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The research on the effectiveness of knee orthoses has shown controversial results. Long-term use does not show any secure benefits, but laboratory results demonstrate positive effects from the biomechanical and sensormotoric point of view. The results presented in this study also underline that patients benefit from an orthosis in challenging coordinative movement tasks. This particularly applies to the sensorimotor preparation of a drop jum. This article describes the way a stabilizing soft orthosis influences the sensormotor behaviour during jump loads.

Introduction

The movement mechanism of the knee joint, while appearing to be simple at first glance, proves to be very complicated and complex at a closer look. For example, the anterior cruciate ligament is the main structure for limiting ventralisation of the tibia over the femur (anterior-posterior shift). It fulfils a similar purpose for internal and external rotation and for varus-valgus loading. The cruciate ligament is extremely important for the kinematics of the knee joint [9].

One of the most common injuries of the knee joint is a rupture of the anterior cruciate ligament (ACL). This is a very serious injury from the biomechanical as well as the sensorimotor aspect. From the biomechanical standpoint, the kinematics of the outer and inner (lateral and medial) compartment differ even in a healthy knee [20, 21]. One feature of an insufficient cruciate ligament is not only the anterior-posterior translation („drawer“), but also the increased impact on the biomechanics of the outer (lateral) compartment [21]. Even when the anterior-posterior translation and the kinematics are adjusted to approach those of the sound side to the greatest possible extent after cruciate ligament reconstruction, the absolute position of the lateral tibial plateau relative to the femur remains different [22]. The operated knee joint continues to display a difference in kinematics of rotation when walking [30]. After ACL reconstruction, the biomechanical function of the knee joint is still considerably impaired, despite the fact that the anterior-posterior shift has been normalised as much as possible. The complex biomechanical disorders remain undetected and promote the premature development of meniscus and cartilage damage as the starting mechanism for osteoarthritis. A meniscus or partial or complete ACL rupture increases the risk of osteoarthritis of the knee by a factor of ten (incidence rate for osteoarthritis: 15 to 20 percent) compared to a group of the same age [10]. From the sensorimotor standpoint, the cruciate ligament is the location of very important mechanosensors whose afferent signals play an essential role in the voluntary activation capacity of the fast motor units of the quadriceps femoris muscle (intramuscular coordination) [13]. The acute loss of these afferents leads to the familiar contractile weakness of the muscle immediately following the injury. It is therefore primarily the result of innervation insufficiency and not of atrophy. Atrophy quickly develops secondarily. Furthermore, the cruciate ligament afferents play a large role for the coordinated action of the thigh flexors (intermuscular coordination). By processing the mechanoafferents from the cruciate ligament along with the information from all muscle spindles, the brain is able to recognise the static and dynamic joint position, which is essential for regulating movement.

The cruciate ligament afferents are thus crucial for the fine regulation of knee joint movement. After an injury, the quadriceps muscle loses considerable strength, caused primarily by the partial functional paresis due to the injury [15, 16, 18] and secondarily by muscular atrophy. This reduces the dynamic active stability of the knee joint and causes greater stress to the passive joint structures [26].

The proprioreception deficit can be reduced by ACL reconstruction, but is not normalized, even after about four years [8]. Deficits of the angle positioning in the middle angle range are particularly persistent. The reflective responses of the hamstring in standing persons due to shear forces that affect the tibia from behind are also ascribed in part to the cruciate ligament afferents. Since such reactions can also be triggered in insufficient cruciate ligaments, receptors of other structures including muscles with their afferents must also be involved. However, the latency times of these muscular responses are delayed in deficient cruciate ligaments. After an ACL reconstruction, the levels no longer reach those of healthy persons [1]. A long-term proprioreception deficit due to the cruciate ligament injury is thus clearly evident despite surgical reconstruction.

