Open Versus Closed Kinetic Chain Exercises in Patellofemoral Pain: A 5-Year Prospective Randomized Study

Erik Witvrouw, Lieven Danneels, Damien Van Tiggelen, Tine Marieke Willems and Dirk Cambier

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A 5-Year Prospective Randomized Study

Erik Witvrouw,* PT, PhD, Lieven Danneels, PT, PhD, Damien Van Tiggelen, PT, Tine Marieke Willems, PT, and Dirk Cambier, PT, PhD
From Ghent University, Ghent, Belgium

Background: Today, no clinical studies have been undertaken to examine the long-term effects of an open kinetic chain or closed kinetic chain program.

Hypothesis: The long-term follow-up results after a conservative exercise protocol are significantly worse than the short-term results. The long-term effect of closed kinetic chain training is significantly better compared to the effect of open kinetic chain training.

Study Design: Prospective randomized clinical trial.

Methods: Sixty patients were randomized into a 5-week conservative program, consisting of only closed kinetic chain exercises or only open kinetic chain exercises. Assessment of muscular characteristics, subjective symptoms, and functional performance was evaluated in this study at the time of initial physical examination, at the end of the treatment period, and 5 years later.

Results: At the 5-year follow-up, both groups demonstrated maintenance of good subjective and functional outcomes achieved immediately after the conservative treatment. No significant difference between both groups was observed at the 5-year follow-up for the majority of the examined parameters. However, on 3 of the 18 visual analog scales, the open kinetic chain group showed significantly less complaints compared to the closed kinetic chain group.

Conclusions: On the basis of these results, the authors conclude that both open kinetic chain and closed kinetic chain programs lead to an equal long-term good functional outcome.

Keywords: patellofemoral pain; conservative treatment; open kinetic chain (OPC); closed kinetic chain (CKC); anterior knee pain

Patellofemoral pain syndrome (PFPS) is often seen in physically active individuals and may account for almost 10% of all visits to a sports injury clinic.[17,22]

It is generally agreed that patellofemoral pain should be managed initially by conservative rather than operative means. The basis of conservative treatment is strengthening of the quadriceps and soft tissue stretching of the quadriceps musculature, patellofemoral mechanism, and hamstring musculature.[38,40] The most successful rehabilitation programs should emphasize progression without increasing symptoms.[24,37] Keeping exercise intensity and patellofemoral stresses low and repetitions relatively high will help to achieve this goal. Today, little consensus exists regarding the most appropriate conservative treatment. Open kinetic chain (OKC) leg extension exercises have been the traditional means of strengthening the quadriceps.[6,20] However, several authors have reported that these exercises exacerbate symptoms in many patellofemoral patients.[8,23,41]

The clinical use of closed kinetic chain (CKC) exercises has significantly increased during the past several years. One of the reasons these exercises have received increased attention within the rehabilitation community is that they simulate and replicate many functional movements.[7,9,22,33]

Because studies[27,30,31] have shown that the major changes as a result of strength training are task specific, it may be better to incorporate the rehabilitation into task-related practice. As such, specificity of training becomes a significant factor.[27,31]

In addition, several authors have demonstrated that PFPS patients may tolerate CKC exercises better than OKC exercises in functional ranges of motion because of lower patellofemoral joint stresses.[11,13,14,27,33,41,42] There-

*Address correspondence to Erik Witvrouw, Ghent University, Faculty of Medicine, Ghent University Hospital (1B3) (REVAKI), De Pintelaan 185, Ghent, Belgium 9000 (e-mail: erik.witvrouw@ugent.be).

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fore, PFPS patients may tolerate CKC exercises better and, consequently, exhibit better functional results after such devised rehabilitation programs.[41] Although these studies have documented the potentially deleterious effects of OKC exercises in patellofemoral patients, only a few clinical studies have been undertaken to scientifically prove this.[34,39] Although these few studies are clinically important, they lack long-term follow-up. Indeed, Powers et al[29] stated that of utmost importance are clinical trials aimed at determining which treatment procedures are most effective in reducing the symptoms associated with patellofemoral pain with a long-term follow-up. In fact, despite the large amount of available literature concerning conservative and operative management of PFPS, no controlled prospective long-term investigations are available to show which exercise protocol is most effective in reducing patellofemoral pain in the long term. Therefore, the purpose of this study was 2-fold. First, we wanted to determine, with a randomized prospective design, whether there is a difference in long-term patellofemoral complaints between an OKC and CKC exercise protocol. In addition, we were interested to find out whether the positive results in both groups observed at short-term follow-up and previously published[39] were preserved at long-term follow-up (5 years). To our knowledge, this is the first study to examine this, and we believe this information is essential for the patients as well for the physicians, physical therapists, and others involved in the treatment and rehabilitation of PFPS.

