Comparison of standardized closed kinetic chain exercises against open chain exercises in ACL-deficient knees

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Abstract

The accelerated rehabilitation protocol after ACL-replacement has become a standard in sports medicine. In order to perform early quadriceps and hamstring exercises a vast number of different training machines are used. These machines allow exercises in open and closed kinetic chain. Purpose of this study was to show if there is a difference in anterior tibial translation between open and closed kinetic chain exercises in ACL-deficient patients? And if there is a difference, is it clinically relevant if tested under realistic rehabilitation conditions?

A normal control group of 10 athletes doing regular training in a rehabilitation center, no history of knee joint injury or pain, mean age, 25 years and clinically stabil knee joints was examined. The study group consisted of 6 patients with a mean time since ACL-injury of 24 months, no meniscal injury, mean age 24 years and 1-2+ Lachman-test.

The open kinetic chain exercise was performed sitting in a special chair pushing a weight loaded lever sitting in front of the tibia into full extension of the knee. Then the leg is flexed again slowly performing a controlled eccentric quad contraction.

The closed kinetic chain exercise involved a leg press in supine position. The patient pushes the slide against a weight block with his feet on a fixed board and comes back to a squatting position performing a controlled eccentric quad contraction. A computerized electrogoniometer-system allowing for four degrees of freedom was used. It could be easily mounted on the knee joint and allowed for free movement of the knee. Patients could be analysed during their normal rehabilitation routine.

In the normal control group there were no significant differences in a/p-translation between open and closed chain exercises. A side to side difference could not be detected. In ACL-deficient patients there was a significant difference between open and closed kinetic chain exercises. Open kinetic chain exercises lead to an increased anterior translation of the tibia between 10° and 80°. Maximum was 8,3mm difference at 30° of knee flexion during eccentric quad contraction. Closed kinetic chain exercise did not lead to a significant increase of anterior tibial translation in ACL-deficient knee joints.

In our experimental setup closed kinetic chain exercises generated significantly less anterior tibial translation during muscular rehabilitation after ACL-surgery. Closed kinetic chain exercises could therefore be advantageous during ACL rehabilitation.

KEYWORDS: KNEE, REHABILITATION, ACL-INSUFFICIENCY, ELECTROGONIOMETER, CLOSED-CHAIN-EXCERCISE
An intensified rehabilitation program enhancing early motion and early muscle activation has become an international standard after ACL-reconstruction \cite{24}. However, biomechanical studies have demonstrated that quadriceps exercises against weight lead to a significant anterior translational force in the knee potentially endangering a biological ACL reconstruction in its vulnerable postoperative phase \cite{1, 8, 10, 26}. Exercises used in rehabilitation of the knee joint usually are divided into two distinct groups. The first group includes exercises being performed without the foot touching the ground. This type of exercise does not allow for axial loading of the knee joint (open kinetic chain) and thus leads to an isolated quadriceps contraction \cite{8, 11, 13, 23, 26}. Exercises belonging to the second group only recently became more popular in ACL-rehabilitation. These exercises are performed with an axial loading of the knee joint. They are called „closed kinetic chain“ exercises \cite{18, 19, 20, 21, 26, 27}. Exercising machines of various designs are marketed for intensified knee rehabilitation \cite{21} and can be grossly divided into closed and open chain type. There is no clear opinion in the orthopaedic community regarding the benefits of a specific training program or the potential hazards of muscle training machines in the early rehabilitation period after ACL reconstruction. This study was undertaken to address potential differences in ACL strain during quadriceps muscle training using open or closed chain rehabilitation machines.

**Material/Methods:**

**Exercises**

We chose two representative exercises and training devices for either open resp. closed kinetic chain training. The closed kinetic chain exercise was the leg-press in supine position. In this exercise the patient is lying on a movable sledge with his shoulders stabilized in a frame. The legs are held in 90° flexion and the feet are pressed against a footrest. The patient has to push the sledge horizontally against a variable weight (fig. 1). This results in an eccentric quadriceps contraction with a constant axial loading of the knee joint. The open kinetic chain exercise was performed with the patient sitting on a special chair. A lever is placed in front of the tibia. The patient has to push the lever against a variable weight from 90° of knee flexion up to full extension. This again leads to a concentric quadriceps contraction without axial loading of the knee joint (fig. 2).
Study group
First we tested 10 athletes without any history of knee injury or knee associated pain. There were 5 male, 5 female athletes with an average age of 24 years. All individuals were instructed to do both exercises two days and again one day before testing in order to get used to the testing apparatus and the exercises. Data of both knee joints was recorded thus providing data on 20 non-injured knee joints. This data was used for a validation of the testing procedure and served as a normal control.

The study group consisted of 6 patients with an arthroscopically verified deficiency of the anterior cruciate ligament. All patients had a 5mm Lachman-test lacking a firm end-point. Two patients had a Lachman-test of 10mm. In all patients stability of the collateral ligaments was normal in comparison to the uninjured knee joint, there were no signs of meniscal injury in any patient. All patients had sustained their ACL-injury more than one year prior to testing (mean 25 mts, ranging from 12 to 48) and they were able to perform the exercises without pain or any other impairments. The injured knee joint was in 3 cases right, in 3 cases left. 5/6 patients had an uninjured opposite knee joint and could be tested side-to-side. One patient had a posterolateral rotational instability on the opposite knee joint. In this patient the opposite knee joint could therefore not be taken as a reference. The tested patients were taken directly from their rehabilitation protocol and tested during a normal exercise session. The open kinetic chain exercise had to be shown to the patients two days before testing since our rehabilitation protocol does not involve open kinetic chain exercises. All patients first performed the open kinetic chain exercise. After a rest period of 5 min. they performed the closed kinetic chain exercise. 10 cycles of each exercise were recorded.