Following cruciate ligament injuries, the structural losses on the sensory side of the sensorimotor system are irreparable. The healed condition is a „functional scar“ [18, 19]. This apparently includes not only the muscle function on the side of the injured knee, but also that on the sound side [12, 13, 14]. From the neurophysiological aspect, after an injury to the knee joint on one limb, no healthy limb remains.

The neuroplasty processes in response to the permanently changed set of afferent information lead to a convergence of the functions of the two sides at a lower level of function over a very long term. Nevertheless, with maximum isometric contraction there are still deficits in innervation on the injured and operated side compared with the contralateral side even after five to six years. IEMG activity (recruitment of motor units) on the injured side is ten to twelve percent lower [19].

If a very detailed and specific patient history is taken, a changed pattern of physical activity can also be seen. The extent, intensity, and frequency of activity are generally clearly below the level prior to the injury.

The biomechanical and neurophysiological changes occur to varying extents in individual patients. They promote premature degenerative development. Since these persons naturally desire to engage in sports, the effect of a stabilising soft knee orthosis on sensorimotor behaviour during jump loads was examined.

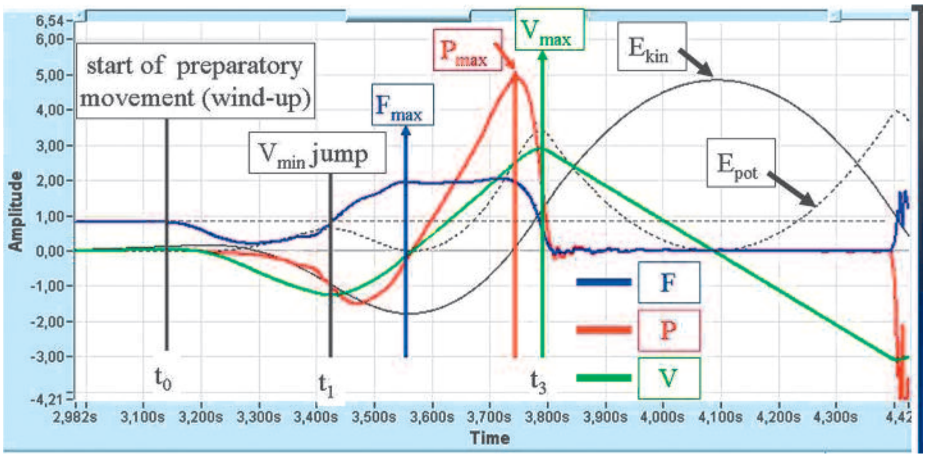

Fig. 1 Illustration of the chronology of the original data of jump behaviour on the dynamometric platform (Leonardo). Speed (green), force (blue), and power (red) are shown. In addition, the courses of kinetic and potential energy are displayed.

Methods

Jumping behaviour with and without the stabilising knee soft orthosis (Genu Direxa Stable Long, Otto Bock HealthCare) was studied on 54 patients after surgical repair for cruciate ligament injuries (28 men: 39.8 ± 11.0 years, BMI 24.5 ± 4.5, 5.8 ± 1.4 years postoperatively; 26 women: 44.8 ± 10.4 years, BMI 26.6 ± 3.0, 5.6 ± 1.1 years postoperatively). The patients were instructed to perform two different jumps on a dynamometric platform (Leonardo):

1. Maximum jump height: reach maximum jump height (height of the centre of gravity) from a two-legged stance with wind-up.
2. Drop jump: jump from a 15-cm-high step from a two-legged stance and combine the landing immediately with a jump to reach maximum height.

Two jumps of each kind were performed, without orthosis followed immediately thereafter with orthosis. After the first jump (Fig. 1), the biomechanical parameters were calculated for maximum height of the centre of gravity (jump height) and the maximum levels for force (KN), power (KW), and speed (m/s). In addition, the parameters for force and power were calculated separately for the left and right limb and the maximum power per kg of body weight in relation to age was indicated (Esslinger Fitness Index). The individual averages were calculated from the results of the two jumps and used to calculate the group results. The data were analysed statistically with the aid of the paired t-test for a single variable (SPSS).