MATERIALS AND METHODS

Initial Patient Group

Between November 1995 and May 1997, 60 PFPS patients, with an average age of 20.3 years (range, 14-33 years), were randomized (by opening a sealed and numbered envelope) into a 5-week conservative rehabilitation protocol that consisted of only CKC exercises (n = 30) or a 5-week conservative program with only OKC exercises (n = 30).[39] Both rehabilitation groups consisted of 10 men and 20 women. The duration of symptoms before the beginning of this study averaged 15.1 months (6 weeks to 28 months). No significant difference in duration between both rehabilitation groups was observed (P = .55). Consistent with the findings in previous studies,[2,32] we observed patellofemoral pain bilaterally in 27 of the 60 patients. Fifteen of them followed OKC exercises, and 12 followed the CKC program (P = .74). For statistical analysis, only 1 knee of each of the 27 patients with bilateral pain was evaluated. The most painful knee was chosen for this study. The criteria for inclusion in this study were based on those used by Insall et al.[15] To be eligible for the study, subjects had to experience anterior knee pain for more than 6 weeks and exhibit 2 of the following criteria on initial assessment: pain on direct compression of the patella against the femoral condyles with the knee in full extension, tenderness on palpation of the posterior surface of the patella, pain on resisted knee extension, and pain with isometric quadriceps contraction against suprapatellar resistance with the knee in slight flexion. Patients with knee problems other than patellofemoral pain were excluded from the study. All patients underwent an MRI of their patellofemoral joints. Patients with visually marked cartilage damage on MRI were excluded from this study. Also excluded from this study were patients with a history of a knee operation. None of our patients had a history of trauma, nor did they have a history of subluxation or dislocation.

All subjects signed an institutionally approved informed consent statement.

All patients received their therapy in the physical therapy department of the university hospital under the direct supervision of a trained physical therapist experienced in knee rehabilitation (first author). The patients were trained 3 times a week for 30 to 45 minutes. During the 5-week training program, patients were not allowed to participate in sports. No medication was prescribed as part of their treatment. Neither brace nor tape was used by any patient during his or her treatment period. Every patient followed the exercise program for the required period of 5 weeks. After the training period, the patients were advised to maintain their muscle strength.

Treatment

Prior to the beginning of the OKC and CKC exercise program, a 10-repetition maximum (10 RM) was determined. On that information, patients were instructed to train at 60% of the 10 RM. A new 10 RM was established at the end of a week of training. Each exercise in both training groups was repeated for 3 sets of 10 repetitions. The patient rested 1 minute after the conclusion of each set.

In the OKC exercise protocol, each exercise was held isometrically for a count of 6 seconds with a 3-second rest between repetitions. Each exercise in the CKC protocol was performed dynamically with a 3-second rest between repetitions. The exercise protocols were as follows:

Therapeutic OKC Exercise Program

- Maximal static quadriceps contractions (quadriceps setting) with the knee in full extension.
- Straight leg raisings with the patient in the supine position.
- Short arc movements from 10° of knee flexion to terminal extension.
- Leg adduction exercises in the lateral decubitus position.

Therapeutic CKC Exercise Program

- Seated leg press.
- Double or single one-third knee bend.
- Stationary biking.
- Rowing machine exercise.
- Step up and down exercise.
- Progressive jumping exercises on mini trampoline.

In both training protocols, the patients were instructed to perform the conventional static quadriceps, hamstrings,

and gastrocnemius stretching exercises after each training session. All subjects were instructed to perform 3 repetitions of a 30-second static stretch of these muscle groups.

5-Year Follow-up

Fifty-one of these 60 patients (85%) attended the 5-year follow-up evaluation. Two (1 from each treatment group) of these 51 patients underwent surgical intervention (1 patellar release and 1 shaving of the patellar surface). Therefore, the results of these patients were not used in the statistical analysis of this follow-up study. Of the 9 patients who were not evaluated at the 5-year follow-up, 2 were injured (1 had a fracture of the tibia, and 1 had an ear operation) at the time of the evaluation and were unable to attend the evaluation, 1 had died in a car accident, 3 had moved (1 to the United States, 2 to France), and 3 could not be traced. Twenty-five of 49 included patients (16 women and 9 men) who were initially treated by a CKC exercise program, whereas 24 (16 women and 8 men) followed the OKC exercise protocol. The mean age of the patients was 24.8 years (range, 19-36 years).

