program. Both groups received the same conventional physical therapy treatment adapted to each patient's physical capacity. Sessions lasted 2 hours a day 5 days a week for a total of 25 sessions. If patients were sufficiently autonomous in daily activities and were discharged before the end of the 25 sessions, they continued rehabilitation (both physiotherapy and low-frequency electric muscle stimulation) as outpatients to ensure that the protocol was completed as planned. Physiotherapy included exercises to increase joint ROM, to increase muscle strength, and to improve functional status. Exercises to increase ROM comprised passive flexion and extension of the hip joint, initially using a continuous passive motion device with patient control and then they were performed manually by the physiotherapist. During these exercises, hip flexion never exceeded 90°. Muscle strengthening was performed bilaterally for flexor, extensor, and abductor muscles of the hip as well as knee extensors and ankle plantar flexors. At the beginning, static and then dynamic exercises without resistance were used. Later, exercises against progressive resistance were introduced. Special care was taken to make sure that any pain felt by patients was minimal and controlled. For the knee extensors, resistance comprised a sandbag fixed to the ankle. Each session lasted 10 minutes and included the following: sequences of concentric-static-eccentric contractions (5s) followed by a phase of myorelaxation (5s). Resistance was fixed at between 30% and 40% of the predetermined maximum muscle strength and was decreased in case of pain or muscle fatigue; it was adjusted every week according to the patient's progress. This resistance training is a validated and safe procedure to increase muscle strength in patients with deconditioning resulting from heart failure[42] or after hip surgery in the elderly.[43] For hip flexors, extensors, and abductors, exercises were initially performed against manual resistance applied by the physiotherapist and then by using a pulley system, with the same sequence as for knee extensors. Walking exercises with the necessary assistive devices were continued until the patient complained of fatigue. We sought to increase the distance on level surfaces and then introduce stair climbing. To limit cardiovascular deconditioning linked to age and hip OA,[44] training on an ergocyclometer was included as soon as healing was sufficient and hip flexion reached 90°. Arm ergometer exercises were also performed to improve adaptation to effort and the ability to move around.[45] The cardiovascular exercises were performed for 15 minutes at low power without causing significant dyspnea, corresponding to a score of 11 to 12 on the Borg scale. If necessary, proprioceptive exercises aiming to improve balance were also included as were exercises to improve autonomy in everyday life.

During rehabilitation, a visual analog scale was used to evaluate hip pain. If pain was evaluated over 5 on a 10-cm scale ranging from 0 (absence of pain) to 10 (maximum imaginable pain) more than 2 times, the patient was dropped from the study.

Measurements

All of the patients were evaluated at inclusion and 45 days later. A period of 45 days was chosen because the functional evolution is greatest between the sixth and ninth week after this kind of surgery.[46] The LOS in the rehabilitation unit was also recorded.

Maximal isometric strength of the knee extensors. Measuring maximal isometric force by dynamometry is straightforward, reliable, and valid even in elderly subjects in the aftermath of surgery for hip fracture, although values may be influenced by motivation, apprehension, and perhaps pain.[47] Patients were seated on a chair used for quadriceps training[b] fitted with a dynamometer.[c] The hips were flexed to 60° and the knees to 90° (0° corresponds to fully extended hips and knees), and the ankles were secured with a strap. A strap was also applied across the chest to minimize trunk motion during the contractions. The mechanical signals were sampled at a frequency of 2kHz and amplified by 5. Measurements were bilateral (the nonoperated lower limb and then the operated lower limb). The exercise began with a muscle warm-up against moderate manual resistance for 30 seconds; this was followed by a 2-minute rest period. Then, each patient was asked to perform 3 maximal isometric voluntary contractions. Verbal encouragement was given during effort. Each contraction was followed by a 1-minute rest period. The greatest force, expressed in Newtons, was used for the analysis.[48] The strength of knee extensors was measured at admission to the rehabilitation unit and 45 days later. The ratio of maximal isometric peak force of knee extensors between the operated and the nonoperated limb was calculated before and after the rehabilitation program.[39]

Walk tests. These tests were performed 45 days after admission to the rehabilitation unit on a 50-m unobstructed path. If needed, the patient used the walking aids (sticks, crutches, or walking frame) that gave the greatest feeling of security with the lowest risk of falling. On the eve of the test proper, the patients had a familiarization trial for the 2 tests. The 6MWT was conducted first and followed by a 30-minute rest period before the 200mFWT. Heart rate was monitored throughout the walk tests with a telemetric device.[d] Patients were also asked to rate dyspnea on a Borg scale at the end of each test.