Results

When executing the jump for maximum jump height from a standing position, no differences were observed in women between the maximum force used on the injured and sound side (Fig. 2). The maximum two-legged force (Fig. 2, left) and the maximum force standardised to body weight (Fmax.rel.; Fig. 2, right) showed only slightly, but nonetheless significantly higher levels. Since almost all women patients had slightly higher values, the comparison of the pairs was significant. For men, the force levels of the sound and injured side are definitely slightly elevated. The

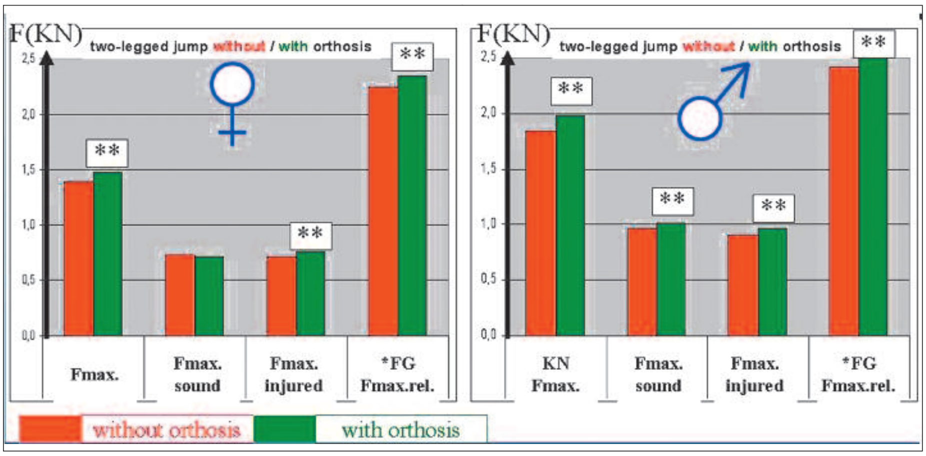

Fig. 2 *Graph of the median values of the parameters for maximum force (both legs) and maximum force for the sound and injured limb and the maximum relative force, standardised for body weight, for women (left) and men (right) for the jumps from a standing position to the greatest possible height.*

maximum two-legged effective force and the relative force were also significantly higher for the jumps with the orthosis.

When executing this jump, the orthosis did not affect the maximum speed of men or women (Fig. 3). The maximum power achieved with two legs and that of the sound and injured limb were also unchanged. For women, when executing the drop jump (Fig. 4), the force levels were not changed by the orthosis. For men, the maximum relative force shows a significant increase. In the take-off for the injured side, while for women, a significant increase was statistically proven only for the uninjured limb.

The maximum age-standardised power per kg of body mass is not affected by the orthosis for the variant maximum jump height from a stance (Fig. 6). However, the jump from a step in preparation for the reactive landing-take-off manoeuvre (for the upcoming very quick stretch-contraction cycle) was executed by women and men with significantly higher maximum power per kg of body weight.