Evaluation

Prior to the beginning of their rehabilitation program and after 5 weeks of training, all patients were evaluated on several outcome measurements.

All patients were reviewed again 3 months and 5 years after completion of their rehabilitation programs. In this study, all tests at all evaluation periods were performed by the same examiners, who were blinded to the study and familiar with the different tests. The results as a consequence of the treatment program (comparisons between the initial evaluation and the 5-week evaluation and between the 5-week evaluation and the 3-month evaluation) have already been extensively described in a previous article[39] and will therefore not be included in this article.

Outcome Assessments

Subjective Assessment. Pain and discomfort during rest and various activities were recorded on eighteen 100-mm visual analog scales (VAS), where 0 = no pain and 100 = extremely intense pain.

The combined subjective and functional evaluation of the knee was made with the standardized scoring scale described by Kujala et al.[21] This scale is specifically designed for patients with patellofemoral pain and is a 0- to 100-point scale (100 = best score evaluating pain during stairs, squatting, running, jumping, and prolonged sitting with the knees flexed; the presence of a limp; swelling; subluxation; the amount of quadriceps atrophy; flexion deficiency; and the need for support in walking).

Functional Assessment. Three additional functional evaluations were performed. All 3 functional tests were performed in the same order following each other immediately after instructions. In this study, we used a unilateral squat test, a step test, and a triple-jump test. During the unilateral squat test, the patients were asked to perform a maximal single knee bend without pain. The maximal flexion angle in the knee was measured using American Academy of Orthopaedic Surgeons[1] instructions. If a patient was able to perform a full knee bend without experiencing pain, he or she was registered as asymptomatic for this test. For the evaluation of the step test, patients were asked to step up and down a 10-cm step. If the subjects did not experience pain, the height of the step was increased by 5 cm until pain occurred. This height was recorded. If the patients were able to step up and down a step of 45 cm without pain, the test ended and the patients were registered as symptom free for this test. Prior to the triple-jump performance, the patients were instructed to stand on their injured legs and had to jump 3 times along a straight line. The total distance was measured in centimeters, and in addition, the patients were instructed to score their pain and discomfort during this test on a 100-mm VAS.

Muscle Strength Measurement. To document the possible improvements in quadriceps or hamstrings strength due to the rehabilitation protocol, an isokinetic strength measurement was performed on the Cybex 350 (Lumex Corp, Ronkonkoma, NY). Concentric knee extensor and flexor peak torque was measured at 3 speeds: 60, 180, and 300°/s. Each subject was positioned according to the Cybex testing manual (Cybex I: isolated joint testing and exercise; Ronkonkoma, NY, 1983).

STATISTICAL ANALYSES

A mixed-design repeated-measures analysis of variation (ANOVA) was used to compare the baseline results with the 3-month and 5-year assessments across the 2 treatment groups (mixed-design ANOVA, generalized linear models type) if the variables were continuous. Changes in the categorical variables across groups and between the different evaluation periods were performed by using Pearson χ^2 statistics. The observed differences were located by post hoc multiple comparisons for tests of homogeneity. Significance was accepted at the .05 level. To determine if we had enough subjects in this study to show a clinically significant difference, we performed power analyses. Because we were dealing with a great number of variables in this study, we performed a separate sample size calculation for each of the variables. The lowest of the different power analyses so determined (by the triple-jump test) was a power of 78%. The power analyses on all the other variables reached 80% or more, which is generally accepted, in combination with a significance level of .05, as good.

RESULTS

Only 19 of the evaluated 49 patients (20%) (9 OKC and 10 CKC) reported to be completely pain free at the 5-year follow-up. At the 5-year evaluation, 37 patients (75%) were active in sports. Of these 37 patients, 22 of the 24 evaluated patients from the OKC group (92%) participated actively in sports 5 years after their treatment. In the CKC group, only 15 of the 25 patients (60%) participated in sports at the 5-year follow-up ($P < .05$). Only 1 of the patients (in the

TABLE 1
Mean, SD, and *P* Values of the 18 Visual Analog Scales for the Closed Kinetic Chain Group