For the 6MWT, patients were instructed to walk as far as possible at a self-selected pace from one end of the path to the other and back throughout the allotted time. The test was monitored, and the time was called out every 2 minutes. Standard encouragement at 30-second intervals was provided. The patients were allowed to slow down or stop to rest. At the end of 6 minutes, the total distance walked in meters was measured. The 6MWT was first validated to assess physical capacity in patients with heart failure.[49] It is reliable and reproducible and has also been used to evaluate functional status after arthroplasty.[50] When an exercise program was implemented in patients after THA, an improvement of more than 10% between the pre- and postoperative scores was reported.[51,52]

The 200mFWT consisted of walking twice up and down the 50-m long path as fast as possible without running. The time elapsed at the end of 200m was measured in seconds. No encouragement or times were given during the tests. This test provides complementary information on adaptation to effort in elderly subjects because it assesses an intermediate level of effort between the 6MWT and maximal capacities.[53] It can be used to quantify improvement in the functional status during a physical exercise program in patients aged over 70 years old.[54]

Length of stay. LOS was defined as the length of time (in days) the subjects were inpatients in the rehabilitation unit.

FIM instrument. FIM was assessed at admission and at day 45 after admission. This generic scale was validated in the evaluation of patients post-THA; an increase of 20 points or more is considered significant and corresponds to a real therapeutic effect.[12,55-57] A FIM efficiency score was calculated as the change in FIM from pre- to posttreatment divided by the LOS (delta FIM/LOS) and expressed as points gained per day.[56]

Statistical Analysis

Data are expressed as mean ± SD. The normality of the data was tested by using the Kolmogorov-Smirnov test for all studied parameters before statistical analysis. At baseline (pre), the anthropometric and the dependent variables for the 2 groups were compared by using a Student *t* test. An independent *t* test was also performed on posttreatment performances for the 6MWT and the 200mFWT, on FIM efficiency, and on LOS. ANOVA with repeated measures (group [low-frequency electric muscle stimulator vs PT] × time [pre vs post] × side [operated vs nonoperated]) was used on the strength of knee extensors. ANOVA with repeated measures (group [low-frequency electric muscle stimulator vs PT] × time [pre vs post]) was used on the FIM score and on the ratio of maximal isometric peak force of knee extensors. Significance was set at

Table 1: Anthropometric Data of the Studied Population

	Age (y)	Sex	Body Weight (kg)	Height (cm)	BMI
LFEMS (n=16)	78±8.6	10M/6F	65±13	164±8	24.2±5.8
Control group (n=13)	76±10.1	8M/5F	69±15	167±9	23.3±3.5

NOTE. Data are expressed as mean ± SD.
Abbreviation: LFEMS, low frequency electric muscle stimulation.

P less than .05. When a major effect or an interaction was found, post hoc analysis was performed by using the Scheffe test. Statistical analyses were performed by using the Statistica program for Windows.[e]

RESULTS

Participants

Thirty-two subjects were included, 16 patients in each group. All of the patients in the low-frequency electric muscle stimulation group completed the protocol, whereas 3 patients in the control group were unable to complete the protocol: 1 because of an infection of the surgical wound, l for pain in the operated hip, and 1 refused to take part in the final tests. There were no problems with regard to the surgery scar for placement of the electrodes on the thigh. No reported local intolerance to low-frequency electric muscle stimulation (in particular, no skin lesions) was found. There were no cases of muscle pain caused by low-frequency electric muscle stimulation (no scores >2 on the pain questionnaire).

The anthropometric data for the 2 groups are given in table 1. There were no significant differences between the 2 groups with regard to anthropometric data.

