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Research Article

A Progressive Strength Training Program Starting 3 Months Post Total Knee Arthroplasty Surgery Improves Strength but Not Functional Outcome

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Abstract

Background: Decreased quadriceps and hamstring strength is common even one year after a total knee arthroplasty. Hence, patients with persistent functional complaints treated at the Maastricht University Medical Centre (MUMC+) received a progressive strength training program.

Objectives: The aim of this study was to investigate the impact of the progressive strength training program on quadriceps and hamstring strength.

Methods: Patients were referred to the outpatient physical therapy department of MUMC+ and received a 6-week progressive strength training program. Their isokinetic quadriceps and hamstring strength and functional ability were assessed before and after the program.

Results: Men significantly improved in terms of all strength parameters assessed at an angular velocity of 60°/sec and 180°/sec. Women only improved their quadriceps strength at 180°/sec. No significant improvement at functional level was seen.

Conclusion: A 6-week progressive strength training program has a positive impact on the isokinetic quadriceps and hamstring strength in both men and women, but not on functional ability.

Level of Evidence: Level 3.

Keywords: Arthroplasty; Knee; Physical Therapy; Rehabilitation; Total

Introduction

A Total Knee Arthroplasty (TKA) generally reduces pain and restores range of motion in patients with end-stage Osteoarthritis (OA) of the knee. This is important as an increase in the incidence of knee OA is expected in the next years due to an ageing population and a trend toward obesity [1,2]. Notwithstanding these generally positive results, however, quadriceps and hamstring strengths remain lower than those of healthy controls, even one year after TKA [3-8]. Decreased quadriceps and hamstring strength negatively influences knee stability, increasing the risk of falls and generating a feeling of uncertainty in patients [9]. Additionally, activities like rising from a chair, standing, walking and climbing stairs become more difficult, which leads to a loss of independency [9-15].

A number of explanations can be given for this decreased strength. Firstly, pain-induced disuse in the pre-surgical phase changes activity patterns and reduces strength [16]. Secondly, the bio-kinematics change due to the surgical procedure, the possible resurfacing of the patella and the removal of the cruciate ligaments [6,7,11]. Thirdly, proprioception is changed as a result of the surgery as such (removal of the tibia and femur ends, removal of the cruciate ligament, cleaving of the joint capsule, and the ingrowth of scar tissue) [6,7,11] And finally, it can result from possibly inadequate post-surgical therapy. Comparison and investigation of

the therapeutic validity of the post-surgical therapy after TKA is difficult because of the considerable diversity in the amount and intensity of therapy applied worldwide, as well as because of the lack of accurate descriptions of the therapy provided [17,18]. Two systematic reviews, by Pozzi, et al. (2013) [19] and Skoffer, et al. (2015), [16] were unable to draw unambiguous conclusions on the effect of progressive strength training on the muscle strength of patients after TKA, based on the results of three (methodologically low-rated) Randomized Clinical Rials (RCTs). However, the studies by Petterson, et al. (2009) [20], Petterson, et al (2011) [21] and Johnson et al. (2010) [22] all showed a significant improvement in isometric quadriceps strength.

In addition to the two reviews based on RCTs, there have been three pilot studies in recent years. A pilot study by Jakobsen, et al.[23] in 2012 found an improvement in isometric quadriceps strength after a two-week, thrice a week, progressive strength training program in 14 patients. They started within 2 days after surgery with leg press and knee-extension exercises at a training intensity of around 80% of one Repetition Maximum (1RM) and performed 2×10 repetitions. Combined with gait training, range of motion exercises, functional activities, balance training and stretching, one session lasted 60 minutes. However, an RCT by Jakobsen, et al. [24] in 2014 did not find a significant difference in quadriceps strength 8 weeks after TKA, compared with pre-surgical values after a 7-week, twice a week, progressive strength training program, and compared with a therapy without strength training. They started between days 6 and 8 after surgery and performed 2×12 repetitions; the exact intensity was not reported, although the authors stated that they had adjusted the load in accordance with the repetitions at each session. Each session lasted 60 minutes, but the strengthening part was only 15 minutes. Husby, et al. [9] performed an RCT in which they compared a maximal strength training program with standard rehabilitation. Their program had a higher intensity (80-90% of 1RM) and fewer repetitions (4-5 repetitions). They were able to find a significant improvement in quadriceps strength after an 8-week, thrice a week program, starting on day 8 after surgery. The total duration of a session was 30 minutes. Both Petterson, et al. [20] and Johnson, et al. [22] found an improvement in functional ability after a strength training program, after 12 months and 4 weeks, respectively. This is in contrast with Husby, et al. [9] who found no improvement in functional ability after their strength training program.