	Time 0: Prior to Treatment		Time 1: 3 Months After Treatment		Time 2: 5-Year Follow-up		
Visual Analog Scale	Mean	SD	Mean	SD	Mean	SD	*P*
Frequency of pain	5.2	3.6	3.8	6.4	3.0	2.0	.19
Worst pain last week	5.3	3.2	3.4	2.7	4.6	2.8	.21
Feeling of giving way	2.6	2.2	1.3	2.2	2.3	2.5	.12
Clicking sensations	5.2	2.7	2.6	2.4	5.5	3.5	.01[a]
Presence of locking	2.0	2.2	0.7	1.3	1.3	1.8	.06
Pain during walking	2.9	2.5	1.6	2.0	2.2	2.2	.38
Feeling of stiffness	2.1	2.3	0.6	1.1	1.6	2.2	.09
Pain ascending stairs	4.7	3.1	1.6	2.2	2.5	2.6	.21
Pain descending stairs	4.8	3.6	1.4	1.9	2.8	2.4	.02[a]
Pain during running	4.5	3.2	2.2	2.5	3.4	2.6	.14
Pain during jumping	4.4	2.6	1.6	2.0	3.3	3.5	.04[a]
Pain during sports	5.2	2.8	2.5	2.3	3.8	2.4	.04[a]
Pain during squatting	5.0	3.3	2.5	2.7	3.0	3.1	.16
Pain during prolonged sitting	6.6	3.6	3.5	2.9	6.4	3.2	.01[a]
Pain during the night	2.3	2.2	0.5	0.7	0.7	1.3	.5
Swelling knee joint	2.2	1.8	0.7	1.2	1.6	2.1	.08
Pain in daily life	3.7	2.3	1.7	1.9	1.8	1.4	.96
Pain during isokinetic test	3.3	3.0	1.1	1.4	1.6	3.2	.47

[a]Significant difference ($P < .05$) between time 1 and time 2.

OKC group) reported wearing a brace during sports activities. After 5 weeks of treatment, all patients were asked to keep performing the instructed exercises (OKC or CKC) at home. At the 5-year follow-up, 66% (n = 16) of the patients from the OKC group and 35% of the CKC group reported that they had not been exercising at home. Four patients (13%) of the OKC group and 6 patients of the CKC group (24%) reported that they performed their daily home exercises but only for a brief period (3-5 weeks) after the end of the 5-week treatment program. Only 4 patients of the OKC group (13%) reported that they still perform these exercises on a weekly basis. To our surprise, 10 patients from the CKC group (41%) reported that they still perform these exercises on a weekly basis 5 years after finishing the treatment protocol.

At initial evaluation (time 0), no statistical differences between both groups were observed for any of the evaluated variables ($P > .05$).[39]

Comparison Between the OKC and CKC Groups at the 5-Year Follow-up

Subjective Assessment. The results of the subjective assessment were obtained by the Kujala score[21] and by 18 VAS (Tables 1 and 2). Statistical analyses revealed a significant difference between both groups concerning 3 VAS scores. The OKC group complained significantly less of swelling of the knee joint ($P = .04$), of pain during descending stairs ($P = .01$), and of pain during the night ($P = .04$) compared to the CKC group. Looking at the Kujala score (Figure 1), no significant difference between both groups could be observed, although a trend toward a lower score in the CKC group ($P = .08$) can be mentioned.

Functional Assessment. Statistical analyses of the results on the triple-jump test and the maximal pain-free knee bend test did not reveal any significant differences between both groups ($P > .05$). Looking at the 45-cm step-up test, 20 (80%) patients of the CKC group and 22 patients (92%) of the OKC were pain free during this test ($P = .23$) at the 5-year follow-up. Seventeen (69%) patients of the CKC group and 20 (79%) patients of the OKC group did not experience any pain during the step-down phase of a 45-cm step ($P = .31$) at the 5-year follow-up.

Muscle Strength Measurements. No significant differences between both groups could be observed for any of the isokinetic hamstring or quadriceps strength measurements at the 5-year follow-up ($P > .05$) (Figures 2-7).

Comparison Between the 5-Year Follow-up and the 3-Month Posttreatment Evaluation for the OKC Group

Subjective Assessment. No significant differences between both evaluation periods could be detected for 17 of the 18 VAS ($P > .05$) (Table 2). The only significant difference was observed for pain during prolonged sitting with the knees flexed. The OKC patients complained significantly more of pain during sitting with knees bent at the 5-year follow-up compared to the 3-month posttreatment evaluation ($P = .04$).