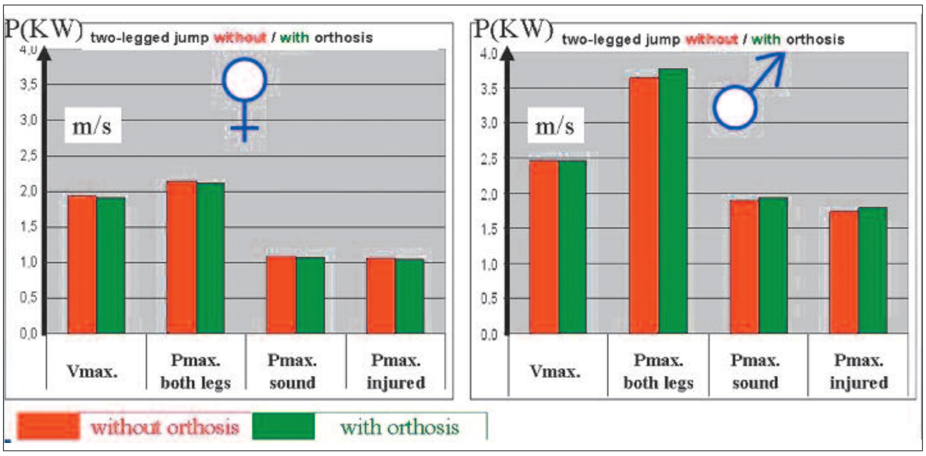

Fig. 3 *Graph of the median values of the parameters for maximum speed, maximum power (both legs), and maximum power for the sound and injured limb for women (left) and men (right) for the jumps from a standing position to the greatest possible height.*

drop jump, the levels for women and men show a significant effect of the orthosis on the maximum jump speed (Fig. 5). The speed increases. Similarly, the maximum power is improved significantly by the orthosis. For men, the power levels with the orthosis were increased on the sound and the

The maximum jump height in cm remained the same for both genders for the jump from a stance. For the reactive jump with an orthosis, the take-off height for men increased significantly for men from 14.5 cm to 20.5 cm (plus 41 percent). There was a statistically significant increase in the absolute level of power per kg of body mass (Wmax/kg) when executing the same jump with the orthosis – for women by 25 percent and for men by 26 percent.

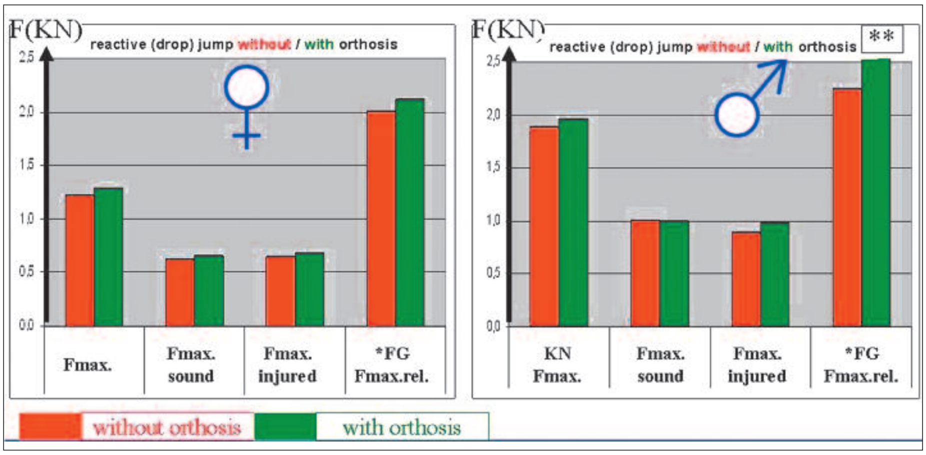

Fig. 4 *Graph of the median values of the parameters for maximum force (both legs) and for the sound and injured limb and the maximum relative force, standardised for body weight, for women (left) and men (right) for the jumps from a 15-cm-high step onto the plate to execute a new jump to the greatest possible height after landing (reactive [drop] jump).*

Discussion

Thus far, no definite advantage for the final outcome following ACL reconstruction – including resumption of sports activity – could be determined due to wearing a knee orthosis for a great part of the rehabilitation period. McDevitt et al. [24] found no difference in outcome between a group with and a group without an orthosis. Birmingham et al. [5] found no differences in the outcome after 12 and 24 months between groups with a functional orthosis and a neoprene sleeve and their conclusion coincides with McDevitt et al.

The results on proprioreception for cruciate ligament patients, measured using joint position sense (JPS) to reproduce a predetermined angle and the threshold to detection of passive motion (TDPM) toward extension or flexion are also inconsistent. Reider et al. [27] additionally indicated that determining the JPS is less reliable than the TDPM. This in itself can lead to different results. The diagnosis of proprioreception deficit thus depends on which diagnostic methods were used and to what extent. Roberts et al. [29] report on studies which all detected a deficit when the three test methods TDPM, active reproduction of a passive change in angle, and the visual estimate of a passive change in angle were used. When only one or two of these methods were used as diagnostic instruments, only three of six studies found a deficit.