The main differences with the program offered in our study is that we started between 3 and 18 months after surgery, in those patients who had remained significantly hampered by a strength deficit. Therapy was initiated when they expressed complaints at a follow-up visit to their orthopaedic surgeon. A second difference is the strength measurement, as we tested isokinetic strength. According to Lauermann, et al. [25] isokinetic and isometric strength improvements should not be mixed, as percentages of muscle weakness based on these measurements differ between the two methods, when compared with controls. Presenting baseline and change values in isokinetic strength after TKA and after a progressive strength training program is therefore useful to understand isokinetic strength development and to enable comparison of therapies. In addition, greater insight into the impact of a progressive strength training program on the quadriceps and hamstring strength is useful in the investigation of the therapeutic validity of post-TKA therapy [2,16,26] This was also noted by Bandholm, et al, [27] who stated that the 'pill' of physical therapy may not contain the right stimulus or may not be given at the right moment. Hence, the main aim of our study was to examine the impact of 6-week progressive strength training program, described in detail and starting at least 3 months after TKA surgery as part of usual care in the MUMC+, on quadriceps and hamstring muscle strength and functional ability of patients after a TKA.

Methods

Design

Patients with complaints after receiving a TKA at MUMC+, who were not receiving physical therapy at that moment, were referred to the hospital's outpatient department for physical therapy. They were offered a 6-week progressive strength training program.

Population

Patients were enrolled during regular follow-up appointments with their orthopaedic surgeon at the knee outpatient clinic at the MUMC+ Department of Orthopaedic Surgery. Patients were eligible to participate if they met the following inclusion criteria: having undergone primary TKA at the MUMC+ at least 3 months ago, age <80 years, subjectively reported complaints regarding physical functioning, and no simultaneous outpatient physical therapy. Patients with a limited cognitive function or with limited command of Dutch which interfered with filling out questionnaires, or who were unable to follow instructions, were excluded. Patients eligible for training were referred to the MUMC+ outpatient physical therapy department by their attending surgeon. The baseline maximal isokinetic quadriceps and hamstring strengths of their affected leg were measured with a Biodex System Pro 3 dynamometer (Biodex Medical Systems, Shirley, NY, USA), by an experienced physical therapist. Values were compared with normative values from healthy controls (n=295). The normative values were calculated using equations obtained in a previous study [3]. The normative values are given in (Table 1). Patients with inadequate strength were informed about the MUMC+ physical therapy program, a 6-week progressive strength training program.

This retrospective study investigated the data of twelve patients who attended the therapy at MUMC+ after a TKA, and was approved by the regional ethics committee (METC 2018-0519). It was performed in accordance with the Declaration of Helsinki. Since patients were treated with usual care, no written informed consent was obtained, but all patients were able to object to the

use of their data in scientific publications. None of these twelve patients did. All patients agreed with physical therapy at MUMC+ and were able to withdraw from physical therapy treatment at any moment.

Surgery

Surgeries were performed by two orthopedic surgeons, both with extensive experience with the prosthesis. All patients received a cemented Scorpio NRG® prosthesis (Stryker, Kalamazoo, Michigan, USA) or an Attune® Knee System (DePuy Synthes, Raynham, Massachusetts, USA). After a medial parapatellar approach, the surgeons used a bony referenced, tibia first technique. A cemented patella component was used in all patients, and a tourniquet was only used during the cementation period of the prosthesis.

Demographics

Relevant demographic characteristics, including age (years), sex (M/F), height (m), weight (kg), Body Mass Index (BMI) in kg/m^2, side of TKA (R/L) and time since TKA surgery (months) were obtained during the baseline measurement.

Measurements

Muscle strength and functional ability were both assessed before and after the 6-week progressive strength training program, by an experienced physical therapist.