Looking at the Kujala score for the different evaluation periods (Figure 1), no significant difference was observed between the 5-year follow-up and 3-month posttreatment evaluation ($P = .78$).

TABLE 2
Mean, SD, and *P* Values of the 18 Visual Analog Scales for the Open Kinetic Chain Group

	Time 0: Prior to Treatment		Time 1: 3 Months After Treatment		Time 2: 5-Year Follow-up		
Visual Analog Scale	Mean	SD	Mean	SD	Mean	SD	*P*
Frequency of pain	5.4	3.5	2.4	1.6	1.3	1.1	.06
Worst pain last week	5.0	3.3	3.5	1.5	2.7	1.7	.23
Feeling of giving way	2.8	2.4	0.8	1.1	1.8	2.4	.23
Clicking sensations	4.8	3.2	3.0	2.9	4.6	3.8	.11
Presence of locking	2.1	1.9	0.7	0.9	0.4	0.7	.32
Pain during walking	3.2	2.8	0.9	1.4	1.1	1.2	.83
Feeling of stiffness	1.8	1.9	0.6	0.8	0.4	0.5	.53
Pain ascending stairs	5.2	3.6	1.3	1.7	1.1	1.0	.95
Pain descending stairs	5.1	3.8	0.9	1.4	0.7	1.0	.86
Pain during running	4.3	3.3	2.1	2.1	1.5	1.5	.53
Pain during jumping	4.4	2.9	2.0	2.3	1.7	2.1	.73
Pain during sports	5.4	2.8	2.7	2.7	1.6	1.9	.26
Pain during squatting	4.7	3.8	2.0	2.0	1.7	2.2	.75
Pain during prolonged sitting	6.7	3.9	2.2	1.8	4.4	3.9	.04[a]
Pain during the night	2.6	2.0	0.3	0.6	0.06	0.3	.18
Swelling knee joint	1.9	1.6	0.1	0.2	0.2	0.4	.16
Pain in daily life	3.4	2.0	1.8	1.8	1.0	1.2	.23
Pain during isokinetic test	3.1	3.6	0.7	0.9	0.4	0.3	.32

[a]Significant difference ($P < .05$) between time 1 and time 2.

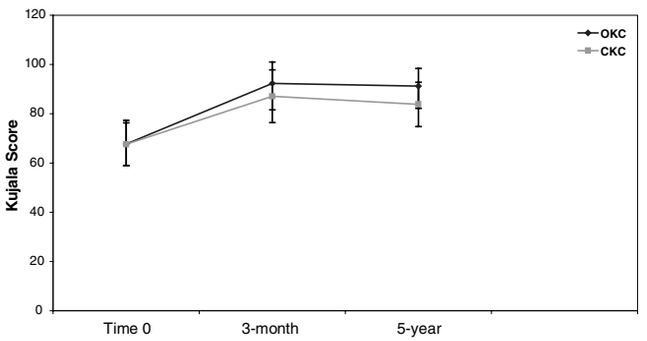

Figure 1. Mean values of both groups on the Kujala scale at the different evaluation periods. OKC, open kinetic chain; CKC, closed kinetic chain.

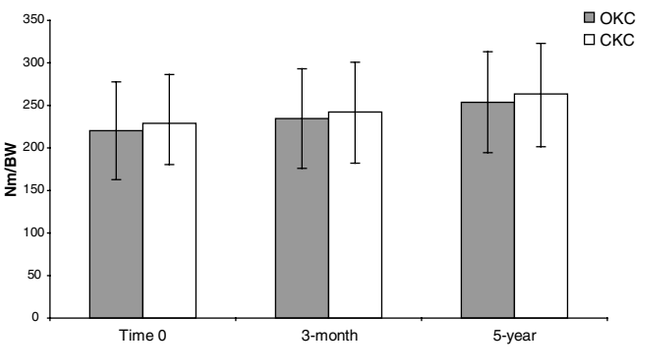

Figure 2. The mean and SD of the isokinetic quadriceps strength at 60°/s over time for both groups. OKC, open kinetic chain; CKC, closed kinetic chain.

Functional Assessment. Statistical analyses of the results of the squat test demonstrated a significant improvement (10° of knee flexion) in pain-free maximal knee bend at the 5-year follow-up ($P = .01$). In contrast, the performance of the OKC patients during the triple-jump test was significantly decreased at the 5-year follow-up for both the injured leg ($P = .01$) and the uninjured leg ($P = .02$). At the 5-year follow-up, 22 patients (92%) were pain free during a 45-cm step-up test. This is a significant improvement over time, as only 73% of the patients were able to perform this test pain free at the 3-month evaluation period ($P = .01$).

