Accelerated Rehabilitation after Anterior Cruciate Ligament Reconstruction: Comparison of Closed Kinetic Chain (CKC) Versus Open Kinetic Chain (OKC) Exercises

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Abstract

Background: Anterior cruciate ligament (ACL) is one of the most commonly injured ligaments of the knee. ACL reconstruction (ACL-R) is the treatment of choice in cases of severe knee instability to avoid recurrent knee injuries and subsequent degenerative changes. Accelerated rehabilitation after ACL-R greatly affects the healing response and significantly helps patients to gain dynamic stability in the knee joint. Much debate surrounds the difference between open kinetic chain (OKC) and closed kinetic chain (CKC) exercises during ACL-R rehabilitation.

Objective: It was the aim of this study to compare the effects of a comprehensive rehabilitation program with quadriceps strengthening in closed kinetic chain (CKC) exercises with the same rehabilitation program with quadriceps strengthening in open kinetic chain (OKC) exercises in patients with ACL reconstruction and to evaluate the effects on knee functions.

Subjects and Methods: Forty consecutive patients with ACL reconstruction for isolated ACL injury were included in this study. They were subjected to a rehabilitation program for 4 months supplemented with OKC exercises in one group and CKC exercises in the second group.

Results: Patients in CKC exercise group showed at the end of the four months’ rehabilitation programs, a statistically significant increase in passive range of motion (PROM) \((p<0.001)\), in Lysholm score \((p=0.002)\) and a significant decrease in number of patients with extension deficit \(\geq 5^\circ\) \((p=0.008)\), all indicating improvement in knee functions, while OKC group only showed improvement in PROM as regards knee functions \((p=0.049)\). Comparing both groups - as regards the outcome of rehabilitation program on knee functions - showed that there was a non significant difference between the two groups concerning PROM, Lysholm score or improvement of extension deficit and thigh atrophy \((p=0.463, p=0.757, p=0.085, p=0.430\) respectively). At the end of the 4 months, there was statistically significant more improvement of knee pain in CKC group than OKC groups \((p=0.018)\) and more number of patients who gave a response of "satisfied" in CKC group than OKC groups \((p=0.027)\).

Conclusion: We conclude that both CKC and OKC exercises appear to be suitable for rehabilitation after ACL reconstruction; however, CKC exercises showed better outcome after rehabilitation than OKC exercises as regards knee function, knee pain and patient satisfaction.

Key Words: Anterior cruciate ligament – Reconstruction – Accelerated rehabilitation – Open kinetic chain (OKC) exercises – Closed kinetic chain (CKC) exercises.

Introduction

THE anterior cruciate ligament (ACL) is one of the most commonly injured ligaments of the knee. In general, the incidence of ACL injury is higher in people who participate in high-risk sports such as basketball, football and skiing; however, injuries may occur in automobile accidents or work related injuries, especially among physically active individuals [1,2].

Complete anterior cruciate ligament deficiency limits the ability to perform demanding activities, such as twisting, cutting, pivoting and jumping [3]. Depending on the extent of injury, instability may develop not only with athletic activity, but also with activities of daily living [1]. In the ACL deficient knee, stability is performed by secondary restraining structures, such as the posterior joint capsule, the collateral ligaments and the menisci [4]. The injury leads to loss of mechanoreceptor feedback and loss of reflex muscular contractions [5]. Besides the immediate associated morbidity, an ACL tear significantly increases the risk of premature knee osteoarthritis [6]. Previous studies reported that 44%-90% of ACL injured patients showed radiographic signs of osteoarthritis 10-15 years after the injury, which means 20-30 years earlier than primary osteoarthritis [7,8]. Associated injuries in the capsule, ligament or menisci are common and most patients have complex injuries.
Joints, when taken together, comprise the lower extremity kinetic chain (CKC) with the same rehabilitation program. In contrast, open kinetic chain exercises use isolated joint and muscle function and the motion is uniplanar [15,16].