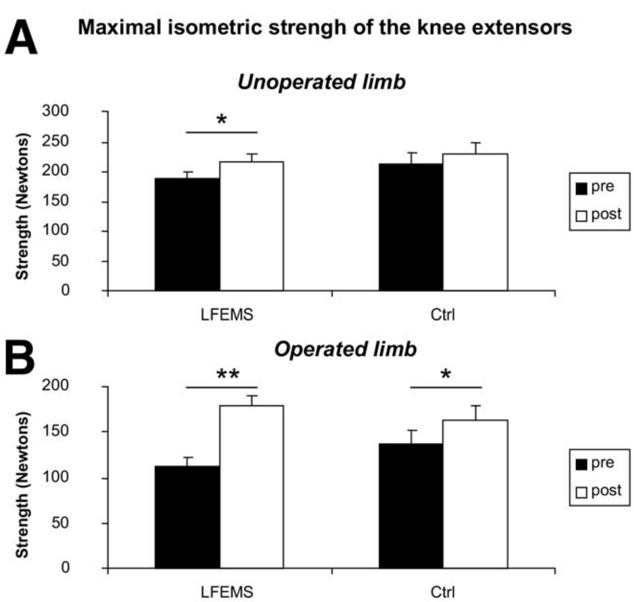

Fig 1. Pre and post trial measurements of the knee extensors, maximal isometric strength of the operated and unoperated limb in the (A) LFEMS group (n=16) and (B) control group (n=13). Data are expressed as mean ± SD. Abbreviation: Ctrl, control group; LFEMS, low-frequency electric muscle stimulation group. **P<.01; *P<.05.

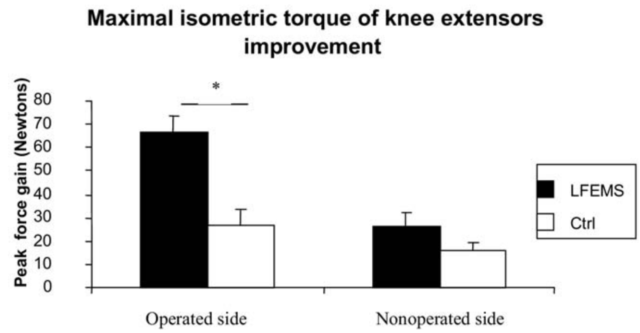

Fig 2. The change in maximal isometric peak force of knee extensors in the operated and nonoperated side. Data are expressed as mean ± SD. Abbreviations: Ctrl, control group; LFEMS, low-frequency electric muscle stimulation group. *P<.05.

Maximal Isometric Strength of the Knee Extensors

Data for strength of knee extensors in the operated limb and nonoperated limb are shown in figure 1. There was no difference between the 2 groups at admission concerning mean strength of the knee extensors.

ANOVA showed a group × time × side interaction effect. Post hoc analysis showed a significant pre-postincrease in the strength of knee extensors on both sides in the low-frequency electric muscle stimulation group (operated side, 112.7±9.3N to 179.4±10.5N [77% increase]; P<.01; nonoperated side, 189.2±11.7N to 215.8±13.4N [15% increase]; P<.05). Improvement in the control group was significant only in the operated side (137.4±14.4N to 164.1±15.4N [23% increase], P<.05). Figure 2 shows the mean change in the strength of the knee extensors for the 2 groups. The low-frequency electric muscle stimulation group experienced a significantly greater gain than the control group for the operated limb (66.68±27.6N [77%] vs 26.7±19.95N [23%], P<.05). With regard to the nonoperated limb, the improvement was also greater for the low-frequency electric muscle stimulation group (15% vs 8%), although the difference did not reach significance.

The size effect ([mean difference post-pre for knee extensor strength]/[SD of preknee extensors]) in the operated side was 7.17 in the low-frequency electric muscle stimulation group versus 1.85 in the control group. In the nonoperated side, size effect was 2.27 in the low-frequency electric muscle stimulation group versus .87 in the control group.

Concerning the ratio of maximal isometric peak force of knee extensors between the operated and the nonoperated limb

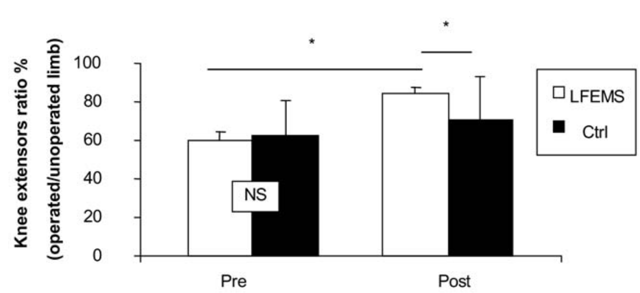

Fig 3. Maximal isometric torque of knee extensors ratio between the operated and nonoperated side before and after rehabilitation. Data are expressed as mean ± SD. Abbreviations: Ctrl, control group; LFEMS, low-frequency electric muscle stimulation; NS, nonsignificant. *P<.01.

