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The effect of a controlled active motion device on proprioception after anterior cruciate ligament plasty.

A prospective randomised study.

A ruptured anterior cruciate ligament leads to both a mechanical and functional instability caused by a proprioceptive deficit. This is the result of damage to the receptors in the anterior cruciate ligament [29]. Thus, sensory motor control of the knee is limited. Accompanying, pain thresholds might be elevated or lowered, as e.g. can be seen in the "giving-way" phenomenon [13]. Several receptors located in the various areas of the knee joint are responsible for proprioception. In 1984, Schultz et al. [35] were the first to histologically demonstrate the presence of receptors in the ACL. Besides receptors in the anterior and posterior crucial ligament, receptors can also be found in the menisci and the soft tissue surrounding the knee-joint.

This system of receptors is extremely important for the joint's proprioceptive performance [13, 18]. Mechanoreceptors collect information about the extension and load condition of the capsule/ligament apparatus and about joint movement. The movement of the joint is coordinated on the basis of this information. The angle reproduction test described by Jerosch [23], among others, is a way of providing a measure of overall proprioceptive ability.

There is evidence that proprioceptive ability is pathologically altered in patients with rupture of the ACL [17, 28]. There is also evidence that no correlation between mechanical and subjective instability exists, but between proprioception and subjective instability [2, 15]. Consequently, for optimum results, operative reconstruction of the ACL should be followed by postoperative, proprioceptive/neuromuscular therapy. Typically, however, only outpatient physiotherapists initiate the required proprioceptive/neuromuscular training after the patient has been discharged from the hospital; reasons include postoperative pain, catheters still in situ, existence of swellings, lack of completion of treatment and lack of range of motion. It should be the aim to begin proprioceptive training as early as possible in order to rebuild sensory motor performance.

Ageberg et al. [1] came to the conclusion that although conventional physiotherapy and the use of continuous passive motion devices (CPM) can increase the range of motion postoperatively, they do not affect the neuromuscular deficit caused by the trauma. Training exercises suggested to address the neuromuscular deficit, e.g., proprioceptive neuromuscular facilitation (PNF) and balance exercises using a wobble board, cannot be carried out in the immediate postoperative phase as a result of the conditions referred to above.

Use of controlled active motion devices (CAM) represents a new approach in immediate postoperative treatment following anterior crucial ligament reconstruction. Using these devices, the patient can begin active movement and coordination-oriented training at an early stage. Training with the CAM device adheres to the physiotherapeutic closed chain principle, since the foot is fixed in the CAM device. In comparison to training on a stationary bike or other types of complex neuromuscular training, using the CAM device allows to adjust the flexion of the knee-joint according to the latest diagnostic conditions. In addition, only minor mechanical loads will be applied, as is necessary during the immediate postoperative phase. This type of training promotes proprioception [14] through high-level coordination of the knee-joint movements and corresponds to the therapy recommended by Rivera [33].

The objective of this study was to investigate whether the proprioceptive deficit caused by the rupture of the an-

	CAM	NOB
Age		
<20		3
20-25	18	18
26-30	4	4
31-35	2	
>35	1	
Gender		
M	24	23
F	1	2
Height (cm)		
160-165		1
165-170	1	2
171-175	9	4
176-180	7	10
181-185	4	4
186-190	4	4
Weight (kg)		
<60	1	
60-65	3	2
66-70	1	1
71-75	9	12
76-80	2	2
81-85	5	3
86-90	2	1
91-95	1	2
>95	1	2
KJ (injured side)		
left	13	11
right	12	14
Surgical technique		
BTB	24	23
STG	1	2
Accompanying injury (menisci)		
IM	6	8
AM	2	5
IMAM	3	2
none	14	10

Fig. 1 ◄ **patient data and accompanying injuries**

Fig. 2◄ **Unlike a bed-bicycle, the CAM device allows for a linear movement**

terior crucial ligament can be reduced by a combination of an anterior crucial ligament graft and the use of a controlled active motion (CAM) device in the immediate postoperative phase.

Materials and methods

Patients

A prospective randomized study was carried out on 50 patients. The ethical committee of the University of Ulm/ Germany approved the study (No. 165/ 2001). Participating patients and healthy volunteers had given their written agreement.

All patients had a rupture of the anterior crucial ligament. The patients were clinically examined and the active range of motion of both knee joints was measured. In addition, the time between trauma and surgery was registered. The patient clientele was divided into two therapy groups (25 patients per group) using letter randomization. The CAM group (physiotherapy and CAM device) consisted of 1 woman and 24 men; the PT group (physiotherapy only) consisted of 2 women and 23 men.