ACL injury results in thigh muscle weakness, especially of the quadriceps muscle [15]. The quadriceps muscle is an important stabilizer of the knee joint, so regained quadriceps strength is therefore regarded as an important goal for successful ACL rehabilitation [17]. Several years ago it was suggested that ACL injury and ACL reconstructed patients should be treated with closed kinetic chain exercises rather than open kinetic chain exercises for strengthening the quadriceps muscle and for protecting the ACL graft from detrimental strain [18] and since then the closed kinetic chain protocol has become a standard means when treating patients after ACL injury and ACL-R [15]. However, open kinetic chain exercises are essential because they considerably task the quadriceps musculature [19].

Musculoskeletal pain may affect the performance of exercises and alter the muscle activation pattern [20]. In addition, swelling in the knee joint may also contribute to a changed movement pattern. Since effusion has been shown to lead to quadriceps inhibition, it may interfere with quadriceps strengthening [21]. Therefore, most ACL rehabilitation programs incorporate early joint motion as it is beneficial for pain reduction and can minimize capsular contractions and normalize range of motion (ROM). Goals in the early rehabilitation phase are full knee joint ROM, achieved muscular control, and reduced swelling [18].

It was the aim of this study to compare the effects of a comprehensive rehabilitation program with quadriceps strengthening in closed kinetic chain (CKC) with the same rehabilitation program with quadriceps strengthening in open kinetic chain (OKC) in patients with isolated ACL reconstruction as regards the outcome on knee function.

Patients and Methods

Forty consecutive patients with ACL endoscopic reconstruction were included in the present study. All patients were attending the Orthopedics outpatient clinic and the Rheumatology and Rehabilitation outpatient clinic in Kasr El-Aini hospitals,
Faculty of Medicine, Cairo University in the period from March 2006 to February 2008. Reconstruction of the ACL was done using an autogenous graft taken from the ipsilateral hamstring tendons, namely the semitendinosus and gracilis tendons. Graft fixation was done by using cross pins at the femoral side and interference screws at the tibial side. The indication for operation was symptomatic instability secondary to rupture of the ACL confirmed by clinical examination. All patients had isolated ACL injury confirmed by MRI, with an uninjured contralateral knee and a maximum duration for ACL injury of 3 months. Patients were excluded if they had postoperative complications at the graft site, additional injury or previous surgery to the lower extremities. All patients were informed about the study.

All patients were subjected to full history taking and thorough clinical knee examination (age, duration of ACL injury, cause of injury, anterior knee pain, knee swelling). Anterior drawer tests, Lachman test as well as Pivot shift test were performed preoperatively for all patients to help in the clinical diagnosis of ACL injury.

**Measurements:** Clinical measurements were performed before the start and at the end of 4 months period of rehabilitation program in the form of:

1- Passive range of motion (PROM) in knee extension and flexion was measured with a standard plastic goniometer with the patient relaxed supine on the examination table. Extension was measured with a block under the patient’s heel to allow for hyperextension. The arms of the goniometer were aligned with the greater trochanter and lateral malleolus and the axis of the goniometer was placed over the knee joint line just below the lateral femoral epicondyle. Goniometric measurements of the knee using a standard plastic goniometer have shown to be reliable and valid [22]. Extension lag ԑ .5 was considered to be of clinical significance [23].

2- Complete neurological examination was carried out to assess muscle power and coordination.

3- Thigh atrophy was measured as the difference between the two sides at a point 10 cm above the superior pole of the patella, a difference of ԑ .1 cm is considered clinically significant [24].

4- The Lysholm knee scale was used to evaluate specific symptoms related to knee function including limp (5 points), support (5 points), locking (15 points), instability (25 points), pain (25 points), swelling (10 points), stair climbing (10 points) and squatting (5 points). The Lysholm score consists of 8 different items on a 100 point scale attributed to instability and pain and answered at pre- and post rehabilitation assessments [25].

5- The visual analogue scale (VAS) was used for anterior knee pain rating. Pain was recorded for site and severity using an analogue score from 0 (no pain) to ten (most severe pain) [26].