(fig 3), ANOVA showed a group × time interaction effect. Post hoc analysis revealed a significantly greater improvement for the low-frequency electric muscle stimulation group (59.8±7.6% to 84.3±10.8% and 62.8±14.3% to 70.4±12.9% in the low-frequency electric muscle stimulation and control group respectively, $P<.01$).

Walk Tests

There were no cases of osteoarticular pain severe enough to disturb the tests. There was no significant difference between the 2 groups with regard to walk-test performances evaluated on day 45 (276±89.4m vs 283.2±107m) for the low-frequency electric muscle stimulation and control group, respectively, for the 6MWT and (226.7±102.5s vs 212.8±123.6s) for the 200mFWT.

FIM Instrument

The FIM scores for the 2 groups at admission were comparable (99.8±9.7 vs 97.8±10.8 for the low-frequency electric muscle stimulation and control group, respectively). ANOVA showed a group × time interaction effect. Post hoc analysis showed a significant pre-postimprovement only in the low-frequency electric muscle stimulation group (121.1±3.8 [21.8% increase] vs 113.4±6.8 [16% increase], $P<.05$).

Length of Stay

The LOS as an inpatient in the rehabilitation unit was comparable in the 2 groups (24.33±5.2d compared with 26.33±7.38d) in the low-frequency electric muscle stimulation and control group, respectively.

FIM efficiency (Delta FIM/LOS) was significantly greater in the low-frequency electric muscle stimulation versus control group, .90±.30 and .60±.20 points per day, respectively ($P<.01$).

DISCUSSION

Our results suggest that low-frequency electric muscle stimulation associated with conventional physiotherapy is superior to physiotherapy alone in increasing strength of the knee extensors, which is accompanied by a return to better muscular equilibrium between the operated and nonoperated limb. The low-frequency electric muscle stimulation also led to a greater degree of independence as measured by the FIM. However, the hospital LOS was not reduced, and the walking performances were not better in the low-frequency electric muscle stimulation group compared with the control group.

Hip OA is the cause of deterioration in both muscle mass and strength in the ipsilateral quadriceps,[23] especially in older patients.[21] A number of mechanisms are involved in this deterioration, including pain, prior decrease in physical activity because of the hip OA, and perioperative immobilization.[58] Disturbances in myostatin secretion of muscle cells are also implicated in amyotrophy of the quadriceps, which accompanies hip OA before arthroplasty.[59]

To our knowledge, this is the first study to explore the effects of an association of low-frequency electric muscle stimulation and resistance training on the functional status of elderly patients who had undergone THA for hip OA. As noted after knee arthroplasty, low-frequency electric muscle stimulation associated with physiotherapy improved knee extensor strength[37] but was not associated with better walking capacity.[60] This gain in strength of knee extensors was significantly greater in the operated side in the low-frequency electric muscle stimulation group, and the size effect was greater than that observed in the control group. Patients who received low-frequency electric muscle stimulation did not perform better in walking tests than did patients who received standard physical therapy, despite the more marked improvement in muscle strength in the low-frequency electric muscle stimulation group. This absence of correlation between muscle strength and walking speed has already been reported.[39,61] A nonlinear relationship between these 2 variables has been shown in healthy older adults and may have been more marked in this study because of motor disturbances that are secondary to hip OA and to the surgery or differences among patients with regard to cardiovascular fitness.

We chose to measure outcomes 45 days after admission to rehabilitation as the evolution in the functional status of patients is greatest between the sixth and ninth week after surgery.[46] However, this previous work was performed on younger patients (mean age, 60.2±11.2y). Moreover, the time lag between gains in strength as found in our study and their transfer to improvements in functional capabilities remain unknown. This may explain the great diversity in the results for walk tests, and it may be useful to repeat them after more time has elapsed after surgery.

Low-frequency electric muscle stimulation resulted in a more even balance of strength between the 2 limbs, which can lead to less reliance on the unoperated leg and reduce the need for a walking aid. This could be one of the factors that accelerate the recovery of independence, as measured with the FIM instrument. Moreover, this better balance could reduce gait asymmetry and thus reduce the metabolic cost of walking[62] as well as the incidence of falls.