There were no significant differences in respect of age, weight and body size between the two groups. In the CAM group, the left knee was affected in 13 patients and the right knee in 12 patients, whilst in the PT group the left/ right division was 11 to 14. There were no clinically relevant differences in relation to the number and type of accompanying injuries in both groups (◘ Fig.1).

Exclusion criteria for this study were bracing requirements, contraindications in respect of CAM/CPM treatment, limitations to range of motion due to the surgery, postoperative infection, deep vein thrombosis, neurological impairment, metabolic vascular disease with neurological components, upper and/or lower ankle joint injuries, hip injuries and passive range of motion less than 70%.

Fig. 3▲ **Testing apparatus with goniometer for passive angle reproduction test**

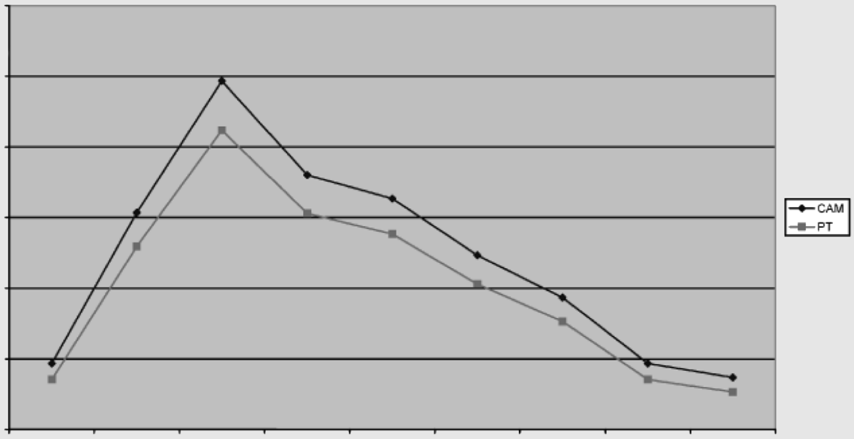

Fig. 4 ▲ **Pain level over time, determined via visual analogue scale (VAS, range from minimum 1 to maximum 10)**

Surgical techniques

The surgical treatment of the ACL rupture was carried out using either a bone-tendon-bone graft (BTB) or a semitendinosus gracilis tendon graft (STG) with a total of 4 tendon strands. Patients were free to choose between the two operative procedures following appropriate consultations. In the CAM group the ratio of BTB versus STG was 24:1 and 23:2 in the PT group. With both techniques, the transplants were fixed using biodegradable screws in the tibia and femur. The same two surgeons (B.F./W.S.) performed all surgeries.

Postoperative treatment

Patients in both groups were allowed to freely move their knee joints according to pain tolerance. Conventional physiotherapy consisted of lymph drainage, gait training, active and passive motion exercises and isometric stretching exercises for both knee joints. Postoperatively, all patients were allowed sole contact. Particular attention was paid to early extension exercises. Patients in the CAM group received the CAM device following the removal of the drainage tube on the second postoperative day. Patients in the CAM group used the CAMO®ped controlled active motion device (OPED (j), Valley, Germany, ◘ Fig. 2).

The patients in the CAM group were expected to train with the CAM device for 2 to 4 hours per day. Patients in the PT group followed the same conventional physiotherapeutic protocol as the patients in the CAM group; they just did not receive the CAM device.

Using a standardized procedure, all patients were admitted to the hospital one day before surgery and discharged on the 7th postoperative day. Therefore, patients were hospitalized for 9 days in order to create comparable, controlled conditions for the study.

Angle reproduction test

In order to determine the patients' proprioception, the angle reproduction test as described by Jerosch et al. [22, 23] was used. We carried out wholly passive measurements. Angles were measured using an electrical goniometer (Penny & Giles (R), Dorset, GB, accuracy of goniometer ±0.5°). The instrument was fixed laterally to the knee with double-sided adhesive tape (Tesa ®, Hamburg) (◘ Fig. 3).

Once the measuring controls were positioned, the knee was extended to 0° and the goniometer was calibrated. Now, each patient was required to bend the leg several times to 90° and the accuracy of the measurements was verified. Using a blindfold, visual stimuli were taken away from the patient. The leg was then moved passively to three previously defined angle settings in sequence (right: 15°, 30°, 50°; left: 10°, 35°, 60°). Patients were asked to memorize each position.