6- The following supplementary questions were added at the post rehabilitation assessment: How do you experience the effect of the physiotherapy treatment (satisfied, or unsatisfied?).

Weight bearing antero-posterior (AP), lateral, and femoral-patellar in 30º flexion radiographs were taken for both knees (ipsi- and contralateral) in all cases to exclude osteoarthritis. MRI was done to all cases to exclude other concurrent injuries or knee pathology.

As soon as the patient awakens from anesthesia, quadriceps co-contractions make up the first exercise that the patient should be taught for the maintenance of terminal extension. Passive motion is emphasized with active flexion and assisted extension, with ice packs and elevation of the leg. The patient then begins gait training with crutches. On the day 15 postoperative the stitches were removed.

Patients were then subjected to a rehabilitation program for 4 months supplemented with quadriceps strengthening in CKC or OKC. Aside from these exercises, the two rehabilitation programs were identical. An early range of motion was the goal in order to prevent stiffness. The patient progressed from partial weight-bearing to weight-bearing as tolerated. Overall, the rehabilitation program consisted of range-of-motion exercises and lower-extremity muscle strengthening. Patients were assessed after 4 months of rehabilitation. Knee functional outcome and subjective rating were evaluated.

We defined OKC exercises as those in which the foot is not in contact with a solid surface. Leg extension exercises and kicking are examples of OKC exercises. We defined CKC exercises as those in which the foot is in contact with a solid surface. The foot is opposed by a ground reaction force, which is transmitted to all of the joints in the lower extremity. Examples of CKC exercises are the squat, leg press and lunge.
Patients were divided into two groups, each of 20 patients:

Group A (CKC exercises): This group trained only with closed kinetic chain exercises. These exercises are introduced after swelling from the injury has decreased.

Group B (OKC exercises): This group trained only with open kinetic chain exercises. These exercises are introduced after swelling from the injury has decreased.

Statistical analysis:

Data were coded and summarized using SPSS (statistical package for Social Sciences) version 15.0 for Windows. Quantitative variables were described using mean ± standard deviation and categorical data by using frequency and percentage. Mann-Whitney U test compared independent groups for continuous variables while Pearson’s \( \chi^2 \) test or Fisher’s exact test compared independent groups for categorical variables. For continuous and ordinal data, comparisons between the results at the start and four months after the rehabilitation were made using the Wilcoxon signed-rank test while for nominal data, comparisons were made using McNemar’s test. \( p \) value of <0.05 is considered of statistical significance.

Results

Forty consecutive ACL reconstructed patients without postoperative complications were included in the present study. All patients had isolated ACL injury of no more than 3 months duration. They were 37 males (92.5%) and 3 females (7.5%), their ages ranged from 19-42 years with a mean 25.4 ± 5.8 years and the duration of ACL injury ranged from 0.5-3 months with a mean duration of 2.06 ± 0.83 months.

Patients were enrolled into a comprehensive rehabilitation program for 4 months. They were divided into two groups according to either CKC or OKC exercises were used for Quadriceps strengthening:

Group A (CKC exercises): Comprised 19 males (95%) and one female (5%) with a mean age (33.13±10.06). This group trained only with closed kinetic chain exercises.

Group B (OKC exercises): Comprised 18 males (90%) and two females (10%) with a mean age (30.4±7.45). This group trained only with open kinetic chain exercises.

Among 20 patients with CKC exercises, 13 cases (65%) had their injury in the dominant leg while 12 cases out of 20 (60%) had their injury in the dominant leg in the OKC group and thus the possible effect of the imbalance in leg dominance on the strength results of the injured knees was likely eliminated.

The general and clinical features of both groups are illustrated in Table (1).

Comparison of pre and post rehabilitation knee functions in both groups:

At the end of the four months’ rehabilitation programs, the outcome in both groups as regards knee functions was evaluated.

Patients enrolled in the CKC exercises program showed statistically significant increase in PROM measured by goniometer, in Lysholm score \((p<0.001, p=0.002\) respectively), a significant decrease of VAS of knee pain and a decrease in number of patients with extension lag ≥5º and in patients with thigh atrophy \((p<0.001, p=0.008\) and \(p=0.031\) respectively) as shown in Table (2).