Using TDPM, Risberg et al. [28] found no difference after one and two years between the injured and the sound knee joint and between the patients and control subjects. A review by Beynnon et al. [2] found there was generally no effect on JPS in ACL patients, although deterioration was also found. In contrast, TDPM is definitely affected negatively, but only to a very slight extent. The authors therefore doubt the clinical relevance. Mir et al. [25] also examined JPS and TDPM without loading over an observation period of eleven months after the operation. They found no differences between the injured and the sound side or between the patients and healthy control subjects. However, Bonfim et al. [6] found reduced perception of the joint position, a higher TDPM threshold, but also longer latencies of the hamstrings and less posture control in patients with a ruptured ACL. The affected posture control in particular characterises a generalised impairment of movement regulation. This affects not only the knee joint. The sequence of movement of the sensorimotor component of the target sensorimotor function as well as the sensorimotor support function integrated in it are both changed after the injury. Even though they may not be detected by the naked eye, the sequences of movements for routine and formerly mastered athletic movements are changed.

Roberts et al. [29] even found a reduction of TDPM on average two years after the operation, not only on the injured, but also on the uninjured side. The authors recommend taking both sides into consideration for treatment as well as for the prognosis. Reider et al. [27] also measured deterioration of the TDPM pre-operatively on both sides in patients with a torn cruciate ligament. Within six months after the operation, the results approached those of the control subjects. The bilateral impairment of sensorimotor function can also be proven by neurophysiological tests. After an injury and during rehabilitation, the healthy limb is

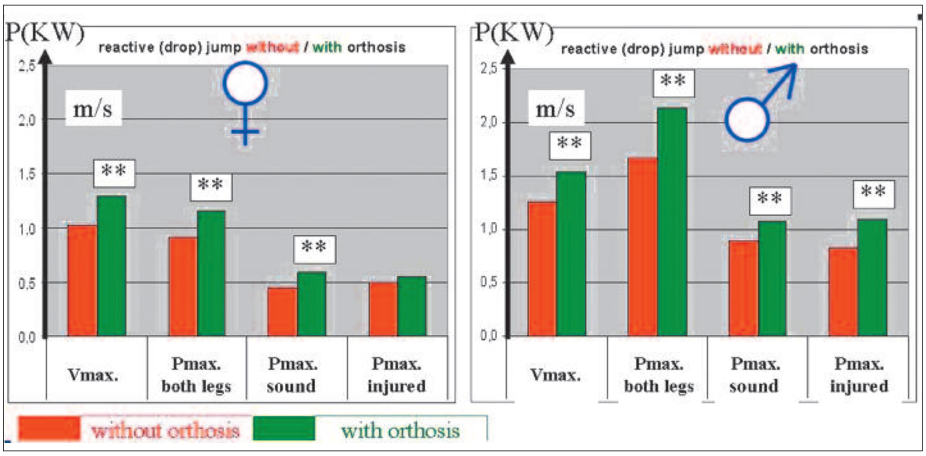

Fig. 5 *Graph of the median values of the parameters for maximum speed, maximum power (both legs), and the maximum power for the sound and injured limb for women (left) and men (right) for jumps from a 15-cm-high step onto the plate to execute another jump to the greatest possible height after landing (reactive [drop] jump).*

also subjected to relative inactivity, which also means the functions of innervation and strength suffer losses. Furthermore, the sensorimotor regulation of the quadriceps femoris muscle of the sound side is involved in the pathophysiological process caused by the injury. This

1. the biomechanical parameters of force, speed of movement, and power are not affected by the stabilising soft orthosis in a relatively easily coordinated movement such as jumping as high as possible from a standing position and