After returning to the initial position and following a passively guided, repeated movement, the patient was asked to indicate when the pre-determined angles had again been reached. Following Jerosch et al. [22, 23], varying angles for the right and left leg were selected to avoid a learning effect. In addition, the sequence of the angles to be followed was varied for each patient. The side-to-side difference between the healthy and injured knee-joint was determined and defined as the proprioceptive deficit of the injured knee.

Additional criteria

In addition to the angle reproduction test, the circumference of the leg was measured 10 cm and 20 cm above the medial knee-joint gap and the pain levels were recorded pre-operatively and up to the day of discharge. The pain was measured using a visually analogue scale (VAS, 10 cm). Each patient participating in the study had to document the daily training volume with the CAM device.

Statistics

Before conducting the study itself, a control group of 20 healthy volunteers was examined using the angle reproduction test as described above. These results were taken into account in order to determine the number of patients necessary per study group for statistical purposes.

According to earlier publications [8, 17, 22, 28], the ACL assumes its main function when the knee joint is near the fully extended position. Therefore, the range of motion near full knee extension has been defined as the main target area and was chosen to determine the proprioceptive deficit. Looking at this main target area, the control group exhibited an average side-to-side difference in angle reproduction of 2.3°±1.9°.

Angles of knee flexion of 30°/35° and of 50°/60° (right/left respectively) were established as secondary target angles. For the 30°/35° angle, the healthy volunteers showed an average side-to-side difference of 2.1°±1.8°. For the 50°/60° angle, the average side-to-side difference was 1.8°±1.0°.

In order to determine the statistically necessary amount of patients, a power of 80% and an error of $p<0.05$ were chosen. This resulted in $n=25$ patients per group. The usual procedures of descriptive and comparative statistics were used for the statistical evaluation. Significance was calculated using the t-test.

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The effect of a controlled active motion device on proprioception after anterior cruciate ligament plasty. A prospective randomised study.

Abstract

Background. A ruptured anterior cruciate ligament (ACL) leads to both mechanical and functional instability. Functional instability is caused by the proprioceptive deficit. The objective of this study was to determine whether using a controlled active motion (CAM) device postoperatively could reduce the proprioceptive deficit.

Patients and methods. A total of 50 patients with an ACL rupture were randomized into two groups. After ACL plasty, the PT group received postoperative physiotherapy, while the CAM group was managed with a CAM device in addition to physiotherapy. Proprioceptive ability was measured with a passive angle-reproduction test.

Results. On the day of discharge, 80% of the patients in the CAM group and 25% in the PT group had a reduced proprioceptive deficit. Considering the main measured value, the CAM group improved by 83.7%, while the PT group worsened by 39.3%. There was no significant difference between the CAM group and a healthy control group.

Conclusion. Using a CAM device in addition to physiotherapy after ACL plasty decreases the proprioceptive deficit significantly in comparison to physiotherapy alone. We recommend the use of a CAM device in the postoperative management following ACL plasty.

Keyword

anterior cruciate ligament plasty, functional instability, neuromuscular training, proprioceptive deficit, controlled active motion device

Results

Pain and active range of motion

On the day of discharge, more than 70% of patients in both groups reported to be completely pain free. There was no difference between the groups (◘ Fig. 4).

Preoperatively, all patients were able to extend both the healthy and the injured knee joint actively and freely. The average active flexion of the healthy knee joint was 134.6° ±7.6° in the CAM group and 128.6°±9.6° in the PT group. On the surgical side, the preoperative active range of motion was 129.6°±9.1° in the CAM group and 117.0° ±16.9° in the PT group.

On the day of discharge, there was no extension deficit in any patient. At discharge, the average active range of motion of the surgical side was 98.8°±14.0° in the CAM group and 85.4° ±20.0° for patients in the PT group. The difference in range of motion between the two groups preoperatively and postoperatively is significant. The significant difference between the two groups can be explained by outliers. The difference in active range of motion pre- and postoperatively is -30.8° ±15.2° in the CAM group and -31.6°±18.0° in the PT group. This difference is not significant.

Main target angle 10°/15°

Preoperatively, no statistically significant difference between the patients in the CAM group and PT group was recorded. The average side-to-side difference was 4.3°±3.9° in the CAM group and 2.8°±5.4°in the PT group. On the day of discharge, the CAM group had a 0.7° ±2.3°(median 1°) side-to-side difference and the PT group 3.9° ±4.6° (median 4°). This corresponds to a reduction in side-to-side difference of 83.7% in the CAM group and an increase of 39.3% in the PT group. This is a significant difference in favour of the CAM group.