Knee-Anatometry System
Each tested patient had a computerized electrogoniometric system
\footnote{CA-4000 Anatomery-System, Orthopedic Systems Inc., Los Angeles/California} fixed to the tested knee joint using velcro straps (fig. 3). The electrogoniometer system was able to record 4 degrees-of-freedom in a realtime mode. Extension/flexion, external/internal rotation, varus/valgus rotation and anterior translation of the tibia was measured simultaneously. Anterior translation was registered using a patellar lever. The electrogoniometer system was chosen as measurement device because all exercises
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could be performed with the applied apparatus without any interference. Furthermore patients could be tested during their normal rehabilitation program.

**Statistical analysis**
For statistical analysis the Wilcoxon-test was used with the level of significance at $p<0.05$.

**Results:**
In the control group there were no differences in anterior translation between the two exercises. No side-to-side difference was observed (fig.4).
In the ACL-insufficient patients however, there was a significant difference between open and closed kinetic chain exercises regarding the anterior translation of the tibia. In the open kinetic chain exercise there was a significant increase of anterior translation inbetween 10° and 80° of knee flexion compared to the non-injured knee joint. Relative anterior translation of the tibia increased up to 5-8mm with a maximum at 30° of knee flexion. The closed kinetic chain exercise did not result in a pathologic anterior translation of the tibia. Knee kinematic was unchanged during closed chain exercise regarding all recorded parameters (fig. 5).
Subjectively patients felt to have a better knee joint control and therefore graded the closed chain kinetic exercises as the more comfortable exercise.

**Discussion:**
In the experimental work done throughout recent years {3, 7, 9, 20, 23, 26, 28} open and closed kinetic chain exercises have been evaluated theoretically and under very well controlled experimental conditions. During rehabilitation however there are no such controlled conditions and especially for quadriceps training commercially available training devices are used. We therefore tested our study group in a realistic setting on commercially available training devices. The electrogoniometer-system has been reported earlier to be reliable in dynamic conditions {22} and did not interfere with free movement of the knee joint.
We could show that in ACL-deficient patients open chain exercises involving knee extension against a weight block lead to a significant anterior translation of the tibia. Anterior translation of the tibia is reduced to normal if closed kinetic chain exercises
are performed in the same subjects. As may be expected, there is no difference between the two types of exercises in intact knees. These results show a high correlation to the results of earlier studies using either a different measurement device \cite{12} or a different testing protocol involving different exercises\cite{25}.

**Clinical relevance**

Early functional rehabilitation involving training devices and weights have become a major part of rehabilitation after ACL surgery. Regarding the present state of „aggressive“ functional rehabilitation \cite{16, 17, 24, 21} after ACL surgery our study shows some important results. We could show that rehabilitation on training devices against weights can induce significant anterior translation of the tibia if wrong rehabilitation procedures are performed. The documented anterior translation of 8mm for an open chain exercise equals the amount of anterior translation induced by a 100N Lachman-test \cite{8}. Even if primary graft fixation tolerates these forces \cite{15} one has to consider the comparatively long phase of remodelling with the risk of weakening and elongation of the ACL-graft \cite{4, 14}. In-vivo studies of ACL-strain during active loaded extension of the knee showed an increase of 5.8\% in ACL-strain. One has to assume that open kinetic chain exercises lead to a similar increase in ACL-strain. Exercises in closed kinetic chain do not lead to an increase in anterior translation and thus do not cause a marked increase in ACL-strain. This is supported by in-vivo studies where closed kinetic chain exercises showed a minor increase in ACL-strain \cite{3}. The improved coordination of the hamstrings and the possibility of co-contraction during closed kinetic chain exercises in line with a higher joint stability due to axial compression of the joint seem to be the advantage of closed kinetic chain exercises \cite{2, 5, 6, 21}.

We therefore conclude that closed kinetic chain exercises in ACL-rehabilitation are advantageous. The rehabilitation protocol should include these exercises as basis for muscular rehabilitation of the knee joint. Open kinetic chain exercises lead to an increased anterior translation of the tibia and have to be regarded as potentially hazardous for an ACL-graft during early ACL-rehabilitation.
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Legends to figures:

Figure 1:
**Closed kinetic chain exercise:** the patient is supine on a sledge and pushes his feet against a board. This leads to a concentric quadriceps contraction with axial loading of the knee joint.

Figure 2:
**Open kinetic chain exercise:** the patient is sitting on a chair and extends his knee joint against a lever sitting in front of the tibia. This leads to a concentric quadriceps contraction without axial loading of the knee joint.

Figure 3:
**Computerized electrogoniometer-system:** The design of this goniometer allows for free movement of the knee joint during the exercises. Movements in four degrees of freedom can be registered simultaneously.
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Figure 1
Figure 2
Figure 3
Figure 4

Anterior translation in open/closed chain kinetic exercises in ACL-insufficient patients

+SEM
* = p<0.05
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Figure 5

Anterior translation in open / closed chain kinetic exercises in normal knee joints

±SEM (no significant differences)

- open chain
- closed chain

Anterior translation in mm

Kneeflexion in °