The FIM instrument is frequently used to quantify the evolution in functional status during the rehabilitation of inpatients.[55] It has been shown that the evolution correlates with atrophy of the vastus lateralis muscle associated with hip OA.[25] The raw change in FIM improvement and FIM efficiency is lower than that reported by Vincent et al,[56] probably because of the older population in our study, but remains significant in the low-frequency electric muscle stimulation group only. In the low-frequency electric muscle stimulation group, this improvement exceeded clinical significance reported by Walker et al,[57] whereas it did not in the control group. This 20-point cutoff must, however, be considered carefully because it was not statistically determined but only observed on a relatively small number of patients. Greater improvement in the FIM score in the low-frequency electric muscle stimulation group could have been partly caused by greater independence in the sit-to-stand transfer and in stair climbing, in which strength of the knee extensors is crucial.

The absence of any effect on the hospital LOS, however, raises certain questions. Even though increased muscle strength significantly improves independence, it does not appear to be a predominant factor among the many described in the introduction that may have an impact on LOS. Moreover, although a decrease in LOS is interesting in terms of medical costs, it does not seem to be the main factor influencing patients' satisfaction, as reported by Grissom and Dunagan.[63]

Very few studies have evaluated the effects of electric muscle stimulation after hip surgery in the elderly. One controlled randomized study in 12 women aged over 75 years investigated the effect of low-frequency electric muscle stimulation of the quadriceps associated with routine physical therapy after surgical repair of hip fracture.[39] Low-frequency electric muscle stimulation was performed at the patient's home for 6 weeks. Evaluation at the end of the program, which included 3 hours of low-frequency electric muscle stimulation per day, showed a trend toward improved autonomy and walking speed, but the improvement was not significantly better than that in a control group of 12 subjects. Also, there was no significant difference in recovery of knee extensor strength. However, the ratio of strength in the operated and nonoperated limb showed that the return to balanced muscle strength was faster after low-frequency electric muscle stimulation, as observed in our study. There was also no concordance between the improvement of muscle strength and walking speed. This does not seem illogical to the authors because the nonlinear relationship between these 2 variables has already been reported.[61] The absence of improvement in knee extensor strength after electric muscle stimulation has also been reported recently by Braid et al[38] in a single blind randomized study of 26 patients (15 with electric myostimulation as compared with 11 with PT alone) after hip surgery for proximal femoral fracture. They found no effect on health status measured with the Nottingham Health profile or on disability measured by the Barthel Index. Our positive results concerning improvements in the strength of the quadriceps may be explained by the prior amyotrophy associated with the hip OA.[30,31]

Another prospective study evaluated recovery in subjects aged 60 years or more after THA for hip OA.[40] Nine patients received standard rehabilitation without resistance training, 11 patients received this rehabilitation associated with resistance training for the quadriceps of the operated limb, and 10 patients received the previous rehabilitation associated with electric muscle stimulation of the quadriceps muscle on the operated limb (pulse rate of 40Hz). Only resistance training increased isometric strength of the quadriceps, whereas electric muscle stimulation neutralized the loss of strength seen in standard rehabilitation without resistance training. Moreover, electric muscle stimulation generated a gain in muscle mass when compared with standard rehabilitation, but this gain was not as great as that achieved with resistance training. The effects on walking ability were not reported in this study. The difference with our study concerning the gain in muscle strength probably lies in the choice of stimulation frequency. The stimulation frequency applied (40Hz) lies between low and high frequency.[64] Electric muscle stimulation at a moderate frequency, when used with resistance training after THA for hip OA, thus appears to be less effective than resistance training alone in building up muscle strength after THA.

The mechanisms involved in the effect of electric muscle stimulation are a question of debate. It has been shown that the metabolic activity of slow-twitch muscle fibers is increased by electrical stimulation at a frequency of 10Hz.[65] The impact of low-frequency electric muscle stimulation is principally peripheral and mainly associated with the increase in the aerobic capacity of muscles with a modification in myotypology. Improvements in peripheral arterial vasomotion have been reported in paraplegic patients after a program of functional electrical stimulation[66] and in patients suffering from chronic heart failure.[67] The absence of any systemic effect is an important limitation when compared with training, in particular with regard to proprioception in patients who often present motor disadaptation associated with deconditioning. However, a partial transfer of muscle strengthening resulting from the effect of low-frequency electric muscle stimulation on motor function has been reported in cardiac disease, leading to an improvement in the 6MWT performance.[33] The mechanisms of this transfer are still unknown. It is possible that the effects of low-frequency electric muscle stimulation on the cortex revealed by functional magnetic resonance imaging are involved.[68] In our study, the persistence of pain and the modifications in gait caused by hip OA and then the THA might explain the absence of any improvement in walking performance even if muscle strength increased.