Muscle Strength Measurements. No significant differences over time between the 3-month posttreatment evaluation and the 5-year follow-up could be observed for any of the hamstring or quadriceps strength measurements ($P > .05$) (Figures 2-7).

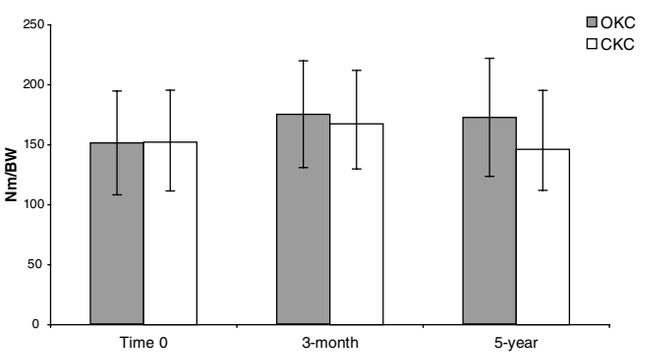

Figure 3. The mean and SD of the isokinetic quadriceps strength at 180°/s over time for both groups. OKC, open kinetic chain; CKC, closed kinetic chain.

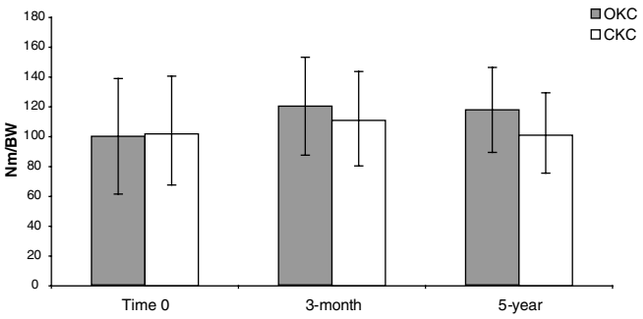

Figure 4. The mean and SD of the isokinetic quadriceps strength at 300°/s over time for both groups. OKC, open kinetic chain; CKC, closed kinetic chain.

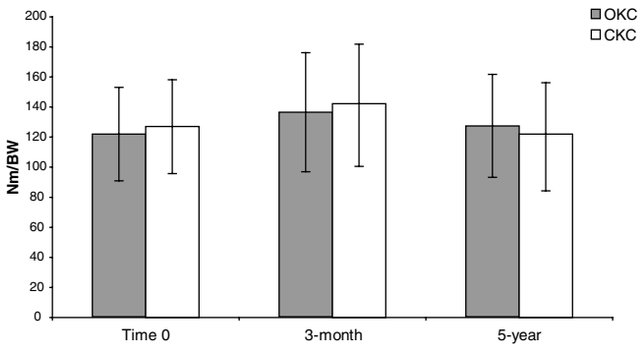

Figure 5. The mean and SD of the isokinetic hamstrings strength at 60°/s over time for both groups. OKC, open kinetic chain; CKC, closed kinetic chain.

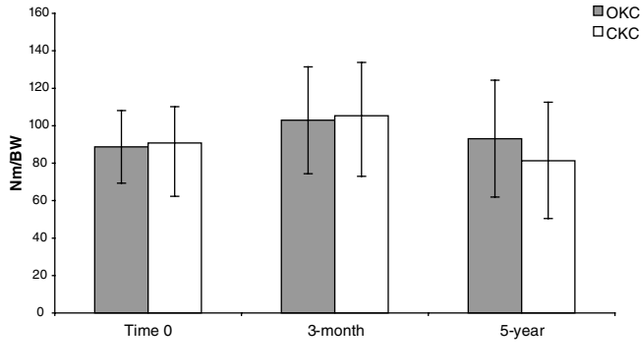

Figure 6. The mean and SD of the isokinetic hamstrings strength at 180°/s over time for both groups. OKC, open kinetic chain; CKC, closed kinetic chain.