Muscle Strength

The maximal isokinetic quadriceps and hamstrings strength, in Newton Meter (Nm), was measured with the Biodex System Pro 3 dynamometer (Biodex Medical Systems, Shirley, NY, USA) at angular velocities of 60°/sec (5 repetitions) and 180°/sec (10 repetitions). The Biodex is a reliable and valid measurement instrument and is the gold standard for measuring maximal isokinetic strength up to angular velocities of 300°/sec [28] Measuring isokinetic strength was preferred to isometric strength measurements: Lauermann, et al. [25] reported that since the percentage of patients diagnosed with muscle weakness was higher when calculated on the basis of isometric muscle strength measurements than with isokinetic strength measurements, the isometric strength difference could be an overestimation of the muscle weakness and could underestimate the effect of an intervention [29].

Functional Ability

Functional ability was assessed with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). This self-administered disease-specific health questionnaire has been designed to measure the functional ability of the osteoarthritic knee before and after TKA surgery [30,31] The WOMAC provides aggregate scores for each of 3 subscales: joint pain, joint stiffness and functional ability. Together, they yield the WOMAC sum score. The 5-point Likert version of the WOMAC was used in our study, with a scale ranging from 0 to 96 points (0 indicating no pain or dysfunction). Afterwards the scores were standardized to a 0-100 scale, with 100 indicating no pain or dysfunction. The WOMAC is a responsive instrument that yields reliable and valid measurements in a population of patients with knee OA and after a TKA, and has been used extensively to evaluate this patient population [30-34]

Physical Training Program

During the 6-week strength training program, patients had two sessions a week (total of 12 session), with at least 48 hours between two individual training sessions. Each session lasted 45 minutes and started with a warm-up cycle ergometer session (5 minutes, at a self-chosen comfortable wattage) and cool-down walking on a treadmill (5-10 minutes, at a self-chosen comfortable speed). Before the start of the strength training program, an X-Repetition Maximum (XRM) assessment of all individual exercises was performed to test individual strength. Thereafter, the Oddvar Holten diagram [35] was used to calculate the 1RM from the XRM [36] The XRM is a frequently used alternative to calculate the 1RM, because the 1RM is often not feasible [37] The resulting 1RM was used to design an individual progressive strength training program, according to the American College of Sports Medicine guidelines, starting at 60% of the 1RM [16,38]. All patients received an individual training protocol, with prescriptions for resistance, as well as the number of repetitions (8-15) and sets (3-4). The patients were instructed to take a pause of 60 seconds between sets. The total workload was adjusted at each session, by raising the resistance and the number of repetitions or sets according to the personal rating on the Borg Rating of Perceived Exertion Score (Scale 0-10) [39]. If patients rated their exertion as 'tolerable' (Borg 0-4), weight was increased (one step being 10 kg for the leg press, 2.5 kg for the leg extension and 2 kg for the leg curl), and the number of repetitions was reduced to the starting value of 8. If patients rated their exertions as 'heavy' (Borg 5-10), the number of repetitions was first increased (from 8 to 10 or in a subsequent session from 10 to 12 repetitions). When patients had reached 3 sets of 12 repetitions, the weight was increased by one step in the next session, and the repetitions were reduced to the starting point of 8. If at that moment an increase in weight was not possible, an extra set was added (4 sets instead of 3). The original weight and repetitions were retained, and in the subsequent session the weight was once again increased, and the number of repetitions again reduced (as described above). Patients were tested and trained on three different stationary resistance training stations (Leg Press, Leg Curl and Leg Extension). To prevent a dominant role of the non-surgical leg in the training, we decided to test and train both legs unilaterally, to achieve sufficient training stimulus for each leg [16].

Data Analysis

Data were analyzed with SPSS, version 22.0 for Windows (IBM® SPSS ® Statistics version 22.0). Descriptive statistics were used for sex, age, height, weight, TKA side and time since TKA surgery. The data for the two sexes are presented separately below. Normality was tested with the Shapiro-Wilk test. In case data were normally distributed, data is presented as means ± Standard

Deviation (SD) and, where appropriate, in absolute numbers and percentages. Otherwise, medians and percentiles are used. Paired sample t-tests were used to test mean differences in continuous data between baseline and follow-up measurements. A cut-off value for significance of 0.05 was used. Values were also compared with normative values calculated using formulas for normative values of healthy controls which we have published earlier [3] (Table 1).