The increase in metabolic activity of slow-twitch muscle fibers by low-frequency electric muscle stimulation is associated with the increase in the proportion of slow-twitch fibers.[65,69,70] Other structural adaptations have been reported, notably the development of mitochondrial apparatus[71] and the increase in capillary density,[70] resulting in increased resistance to fatigue.[72] High-frequency stimulation acts principally on fast-twitch fibers and increases muscle strength and resistance to fatigue,[64,73] whereas low-frequency electric muscle stimulation is able to improve endurance in healthy muscle in humans.[32] It has also been used in the treatment of different neurologic and orthopedic disorders. Theoretically, high-frequency electric muscle stimulation could prove to be interesting in severe muscle deconditionning but is usually not well tolerated in older patients.[38] The difference in strength gain we observed, as compared with other studies using electric muscle stimulation in similar patients, could be because of the different choice of stimulation frequency.[38-40] Thus, low-frequency electric muscle stimulation is better tolerated and appears more efficient than moderate- or high-frequency electric muscle stimulation in increasing muscle strength in elderly patients after hip surgery.

Because low-frequency electric muscle stimulation is now quite cheap and not particularly time-consuming for the physiotherapist, it seems to be an easy-to-use complement to routine physical therapy. Low-frequency electric muscle stimulation is well tolerated among older patients, can be used by the patient himself, and could be self-administered at home after a few training sessions. Moreover, Deley et al[74] recently found that among patients suffering from chronic heart failure, low-frequency electric muscle stimulation induces greater improvements in patients with low exercise capacity than in those with average exercise capacity. Thus, in older patients, often showing major muscular and cardiovascular deconditioning, the benefits to cost ratio seems to be clearly positive. Considering our results, we feel that after THA for hip OA, low-frequency electric muscle stimulation could be adopted in routine clinical practice, especially among older patients.

Study Limitations

The main limitations of this study are the relatively small number of patients, the absence of standardization of the rehabilitation program, the choice of the walk tests, and the absence of a true placebo group. The small number of patients can be explained by the high number of elderly patients with comorbidities that led to exclusion from the study. This may, however, lead to some uncertainty about the broader applicability of these findings. The number of patients enrolled is comparable with or even higher than those reported in published series in this field of research.[38-40] Given the results, this type of therapy could be extended to patients presenting other diseases associated with muscle deconditioning and impaired motor function. The lack of standardization in rehabilitation programs, especially with regard to exercise intensity, is a recurrent problem in this type of study because the functional capacities of patients vary considerably with the age-related comorbidities.[75] Moreover, it is difficult to personalize overall training on cycle ergometers. Indeed, it is impossible to conduct a stress test at the start of rehabilitation immediately after arthroplasty because of the pain and the risk of complications (luxation, loosening of the prosthesis, wound healing). It is, however, worthy of note that in the absence of evaluation by stress tests, exercise, even of moderate intensity, enables elderly patients to improve their physical capabilities.[76] Rather than the walking tests used in this study, the Timed Up & Go test or the Timed Stair Climbing test may be better suited to the evaluation of these patients because they would show the functional impact of the increased strength of the knee extensors linked to the use of low-frequency electric muscle stimulation after surgery.[24,77] The previously mentioned tests explore the action of knee extensors in situations on which the autonomy of the patient depend. They would perhaps be better able to identify the mechanisms involved in the improvement in FIM after low-frequency electric muscle stimulation.

Finally, it would have been possible to conduct a low-frequency electric muscle stimulation/placebo trial (without stimulated muscle contraction), but we ruled out this idea because low-frequency electric muscle stimulation is well known by the public at large, and the absence of a contraction would have been noticed by the patients. This type of limitation occurs very frequently in nonpharmacologic therapeutic trials.

CONCLUSIONS

Low-frequency electric muscle stimulation of the quadriceps, associated with conventional rehabilitation including resistance training after THA for osteoarthritis in elderly subjects, is well tolerated and well accepted. It leads to a significant increase in muscle strength in the operated limb, which is an important factor in the evolution of functional status. Low-frequency electric muscle stimulation also significantly improves the degree of independence that patients enjoy, as measured by the FIM instrument, 45 days after the start of the rehabilitation program. However, it has no direct impact on walking speed or hospital LOS in the short term, both of which are influenced by many other factors. Low-frequency electric muscle stimulation can thus be proposed as a simple, effective, and safe complementary therapy used in conjunction with standard rehabilitation in everyday clinical practice in these patients.

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