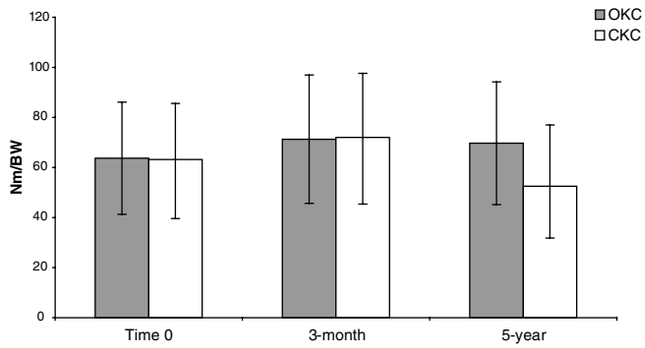

Figure 7. The mean and SD of the isokinetic hamstrings strength at 300°/s over time for both groups. OKC, open kinetic chain; CKC, closed kinetic chain.

Comparison Between the 5-Year Follow-up and the 3-Month Posttreatment Evaluation for the CKC Group

Subjective Assessment. Five of the VAS demonstrated a significant worsening of the pain level over time (Table 1). The CKC patients experienced significantly more pain at the 5-year follow-up during descending stairs (P = .02), jumping (P = .04), sporting activities (P = .04), and prolonged sitting with the knees flexed (P = .01), and they experienced significantly more clicking sensations in the knee joint (P = .01) compared to the 3-month posttreatment evaluation.

No significant change was detected in the Kujala score between the 5-year follow-up evaluation and the 3-month posttreatment period (P = .20) (Figure 1).

Functional Assessment. Twenty (80%) patients of the CKC group performed a 45-cm step-up test without pain at the 5-year follow-up. Because 73% of the patients were able to perform this test pain free at the 3-month evaluation period, statistics did not reveal a significant difference between both evaluation periods (P = .61). In contrast to the OKC group, no significant change over time was observed in the CKC group in the pain-free maximal knee bend (P = .29) and the triple-jump performance (P = .07).

Muscle Strength Measurements. The results of the isokinetic strength measurements of the CKC group at the 3-month posttreatment and at the 5-year follow-up are presented in Figures 2 through 7. In accordance with the findings in the OKC group, no significant differences over time were observed in the CKC patients' quadriceps strength at the 3 tested velocities (P > .05) (Figures 2-4). Studying the hamstrings strength of the CKC group at the 5-year follow-up (Figures 5-7), significantly lower values at the 5-year follow-up were observed at all 3 test velocities when compared with the 3-month posttreatment evaluation (P = .02 at 60°/s; P = .01 at 180°/s; P = .01 at 300°/s).

DISCUSSION

There appears to be no clear consensus regarding how to conservatively manage a PFPS patient. OKC and CKC exercises have been used by other investigators as a rehabilitation protocol,[2,4,5,7,12,23,34,38,39] but no long-term follow-up has been undertaken to compared the results of OKC versus CKC exercises. In a previous study, we have shown that there was a significant improvement in strength and functionality as a result of both OKC and CKC exercise programs, with few significant better results in the CKC group.[39] However, we were very interested to find out (1) if

these good results were maintained over time and (2) if differences between OKC and CKC rehabilitation programs can be observed at long-term follow-up.

The results of this study showed that most of the improvement in strength, functionality, and subjective complaints achieved after the conservative treatment was maintained over a 5-year period. Thus, from this study it appears that the long-term prognoses of PFPS patients who are managed conservatively with an OKC or CKC exercise protocol are relatively good. Our findings are in agreement with the results of other authors[5,16,18,19,32,37] who also reported good functional outcome in the majority of the conservatively treated patients at short- and long-term follow-up.

We believe the maintenance of the quadriceps strength is a notable finding because different authors have emphasized the importance of a good quadriceps function as a premise for a good functional result.[10,18,26,28,35,36] Indeed, this relationship between locomotor function and quadriceps strength was already emphasized by Powers,[28] who stated in the results of his study that the concept of strengthening can be considered as a very useful treatment option in patellofemoral pain patients. A study by Natri et al[26] confirmed this supposition by identifying a strong correlation between the restoration of the quadriceps strength and the long-term final outcome in patellofemoral pain patients. In our study, 75% of the patients were active in sports, with no significant difference between both groups. Most likely, the high physical activity may have contributed to the maintenance of good (quadriceps) muscle function. Therefore, patients with PFPS should on the long term not give up their physical activity. On the contrary, adjusted physical activity might be very important.

Surprising in this study is the significant decline of both groups concerning the issue of prolonged sitting with the knees bent. In this study, this was the only parameter that showed a decline in both groups when comparing the 3-month results with the 5-year follow-up results.