TABLE 1 Normative values				
	Men (n=129)		Women (n=166)	
	mean	SD	mean	SD
Q60	129	17	79	9
H60	78	12	49	6
Q180	84	10	46	6
H180	59	9	35	5

Table 1: Shows the normative values calculated using equations including age and sex [4]. **Nm**: Newton meter. **SD**: standard deviation. **Q60**: isokinetic quadriceps strength 60˚/sec. **Q180**: isokinetic quadriceps strength 180˚/sec. **H60**: isokinetic hamstring strength 60˚/sec. **H180**: isokinetic hamstring strength 180˚/sec.

Results

Thirteen patients were referred to the physical therapy department. One patients had strength values comparable with the normative values for healthy persons and was therefore excluded from this progressive strength training program. The other twelve were included between March 2016 and January 2018. They were seven men (age 66.0 [6.3] years, BMI 28.9 [4.9] kg/m^2) and five women (age 67.4 [7.3] years, BMI 32.5 [9.4] kg/m^2) (Table 2). Patients were referred between 3 and 18 months after TKA surgery. Adherence to therapy was good; all patients completed the program and attended 12 sessions. No adverse events were seen during this period. One patient had a delay of 10 days between the 11th and 12th sessions, due to illness (influenza). Five patients received a Scorpio NRG ® knee system (Stryker, Michigan, USA) and seven patients an Attune® knee system (Depuy Synthesis Companies, Massachusetts, USA).

TABLE 2 Patient Characteristics				
	Men (n=7)		Women (n=5)	
	Mean	SD	Mean	SD
Age (years)	66.0	6.3	67.4	7.3
Height (m)	1.75	0.07	1.59	0.04
Weight (kg)	88.2	13.2	81.9	22.4
BMI (kg/m^2)	28.9	4.9	32.5	9.4

Table 2: Shows the patients characteristics. **BMI**: Body Mass Index, **SD**: Standard Deviation.

Quadriceps and Hamstring Strength

All men improved in terms of quadriceps (Figure 1) and hamstring strength. One woman's hamstring strength decreased, as did another woman's quadriceps strength. Overall, a favorable change of 45-81% was seen: the men had a significant improvement on all isokinetic strength parameters (p= 0.00-0.01). (Figure 2) The overall change for the women was 12-37%, and only the isokinetic quadriceps 180˚/sec strength showed significant improvement (p = 0.02). (Figure 3) Comparison with normative values showed that the men scored 35-46% of these values at baseline. After the 6-week progressive strength training program, this was 59-71% (Figure 2). As regards the percentage of the normative value for women, this was 55-79% before the start of the program and 73-94% afterwards (Figure 3).

FIGURE 1 Individual change in quadriceps strength.

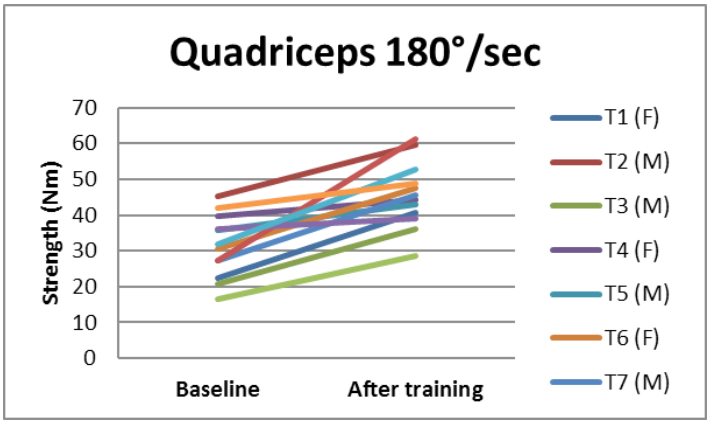

Figure 1: Shows the change in quadriceps strength of all individual patients before and after training, in Nm. Each line represents an individual patient. Their sex is given to the right of the diagram (F[Female] and M[male]).