In addition, comparing pre- and postoperative side-to-side differences in the angle reproduction test, the CAM group performed significantly better than the PT group. The CAM group improved by 3.7° ±3.3° while the PT group's performance decreased (1.1° ±4.8°).

Comparing the postoperative performance of the CAM group versus the healthy control group, no significant difference was seen at the 10°/15° angle.

In order to emphasize the differences between the CAM and PT groups, individual changes concerning the proprioceptive deficit in the angle reproduction test are presented in figures 5 and 6. A reduction in deficit is shown in 80.0% of patients in the CAM group. In the PT group, on the other hand, a reduction of the proprioceptive deficit is observed in only 24% of patients.

Secondary target angle 30°/35°

An average preoperative side-to-side difference of 1.8°±3.7° (CAM) and 1.9°±2.9° (PT) was measured. There

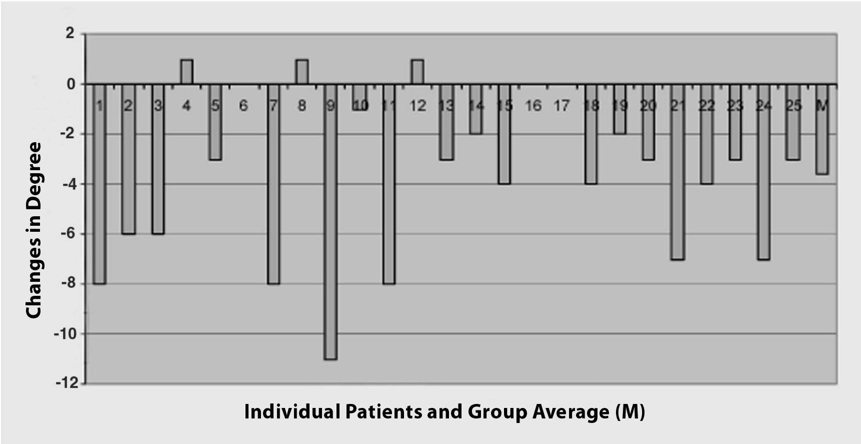

Fig. 5 ▲ **Changes concerning the proprioceptive deficit in the CAM group from day of admission to day of discharge. Column M represents the average change in the group.**

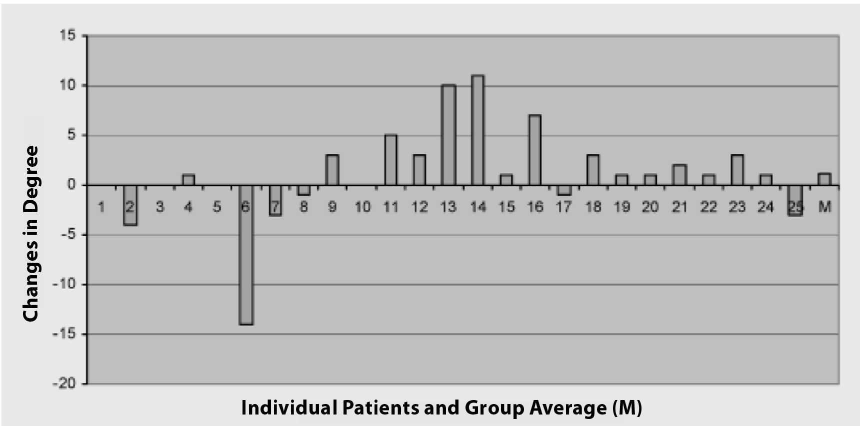

Fig. 6 ▲ **Changes concerning the proprioceptive deficit in the PT group from day of admission to day of discharge. Column M represents the average change in the group.**

was no significant difference between the two groups. Postoperatively, the side-to-side difference was 0.4°±2.1° in the CAM group and 1.5°±4.0°in the PT group. This corresponds to a reduction in side-to-side difference of 78.0% in the CAM group and of 21.1% in the PT group. Although the postoperative results using this test were better when compared with preoperative results (CAM: 1.4° ±3.8°, PT: 0.4° ±4.3°), no significant improvement was measured.

Secondary target angle 50°/60°

In the CAM group the preoperative average side-to-side difference was 1.5° ±3.7°, whilst in the PT group it was 2.2° ±3.3°. There was no significant preoperative difference. The postoperative side-to-side difference was 0.4 °±2.4° in the CAM group and 3.6° ±4.1° in the PT group. The difference between the CAM and PT group is significant.