However, patients in the OKC group showed only improvement in PROM and pain as evidenced by decrease in VAS \((p=0.049\) and \(p<0.001\) respectively) as shown in Table (2).

Comparison of both groups as regards outcome of rehabilitation:

At the end of the four months’ course of rehabilitation program of 3 sessions /week, the PROM increased in both groups indicating improved knee function (Table 2). The mean of improvement in PROM was greater in the CKC group more than in OKC group, yet it was statistically non significant (12º in CKC Vs 8.5º in OKC, \(p=0.463\)).

After rehabilitation, the Lysholm score increased significantly (\( p =0.002\) in CKC group indicating improved subjective evaluation of knee functions in this group (Table 2). The mean of improvement in Lysholm score was greater in the CKC group more than in OKC group although it was statistically non significant (11.4 points in CKC Vs 9.4 points in OKC, \(p=0.757\)).

Also, the number of patients with extension deficits decreased by 66.6% in the CKC group compared to 25% in the OKC group after the rehabilitation program, however this difference was statistically non significant \((p=0.085)\).

The number of patients with thigh atrophy decreased by 85.7% in the CKC group compared to 60% in the OKC group after the rehabilitation program and the difference was statistically non significant \((p=0.430)\).
As for VAS for anterior knee pain, after rehabilitation it decreased in a significant manner in both groups (both with \( p < 0.001 \)), however, improvement of pain as evidenced by decrease in VAS was significantly more in the CKC group (\( p \) value =0.018).

Also, Subjective rating of the effect of rehabilitation on knee functions and of knee satisfaction of both groups at the end of the rehabilitation program showed a statistically significant more number of patients giving a response of "satisfied" in CKC group than OKC group as in Table (3).

Table (1): General and clinical features of both (CKC) and (OCK) groups.

<table>
<thead>
<tr>
<th>Feature</th>
<th>CKC no=20</th>
<th>OCK no=20</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± SD)</td>
<td>33.1±10.05</td>
<td>30.4±7.45</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Duration in months (mean ± SD)</td>
<td>2.00±.745</td>
<td>2.20±.840</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Male/female</td>
<td>19/1</td>
<td>18/2</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Dominant leg injured no (%)</td>
<td>13 (65%)</td>
<td>12 (60%)</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Lysholm score (mean ± SD)</td>
<td>57.3±19.69</td>
<td>61.2±20.72</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Extension deficits &gt;5° no (%)</td>
<td>12 (60%)</td>
<td>8 (40%)</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>

Table (2): Clinical parameters for subjective and objective knee functions before and after rehabilitation in CKC and OKC groups.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Group A (CKC) no=20</th>
<th>Group B (OCK) no=20</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension deficit no (%)</td>
<td>12 (60%) 4 (20%)</td>
<td>8 (40%) 6 (30%)</td>
<td>0.008*</td>
</tr>
<tr>
<td>Thigh atrophy no (%)</td>
<td>7 (35%) 1 (5%)</td>
<td>5 (25%) 2 (10%)</td>
<td>0.031*</td>
</tr>
<tr>
<td>VAS (mean ± SD)</td>
<td>69.5±19.59 42.5±17.43</td>
<td>71.0±20.74 54.0±17.29</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Goniometer (mean ± SD)</td>
<td>92.0±8.94 104.0±10.71</td>
<td>89.0±10.71 97.5±13.62</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Lysholm score (mean ± SD)</td>
<td>57.3±19.69 68.7±13.87</td>
<td>61.2±20.72 70.6±15.89</td>
<td>0.108</td>
</tr>
</tbody>
</table>

Table (3): Subjective rating of knee functions and knee satisfaction.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Group A (CKC)</th>
<th>Group B (OCK)</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good/satisfied</td>
<td>13 (65%)</td>
<td>6 (30%)</td>
<td>0.027*</td>
</tr>
<tr>
<td>Poor/not satisfied</td>
<td>7 (35%)</td>
<td>14 (70%)</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

Reconstruction of the ACL aims to restore normal stability of the knee and allows the return to the level of function before injury. Restoration of normal kinematics may minimize the abnormal shear forces at the femorotibial interface. It is believed that the recurrent episodes of instability which occur after rupture of the ACL are often associated with meniscal damage and cause degenerative changes [3].