Despite the preservation of strength, good functionality, and low subjective complaints over a long-term follow-up in this study, only a minority (20%) of the conservatively treated patients in our study were completely pain free at the 5-year follow-up. Our findings are in agreement with the results of Kannus et al,[18] who concluded that despite the good subjective and functional outcomes at the 7-year follow-up, 80% of the patients still had characteristic patellofemoral crepitation, and one third did not have complete clinical recovery. Accordingly, Milgrom et al[25] reported the presence of persistent pain in 35% of PFPS patients at the 6-year follow-up.

Comparing the results of the OKC group with the CKC group at the 5-year follow-up in this study revealed only a few significant differences. Only on VAS "pain during the night," "swelling of the knee joint," and "pain during descending stairs" were significant differences observed between both groups. Surprisingly, and in contrast to our short-term results,[39] the OKC group demonstrated at the 5-year follow-up significantly better results on these 3 items, compared to the CKC group. Despite these significant differences between both groups, no significant differences could be found on the majority of the measured subjective assessments (the other 15 VAS and on the overall subjective outcome measured by the Kujala score) or on any of the functional assessments or muscular measurements. Yet studying the results of the comparison between the 3-month posttreatment evaluation and the 5-year follow-up for the OKC and CKC, a similar slightly more positive view was seen in the OKC group. The OKC patients maintained their muscular strength. They preserved all, except for 1, of their subjective assessments, whereas a significant increase was observed on 2 of the 3 evaluated functional tests. The CKC group revealed a significantly worse result on 5 VAS but maintained their overall subjective outcome (Kujala score) and functional performance and demonstrated a significant decrease in hamstring strength.

Possible reasons for these findings can be found in the overall better results on subjective assessment of the CKC group immediately after the end of the rehabilitation period compared to the OKC group.[39] Apparently, this study showed that the few better results obtained immediately after a 5-week rehabilitation period with CKC are lost over a longer follow-up time. Based on the results of this study and a previous study,[39] we can conclude that a CKC program is a little more effective in improving the functional results after a 5-week treatment program at short follow-up. At longer follow-up, however, we have shown that the CKC group loses more on subjective and functional results compared to the OKC group. Consequently, this leads to a situation in which at the 5-year follow-up, the overall outcomes of the patients are usually good but equal for both groups. In other words, the slightly better results after a CKC treatment are only true for a relatively short period of time.

In addition, it must be mentioned that in this study, the sports participation of the OKC patients (92%) is significantly higher compared to that of the CKC patients (60%). This observation is potentially important because it has been shown that increased physical activity in PFPS patients may contribute to an improvement of functionality and muscle function.[3,10,28,36] Therefore, this difference in sports participation between both groups in this study may be a reason for the observed difference over time (between the 3-month posttreatment evaluation and the 5-year follow-up) between the CKC and OKC groups, with a somewhat better result in the latter group. However, on the basis of the results of this study, it is impossible to know if the increased sports participation in the OKC group is a consequence or a cause of the slightly better functionality in this group.

Interesting in this study was the observed higher compliance in performing the instructed exercises at home after the 6 weeks of treatment in the CKC group (41%) compared to the OKC group (13%). The reason for this observed difference remains enigmatic. Possibly, this could be due to the nature of the exercises. Our clinical experiences with patients demonstrated that in general, CKC exercises are experienced as less boring than OKC exercises. On the other hand, the CKC patients in our study are maybe more compliant than our OKC patients because the

CKC group in this study experienced a more significant decrease in functionality after their treatment program compared to the OKC group. A limitation of this study is that we did not include a control group. Therefore, the results of this study at the 5-year follow-up can be the consequence of the treatment program or can simply represent the natural history of this condition.

CONCLUSION

Overall, the results of the present study revealed that both groups demonstrated maintenance of good subjective and overall functional outcome at the 5-year follow-up.

Moreover, comparisons at the 5-year follow-up showed that in the majority of the examined parameters, there were no significant differences between both groups. Hence, on the basis of these results, we dare to conclude that both groups have an equal long-term, relatively good functional outcome. Regardless of these good results, the majority of our examined patients did have some minor pain problems at long-term follow-up.

Hitherto, this is the only study examining a possible difference in the long-term outcome between patients treated with OKC and those treated with CKC. Yet based on results of this study, we believe that the allegation frequently encountered in the literature that OKC exercises are absolutely to be avoided in the treatment of PFPS is not founded.

We therefore do not advocate replacing the traditional OKC exercises with CKC exercises but rather suggest a combined use of both types of exercises. The results of this study give the clinicians greater clinical confidence in the long-term value of CKC and OKC therapy.

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