Looking at the side-to-side difference pre- and postoperatively, the CAM group showed significantly better results than the PT group (1.1°±5.2° vs. -1.4°±3.3°). The side-to-side difference was reduced by 73.3% in the CAM group, while it increased by 63.6% in the PT group.

Thigh circumference / Training volume

Preoperative and postoperative measurement of thigh circumferences did not reveal any significant difference between the groups.

Average daily training volume with the CAM splint was 183±39 minutes, ranging between 49 to 240 minutes.

Discussion

The objective of this investigation was to find out whether adding a CAM device to the immediate postoperative rehabilitation could reduce the proprioceptive deficit in patients with anterior crucial ligament graft. In this study we have shown that using a CAM device in the immediate postoperative phase in conjunction with conventional physiotherapy significantly reduces the proprioceptive deficit in comparison to physiotherapy alone. On the day of discharge, patients in the CAM group showed no significant difference compared to a healthy control group.

The positive effect of neuromuscular training regarding proprioception has been documented in many studies [4, 9, 21, 27]. Bouet et al. [9] showed that proprioception could be improved simply by 10 minutes of training on a stationary bike. Other authors provided evidence of better proprioception in gymnasts compared to the average population [27] and also better proprioception in sportsmen/-women following a warm-up [4].

Evidence that patients with injuries to the anterior crucial ligament exhibit an apparent limitation of proprioceptive performance of the knee-joint was provided in several studies [8, 17, 19, 21, 24, 30, 36]. We were able to confirm these findings with our preoperative measurements. Therefore, reducing the proprioceptive deficit through active neuromuscular motion training is clearly indicated.

Jerosch [21] gave evidence that proprioceptive training positively influences sensory motor control following crucial ligament injuries. In his study, some patients had better results than healthy volunteers in a control group – something we could not see in our investigation.

In our study, on the day of discharge, patients in the PT group demonstrated a slight, insignificant decline of proprioceptive capabilities. We feel that along with the rupture of the anterior crucial ligament the surgical intervention further influences the proprioceptive deficit.

Immediately postoperative, due to drainage in situ, postoperative pain, swelling, limited range of motion and restricted weight bearing, many "classical" sensory/neuromuscular exercises, such as using a wobble board, proprioceptive neuromuscular facilitation (PNF) or leg press, cannot be performed. The CAM device facilitates immediate postoperative therapy in a closed chain to reduce the proprioceptive deficit. Therapy with the CAM device corresponds to the neuromuscular training as demanded by Rivera [33]. This type of therapy involves exercises with muscular activity in a closed chain according to normal proprioceptive mechanisms.

Using the CAM device, the good results of a neuromuscular rehabilitation program documented in before mentioned studies, can be obtained as early as in the first postoperative week. The results of our study relate only to the first postoperative week. It has not yet been ascertained whether the reduction of the proprioceptive deficit obtained in the first postoperative week persists in the long term. In a study presented during an illustrated lecture at the ISAKOS conference Auckland/New Zealand, March 2003, Feil and Pässler showed that even 12 weeks after an ACL reconstruction clear advantages during functional testing exist when comparing rehabilitation including a CAM device (4 weeks of use immediately post-op) to rehabilitation with physiotherapy alone. Therefore, we assume that the proprioceptive performance can be improved in the long term by continuing the CAM therapy after the patient's discharge from the hospital. In fact, continuing outpatient use of the CAM device seems absolutely essential, since a 9-day inpatient treatment as undertaken in our investigation is by no means the norm. However, in order to evaluate the effect of the active motion device we tried to create the most standardized conditions possible.

Supposedly, proprioception would be limited to a lesser degree when surgically repairing (sewing) a ruptured anterior crucial ligament compared to replacing the ACL using a graft [26], due to the remaining presence of mechanoreceptors. However, considering mechanical stability, the surgical repair compares poorly to the graft [12].

Most authors agree that it is only the combination of anterior crucial ligament graft and neuromuscular training that leads to improved functional stability [10, 14]. Beard et al. [5] consider a crucial ligament plasty as the ideal precondition for good sensory motor function, as in patients with chronic insufficiency of the anterior crucial ligament they found a significant postoperative improvement in proprioceptive performance.

Another hypothesis is based on the assumption that mechanoreceptors and nociceptors can be found in a crucial ligament graft, affecting proprioception. However, there are contradictory results in this regard [3, 11, 20]. During the immediate postoperative phase, as considered in our investigation, we reckon that no mechanoreceptors and nociceptors in the crucial ligament plasty are influencing proprioception.