Rehabilitation plays a central role following ACL reconstruction. In the early rehabilitation phase after ACL reconstruction the graft needs to be protected against excessive strain. Some strain during the healing process increases graft strength although excessive strain can stretch or rupture the graft [3,11]. At the same time, it is important to introduce more demanding exercises to the patients to facilitate the regain of muscle function and neuromuscular control [16].

It is very important to understand what form of kinetic exercise is more beneficial to restore functions of the knee joint. Much debate surrounds
the difference between OKC and CKC exercises during ACL rehabilitation. The difference concerns the assumption that CKC exercises are safer than OKC exercises because they produce less strain on ACL graft and less patello-femoral pain. The second assumption is that CKC exercises are more functional and are effective in improving quadriceps muscle power because in a CKC exercise, balance and coordination are stimulated simultaneously as the muscle strengthens [15].

In this study, we tried to compare the effects of a comprehensive rehabilitation program with quadriceps strengthening in closed kinetic chain (CKC) with the same rehabilitation program with quadriceps strengthening in open kinetic chain (OKC) in patients with ACL injury and to evaluate the effects on knee functions.

Forty consecutive patients with ACL reconstruction for isolated ACL injury were included in this study. They were subjected to a rehabilitation program for 4 months supplemented with OKC exercises in one group and CKC exercises in the second group.

In our study, most of our patients with ACL injury were males [37 males (92.5%) and 3 females (7.5%)]. In agreement with our data, it was reported that more males sustain an ACL injury than females due to the greater absolute number of male participants in sport activities which was the case in our patients [1]. However, the risk of sustaining an ACL injury is reported to be two to eight times higher among female athletes compared to their male counterpart [2]. On the other hand, a recent study found small gender differences in the overall risk of sustaining an ACL tear although gender differences in injury rates were found when specific sports were compared [27].

Limited range of motion, due to a number of different pathologies or injuries, is often encountered in joint and periarticular structures injuries [28]. This impaired range of motion prevents normal function. In terms of knee range of motion even a small reduction after ACL reconstruction, may play a major effect on daily activities and on athlete’s career in certain sports [23].

In our study, PROM was measured using a long arm goniometer. The universal goniometer is the most common instrument for measuring range of motion [28]. Jagodzinski et al., 2000 [29] recommend the use of a long arm goniometer to reduce the amount of error of measurements. In general, ≥5° change in range of motion is suggested to be of clinical value in most joints, however, in terms of knee extension even a smaller change might be of interest, especially when it comes to hyperextension [28]. International Knee Document Committee (IKDC) form suggests that a difference in knee extension of ≥5° has to be detected in order to categorize knee function properly [30]. In our study, all the range of motion measurements were done with a long arm goniometer in order to minimize the measurement error as much as possible. According to the IKDC form we also chose 5° to be a difference of significance.

As regards knee functions, at the end of the four months’ rehabilitation programs, patients enrolled in the CKC exercises program showed a statistically significant increase in PROM measured by goniometer [92.0±8.94 before Vs 104.0±10.71 after, p<0.001] as compared to OKC group [89.0±10.71 before Vs 97.5±13.62 after, p=0.049]. Also, patients enrolled in the CKC exercises showed after 4 months of rehabilitation a statistically significant increase in Lysholm score (p=0.002) and a significant decrease in number of patients with extension lag ≥5° [12 (60%) Vs 4 (20%), p=0.008], all indicating improvement in knee functions. OKC group only showed improvement in PROM as regards knee functions (p=0.049), otherwise there was a non significant improvement in Lysholm score nor a decrease of patients with extension deficit (p=0.108, p=0.5 respectively).