FIGURE 2 Quadriceps and hamstrings strength for men

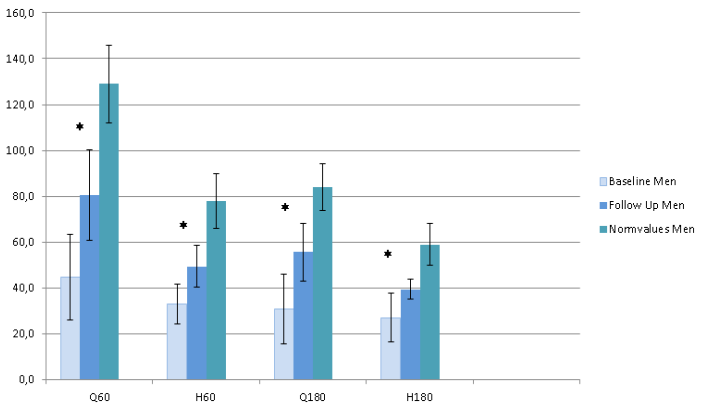

Figure 2: Shows the mean quadriceps and hamstrings strengths in men, at baseline and after the training program, in Nm with standard deviations

Q60: isokinetic quadriceps strength 60˚/sec. **Q180**: isokinetic quadriceps strength 180˚/sec. **H60**: isokinetic hamstring strength 60˚/sec. **H180**: isokinetic hamstring strength 180˚/sec. Normative values are the means of the individual normative values based on sex and age. * Significant improvement between baseline and post-training assessments ($p < 0.05$)

FIGURE 3 Quadriceps and hamstrings strength for women

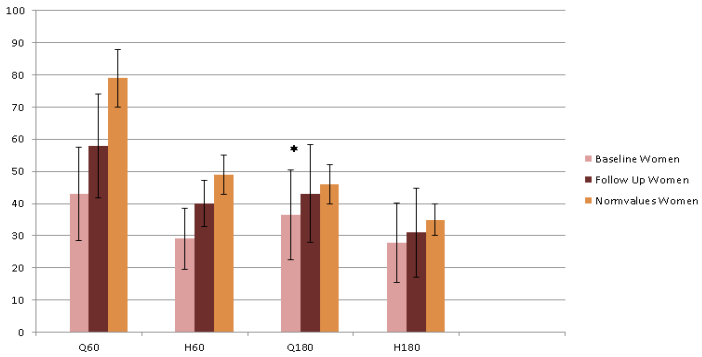

Figure 3: Shows the mean quadriceps and hamstrings strengths in women, at baseline and after the training program, in Nm with standard deviations **Q60**: isokinetic quadriceps strength 60˚/sec. **Q180**: isokinetic quadriceps strength 180˚/sec. **H60**: isokinetic hamstring strength 60˚/sec. **H180**: isokinetic hamstring strength 180˚/sec. Normative values are the means of the individual norm values based on sex and age. * Significant improvement between baseline and post-training assessments ($p < 0.05$).

Functional Ability

The variance in the change in functional ability was high, with five patients improving their WOMAC function score, four patients deteriorating and three not showing any change (change < 5 standardized points). The individual change is shown in (Figure 4).

FIGURE 4 WOMAC

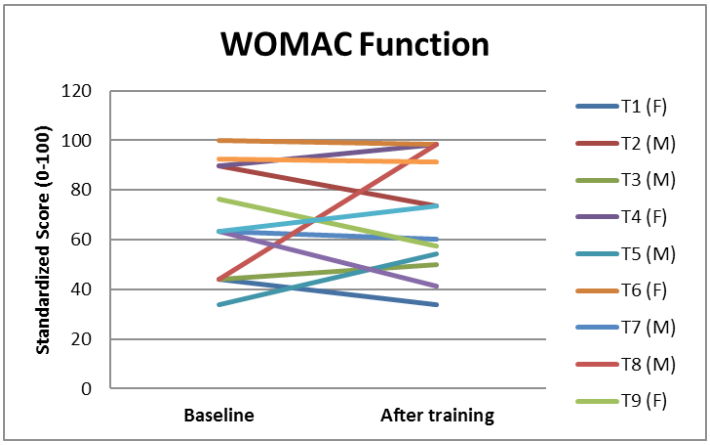

Figure 4: Shows the change in WOMAC Function score of each individual patient before and after training. Each line represents an individual patient. The sex is given to the right of the diagram (F[Female] and M[male]).