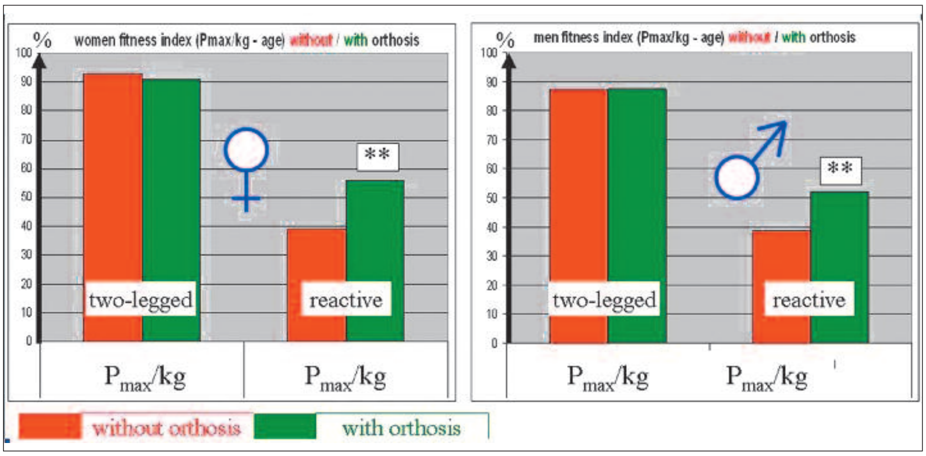

Fig. 6 *Illustration of the maximum power per kg of body weight in relation to age (Esslinger Fitness Index: age-dependent correlation Pmax/kg body weight; 100 percent indicates that the patient's value is on the regression curve). For jumps from a stance to the maximum height, there is no effect on the relative maximum power when using the orthosis. For the reactive jumps, the value increases significantly for women and men.*

leads to a reduction of the maximum isometric force due to the innervation insufficiency [13, 14]. However, the deficits on the injured side are clearly more rapid and considerably greater.

It is not inactivity that is the major cause of loss of function, but neurophysiological mechanisms. When the maximum isometric force and the associated EMG of the sound and the injured side are measured in cruciate ligament patients [12, 13, 14] before and after vibration (50 Hz, 1.5 mm displacement, force 30 N, 20 minutes), the results indicate an effect on the γ-loop caused by the injury on the „sound" side as well. The massive impairment of drive of the γ-loop due to the lack of mechanoafferents of the ruptured cruciate ligament causes partial functional paresis [16, 18, 19] of the quadriceps femoris muscle on the injured side. This apparently also affects the sound side.

The functional parameters on the healthy side must therefore be observed critically as reference points. At the same time, the loss of function on the injured side is thus underestimated.

The results of this study demonstrate impressively that

2. that these biomechanical parameters of movement behaviour are clearly improved in more complex sensorimotor activities such as a jump in preparation for a rapid stretch-contraction cycle (reactive [drop] jump).

The details of this apparently same sequence of motions are changed by the different dynamics provided by the soft knee orthosis. From the neurophysiological standpoint, the pressure-related mechanoafferents stemming from a large skin surface area and probably from the peripheral muscle layers must be held responsible for this effect on sensorimotor movement behaviour. In addition, the orthosis has a direct effect on body positioning and thus on the respective afferent set.

The afferent set of information affects the characterisation of the baseline condition before movement at the central conscious and subconscious level. Furthermore, it influences the regulation of movements during activity as a reafferent set. At the same time, the afferents at the spinal and supraspinal-subcortical levels (for example, brain stem region: postural regulation) probably modify the basic components of movement used by the voluntary system. This is also how they affect its auto-organisation (dynamic approach to regulation of movement) for the target and support sensorimotor system. This is why there is also an impact on postural stability [11].

The dynamic approach to movement regulation operates on the assumption that not all elements of movement are primarily centrally planned and peripherally „directed". Components of movement arise from the complex interplay between interconnected neuron populations. Coordination of movement is thus not entirely „centrally planned". It arises to a considerable extent as a result of the movement-specific neuronal auto-organisation of the executing system at the spinal and supraspinal levels. This is why movement errors are difficult or even impossible to correct once they have been learned. They are firmly established structurally.