The mechanisms leading to a reduction of the proprioceptive deficit in our study are not clear. We assume that a crucial ligament plasty indirectly affects proprioception of the knee joint. We consider a crucial ligament plasty to be a method of restoring the mechanics of the joint (homoeostasis) and with them the physiological movement and load-bearing functions to the greatest degree possible.

Finally it is not clear whether most of the proprioceptive deficit is caused by failure of proprioceptive performance in the anterior crucial ligament and/or by malfunctioning of other joint structures due to mechanical instability. We assume that a rupture of the anterior crucial ligament affects changes to the state of tension of the capsule and especially the posterior crucial ligament. This then leads to malfunctioning of the receptor within these structures, which causes the proprioceptive deficit.

These assumptions can be supported by a study carried out by Ochi et al. [31]. It provides evidence of morphological changes to the anterior crucial ligament after rupturing the posterior crucial ligament. These changes refer particularly to receptor density, which was reduced even though the anterior crucial ligament was not injured.

Various procedures can determine sensory motor performance. Most common are the angle reproduction test (active or passive) and the passive motion recognition test [16].

These tests are designed to determine the proprioceptive capability of the knee joint.

In addition, it is possible to use EMG measurements in conjunction with jump and gait analyses [34], measure the postural reflexes [7] or utilize latency time testing [6] to make an assessment of the performance of the entire sensory motor system. However, generally, the last three processes mentioned cannot be used in the immediate postoperative phase (1st postoperative week).

Thus far, only two clinical studies investigated whether the type of anterior crucial ligament plasty could have an effect on proprioception. MacDonald et al. [30] were unable to determine any difference concerning the proprioceptive deficit between the operative techniques also used in our investigation. Reider et al. [32] confirmed these findings. Aforementioned investigations used either the angle reproduction or passive motion recognition test. These tests are the two most common procedures for measuring proprioceptive performance [16].

Rudroff [34], on the other hand, saw advantages in a semitendinosus graft over a bone-to-bone graft. The results obtained are based on EMG analyses during gait and jump as well as isometric exercises. When analyzing complete motion sequences, characterized by a complex stimulation of afferent/efferent sensory motor pathways and in particular the tendon reflexes, one can expect different results for the different graft types as the graft type may influence its own reflex pathway [34]. However, these complex mechanisms of gait stabilization do not play a significant role in the angle reproduction test.

The possibility of postoperative pain affecting the varying results in the two groups can be neglected, as the course of pain was almost identical between the groups.

Following injuries to the knee joint, the M. vastus medialis in particular seems to atrophy [13]. Additionally, atrophy can frequently be observed after surgical intervention. This is also ascribed to disturbed proprioception of the knee joint caused by damage to the mechanoreceptors in the joint [25].

In our study, we also measured muscle circumference in the femoral area preoperatively and on the day of discharge. However, we were not able to demonstrate that training with the CAM device, compared with conventional physiotherapy alone, reduces muscle atrophy to a greater extent. Then again, this was not expected in the short postoperative period of our investigation.

Analyzing the results of our study, the significant difference in respect of active range of motion between the two groups, both pre- and postoperatively, is striking and was not expected in a randomised study. However, outliers can explain the variation in range of motion. In the CAM group, no patient demonstrated less than 110° of active flexion preoperatively. In the PT group, two patients could actively flex less than 110° (60°, 85°).

Postoperatively, all patients in the CAM group reached at least 60° of active flexion. In the PT group, postoperatively, three patients could actively flex to a lesser extent (40°, 45° and 45°). The passive range of motion was at least 70° in all patients. Therefore, the angle reproduction test could be carried out in all cases. The secondary importance of the difference in range of motion is underlined by the insignificant difference between pre- and postoperative variation in range of motion.

Practical relevance

We showed that the preoperatively existing, proprioceptive deficit can be reduced significantly by combining anterior crucial ligament plasty and neuromuscular training immediately postoperative using the CAM device. A combination of anterior crucial ligament plasty and conventional physiotherapy alone did not affect the same result. Therefore, we recommend including the CAM device as an integral part of the therapy directly after surgery. It remains to be investigated whether the advantages of the CAM device persist long-term over a period of more than 6 months.

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Conflict of interests: The author assures that there are no connections with any company whose products are named in the article, nor a company, which distributes a competing product.

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