Comparing both groups -as regards the outcome of rehabilitation program on knee functions- showed that there was a non significant difference between the two groups concerning PROM, Lysholm score or improvement of extension deficit and thigh atrophy (p=0.463, p=0.757, p=0.085, p=0.430 respectively). However, subjective rating of the effect of rehabilitation on knee functions and of knee satisfaction of both groups at the end of the rehabilitation program showed a statistically significant more number of patients giving a response of "satisfied" in CKC group than OKC group (p=0.027).

In agreement with our results, Beynnon et al., 2005 [31] reported that both CKC excercises and OKC exercises can be used in ACL-R rehabilitation with equal outcome on knee functions. Bynum et al., 1995 [14] performed a clinical trial comparing outcomes after ACL reconstruction with patellar tendon grafts and patients were randomized to rehabilitation programs that consisted of either OKC or CKC exercises. They reported no significant differences in Lysholm score, subjective rating of the knee, or ranges of knee motion. Their patients with CKC began jogging at 8 wk and progressed
to more specific exercises at 16 wk, whereas the OKC group did not begin jogging until 16 wk and sport-specific exercises were initiated at 7 to 8 months. However, Mikkelsen et al., 2000 [32], compared CKC exercises with combined CKC and OKC exercise and reported that combined closed and open kinetic chain exercises were superior to closed kinetic chain exercises alone concerning greater improvement in knee functions and a higher number of patients that were able to return earlier to sport and at pre-injury level without compromising knee joint stability. However, the greater amount of training that the open kinetic chain group received might show that the closed kinetic chain group received too little training for strengthening the quadriceps muscle. On the other hand, Tagesson et al., 2008 [33] reported that OKC exercises produced more quadriceps strength than CKC exercises; however, they reported no group difference as regards the outcome of knee function and subjective knee pain rating for knee function between both groups. The difference in their study from our results may be due to that, in their study they included both injured and uninjured legs in the evaluation which was not the case in our study.

Our results showed that patients in CKC group experienced less patellofemoral pain at the end of rehabilitation program compared to OKC group (CKC 42.5±17.43 Vs OKC 54.0±17.29, *p*=0.018), suggesting that CKC exercises exerts less stress on ACL graft and patellofemoral joint, due to reduced patellofemoral joint forces during CKC exercises which are generally performed near full extension compared to OKC exercises performed in 30º-90º flexion. Full knee extension (or hyperextension) and good quadriceps strength are factors that have been reported to prevent anterior knee pain after ACL reconstruction [34]. Our results are in agreement with Bynum et al., 1995 [14] who stated that CKC exercises are preferred in ACL rehabilitation because of a lower incidence of patellofemoral pain. However, Tagesson et al., 2008 [33] and Morrissey et al., 2002 [38] reported that a difference in patellofemoral pain was not verified in their studies.

In our study, the rehabilitation program was initiated early after ACL reconstruction and the mean duration of the injury was 2.06±0.83 months. In agreement with our study, Isberg and his co-workers, 2006 [36] reported that early initiation of rehabilitation didn’t result in increased ACL strain or a deleterious effect on the ACL graft after ACL reconstruction. However, two studies by Heijne and Werner, 2007 [37] and Beynnon et al., 2005 [31] have evaluated early versus late initiation of OKC exercises for quadriceps in patients with ACL reconstruction. Early start of OKC exercises after ACL reconstruction resulted in increased knee laxity.

We conclude that both CKC and OKC exercises appear to be suitable for rehabilitation after ACL reconstruction; however, CKC exercises showed better outcome after rehabilitation than OKC exercises especially as regards knee functions. Also, patients were satisfied more with the CKC exercises at the end of the rehabilitation and felt more improvement of knee pain than OKC group. Early initiation of quadriceps exercises after ACL reconstruction is recommended to prevent any deleterious effect of deformities or weakness on knee functions. However, the appropriate time for introducing OKC quadriceps training is indecisive and needs further investigation.

References