The results on the influence of proprioreception or of movement regulation by means of orthoses, bandages, or even a simple neoprene sleeve are also not consistent. For example, the data of Beynnon et al. [2] show no effect on TDPM when using a conventional orthosis or a neoprene sleeve. However, an elastic knee bandage improved the JPS after a cruciate ligament tear. A compression bandage for the patellar ligament increases EMG activity during isometric maximum contraction, a two-legged, and a one-legged half squat, without reaching the level of the uninjured side [17, 19]. The facilitation of movement sequences of the motoneuron pool by the mechanoafferents of this ligament as well as of the structures affected by the circular position can thus be proven.

There have not been any studies this far on the effects of an orthosis such as intensity of pressure and location and/or size of the area where pressure is applied. The fact that results on such factors are so important can be seen from the results of Hassan et al. [11]. The authors studied 49 women and 19 men (median age: 67.1 years) with symptomatic and x-ray detected osteoarthritis of the knee in a crossover study. With a standard bandage (applied according to manufacturer's recommendations; no pressure on the patellofemoral joint) and a one-size-larger, „loose" bandage, the postural stability (balance performance monitor), proprioreception of the knee joint (reproduction of the passive position), and knee pain during various activities were studied. The firm bandage had no effect on knee pain, proprioreception, or postural variations. However, wearing a loose bandage was significantly associated with a reduction of knee pain and an improvement of postural stability. On the other hand, this bandage had no effect on knee proprioreception.

From the biomechanical standpoint, wearing an orthosis reduces the anterior-posterior shift to the level of an uninjured knee for patients with anterior knee instability. However, this can be determined only under full loading or relief. The transitional stages are not affected by the orthosis. On the injured side, shifting of the tibia relative to the femur is 3.5 times greater [3]. Fleming et al. [7] also measured a reduction of ventral translation for a functional orthosis up to a load of 130 N when the knee was loaded or relieved. The internal torque of the tibia in an unloaded knee joint was reduced by the orthosis to levels of nine Nm. In view of the insufficient innervation on the injured side in the sense of partial paresis with subsequent functional scar [18, 19] and the at least partial impact on the anterior-posterior shift [3] during loading and unloading, it is recommended that patients should wear a soft orthosis such as the Genu Direxa Stable Long for certain demanding and biodynamically stressful activities such as alpine skiing, hiking in difficult terrain, and for sports with intensive reactive and rotary elements (tennis, squash, and other sports) even years after the injury and operation. In addition to the changes in coordinated movement behaviour due to the orthosis, the purely biomechanical components should also have a positive value for the loading capacity and load tolerance of the musculoskeletal system.

Regardless of whether they are wearing an orthosis or not, these people must be particularly careful when executing athletic activities and pay special attention to the cycle of loading and relief. Studies with a lower back brace have shown that there was a positive effect on the EMG activity of the paravertebral musculature. However, a result such as this can be achieved only when the movement is mastered and executed with good coordination or athletic technique [17, 19].

After knee injuries, the absolute load-bearing capacity of the joint is permanently impaired despite the orthosis because the original structure and thus function incur long-term damage. The status post injury is therefore equivalent to a disposition for premature degeneration. In their review on the frequency of post-traumatic knee osteoarthritis, Gillquist and Messner [10] showed that after all knee injuries, x-rays show that the signs of knee osteoarthritis are significantly more frequent than on the uninjured side. Isolated meniscus and cruciate ligament injuries without major concomitant injuries increase the risk of knee osteoarthritis by a factor of ten compared with healthy patients of the same age. A meniscectomy with no further ligament injuries doubles the risk of osteoarthritis. Some 50 to 70 percent of persons with a cruciate ligament rupture including concomitant injuries have signs of osteoarthritis after 15 to 20 years.