Discussion

This study examined the impact of a 6-week progressive strength training program, started at least 3 months after TKA surgery, on the change in isokinetic quadriceps and hamstring strength and the functional ability of patients who had undergone a TKA. The results show a significant improvement in all strength parameters for men and for one quadriceps strength measurement in women. No significant improvement in functional ability was seen, since the change in functional ability was highly variable. Our results are in agreement with those of several previous studies [9,20-23]. Although all of these studies started the training program earlier after surgery than ours, it is useful to know that progressive strength training which starts at a later moment after surgery still has a positive impact on muscle strength. It is important to notice that direct comparison with our results is impossible, since these other studies used isometric instead of isokinetic strength measurements, and did not present their results for men and women separately, or failed to describe their interventions in detail. Although the sample size in our study was small, the fact that two women showed a decrease in one of the two hamstrings or quadriceps strength measures suggests that women only improved significantly regarding quadriceps strength at an angular speed of 180˚/sec. It is important to note that the two women whose hamstrings or quadriceps strength deteriorated both reported mild influenza complaints.

No adverse events were reported during the therapy sessions in our study. In general, patient compliance was high and most of the patients continued their exercise training after our program, since the training and the strength measurement results encouraged them to maintain training. In addition, they experienced a positive change in their daily life and became enthusiastic about the training sessions. Our findings confirm that progressive resistance training is possible and safe in patients after a TKA. Although our patients improved their muscle strength, there was high variance in the change on the WOMAC function score. Due to this high variance and the small sample, no conclusions can be drawn regarding functional change. This corresponds to what has been reported in the literature [9], although Johnson, et al. [22] found an improvement on the Timed Up and Go test after their 4-week program. An explanation for this difference may lie in the fact that performance-based tests are driven by muscle strength while self-reported questionnaires are driven by pain, as mentioned by Pozzi, et al. [19] Possible reasons for the high variance we found could be the short duration of our program, as 6 weeks may have been too short to see an improvement in functional ability, since patients were adjusting their daily life routine to this therapy. In addition, the statistical power of our study may have been too low to detect a significant change in functional ability. Finally, the patients expanded their activities, which might mean they experienced their limitations more clearly, giving them a better insight into their individual functional abilities and problems, which could result in greater acceptance of their position in the rehabilitation process.

Study Limitations

Our study had some limitations. Firstly, given the small sample size, the power was too small to draw conclusions regarding the change in functional ability. Secondly, the fact that we did not find a significant difference in functional ability might have been influenced by the fact that we chose a patient-reported outcome measure; a performance test might be more directly related to muscle strength. Thirdly, our pre-post study design had some limitations as regards studying the effectiveness of a progressive strength training. Therefore, the results have to be interpreted with caution. Nevertheless, this study has yielded important evidence and starting points for future studies to evaluate the addition of progressive strength training to the standard physical therapy program after TKA [40].

Future Research

Although the results of this study are promising in terms of improving the quadriceps and hamstring strengths of patients after a TKA, further studies are required to compare our progressive strength training with the functional training often given in outpatient physical therapy departments and to investigate the effect of progressive strength training on the change in functional ability in a larger population. Additionally, the long-term effects of a progressive strength training program on strength remain unknown, as do the optimal and ultimate moments for starting strength training. Finally, the optimal duration of the program should also be studied.

Conclusion

In conclusion, a 6-week progressive strength training program starting at least 3 months after TKA surgery had a positive impact on isokinetic quadriceps and hamstring strengths in men and women, though no significant improvement in functional ability was detectable.

Key Points

A 6-week strength training program, starting at least 3 months after TKA surgery, has a favorable effect on quadriceps and hamstring strength, though not on functional ability. Caution is necessary in interpreting our findings, since we only included a small population and we did not compare with other therapies. Therefore, further research to investigate the long-term impact of a strength training program, comparing our program with other therapies, would be useful, and impact on functional ability should also be investigated in a larger population.

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Conflict of Interest

The regional ethics committee (METC of the azM/UM) approved this study under number METC 2018-0519. The authors certify that there is no conflict of interest and that this study did not have any financial support.

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