With this and another extensive literature analysis [4], it can be stated with certainty that a cruciate ligament injury leads to functional impairment. It can be considered a disposition for further injuries as well as for premature osteoarthritis. According to Lohmander et al. [23] as well, approx. 50 percent of these patients suffer from osteoarthritis with the associated clinical symptoms including functional impairment 10 to 20 years after the injury. There is still no evidence for a preventive effect of surgery. However, the recommendation to wear a soft knee orthosis can be given despite the fact that there is still no objective proof of a positive outcome. According to Wright and Fetzer (2007) [31], ROM orthoses, which are used less frequently in Europe but are preferred in the US, have no reliable impact on pain, range of movement, stability of the transplant, and prevention of subsequent injuries. However, the comparability of these orthoses with the bandage-like soft orthoses has not been sufficiently studied yet.

Summary

A cruciate ligament injury is a severe injury from the biomechanical and sensorimotor standpoint. The knee joint is permanently subjected to a changed biomechanical situation, which cannot be adequately described by anterior-posterior translation („drawer“) alone. The irreparable destruction of the mechanosensors of the cruciate ligament impairs the movement regulation of the knee joint. This has an additional negative impact on the biomechanics of this joint. The sensorimotor disorder is relatively easy to detect in an EMG examination. Over many months, it is proof of the partial functional paresis and later the functional scar in the function of the quadriceps femoris muscle.

The sensorimotor function of the knee joint is tested with proprioreception tests (angle reproduction, movement threshold, etc.). But these tests are not sufficiently interchangeable. Therefore, changes in sensorimotor function can be reliably determined only when the entire battery of tests is given to the same patient. However, there is a sensorimotor function disorder not only in the knee joint. An impact can also be found on the sensorimotor coordination of total body movement.

Both factors reduce the knee’s load-bearing capacity and they therefore are together a disposition for premature degeneration of the joint. This disposition for osteoarthritis has been reliably proven.

Thus far, research results on the effectiveness of an orthosis have been very contradictory. In summary, the status of the results can be described as follows: On the one hand, no definite advantage has been proven for the long-term systematic wearing of an orthosis, but on the other hand, laboratory results show a positive effect for biomechanical and sensorimotor aspects.

But this effect is also not universal. For one thing, the effect is limited to a certain load range. And for another, the orthosis allows the status of the uninjured knee to be approximated only for loaded and unloaded conditions and not for transitional stages. The latter is probably to be considered responsible for the lack of evidence of a difference in outcome after long periods of wearing. The laboratory results presented show a beneficial effect of the soft orthosis on movement behaviour for a demanding coordination task. A simple jump from a standing position is not affected. However, movement behaviour in preparation for a reactive jump is favourably affected.

As in other laboratory examinations, the concrete causes of the effectiveness of a soft orthosis remain unclear. Due to the compression, the orthosis certainly has an effect on the set of mechanoafferents from the skin, the subcutis, the joint capsule, and the superficial layers of muscle tissue. However, it is still unclear what effect the intensity and the area of the pressure and the combination of the two factors have on the flow of afferent information and what neurophysiological impact this has on the regulation of movement at the spinal and supraspinal levels.

Furthermore, the effect that various movements have on the effectiveness of an orthosis, and in particular, the quality with which the movements are executed (sensorimotor coordination or synonymously, movement or athletic technique), must be explained in the future. The research should include questions on the relation between loading and relief and on the use of physiotherapy applications (promoting joint tropism, blood flow, etc.).

Although certain sports are especially enjoyable, the fact that the load-bearing capacity or load tolerance of the biomechanically and sensorimotor damaged knee are decisive for the progression of joint degeneration cannot be ignored. Orthoses change movement behaviour. Even if the explanation still requires intensive research, the laboratory tests conducted thus far on the short-term effectiveness of an orthosis allow us to infer that it contributes to supporting load-bearing capacity.

Literature is available at the author’s.

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