Changes in stretch reflex excitability are related to "giving way" symptoms in patients with anterior cruciate ligament rupture

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Running head: Altered stretch reflex excitability after ACL rupture
Abstract

Anterior cruciate ligament (ACL) rupture usually leads to an altered stretch reflex excitability of the thigh muscles that stabilize the knee. The purpose of this study was to quantitatively assess reflex activity in the m. semitendinosus/semimembranosus after anterior tibial translation in 21 patients with isolated ACL ruptures. The patients were divided into a group with "giving way" symptoms (non-copers, n=12) and without "giving way" symptoms (copers, n=9). While the patients were standing upright with 30 degrees knee flexion, a force of 300 N was applied to the calf to induce anterior tibial translation. Activity of m. semitendinosus/semimembranosus was measured using surface electromyography (EMG). A linear potentiometer was placed on the tibial tuberosity and measured maximum tibial translation during standing, i.e. a functional condition. Knee laxity was assessed with a KT1000 arthrometer under passive conditions. After ACL rupture, the short latency response (SLR) latency remained unchanged (p=0.21), whereas for the medium latency response (MLR) it was significantly longer (p<0.001). Significantly longer MLR latencies were noted for non-copers compared to copers (p<0.01), while SLR latencies were similar. Significant differences between healthy and injured legs were noted after tibial translations using KT1000 (p<0.001) and during stance (p<0.001). Mechanical knee instability was found to be unchanged between copers and non-copers (KT1000: p=0.97; tibial translation: p=0.31).

These results indicate that ACL rupture is associated with altered stretch reflex excitability which may lead to "giving way" symptoms, and that these changes may be more important for the development of "giving way" than the mechanical knee instability.

Keywords: ACL rupture, giving way, anterior tibial translation, hamstrings, EMG
Introduction

Results of previous studies suggest that the hamstrings play a crucial role in ensuring knee stability and that they directly protect the anterior cruciate ligament (ACL) during movements of the tibia relative to the femur (Beard et al. 1993; Johansson et al. 1990; More et al. 1993). Moreover, the ACL with a tensile strength of up to 2000 N (Woo et al. 1991) not only has a mechanical function but, as was shown in histological studies (Freeman and Wyke 1967; Haus and Halata 1990; Schutte et al. 1987; Sjolander et al. 1989; Zimny et al. 1986), also contains different types of mechanoreceptors, most of which are located close to the ligament insertion sites (Raunest et al. 1998). Animal experiments provided the first evidence of a specific reflex arc between the ACL and the hamstrings and suggested a contribution of the ACL in the neuromuscular stabilisation of the knee (Johansson et al. 1991; More et al. 1993; Solomonow et al. 1987). More recent studies on humans were able to demonstrate such a reflex arc between the knee and the hamstrings after electrical stimulation (Dyrhe-Poulsen and Krogsgaard 2000; Miyatsu et al. 1993; Tsuda et al. 2003) and under functional conditions (Beard et al. 1993; Bruhn 1999; Friemert et al. 2005b). In addition, Friemert et al. (2005b) provided evidence that this reflexive muscle response consisted of a monosynaptic reflex of the hamstrings (short latency response, SLR), mediated by group I afferents and a later second presumably polysynaptic reflex (medium latency response, MLR).

Clinical tests such as the angle reproduction test, posturography, and gait analysis revealed pathological changes after ACL rupture (Beard et al. 2001, Beard et al. 2000, Hogervorst and Brand 1998; Jerosch and Prymka 1996). Despite successful ACL surgery, patients report, for example, symptoms of knee instability and complain of a feeling of "giving way" that may be due to loss of proprioception and altered stretch reflex excitability. There are, however, also patients who have mechanical instability (no surgery) but no "giving way" symptoms. In addition, it is still unclear whether the “giving way” phenomenon is associated with mechanical knee instability. Beard et al. (1994) and Bruhn (1999) mechanically induced
posterior-anterior tibial translation in patients with ACL rupture during standing and reported a significant increase in the latency of the ACL-hamstring reflex. These studies and also Wojtys et al. (1994) for the first time provided evidence for the presence of altered stretch reflex excitability. However, they did not describe the possible underlying neurophysiological mechanisms and its connection with the kinematic characteristics of tibial translation. An understanding of these qualitative aspects is, however, of primary importance in planning the therapeutic intervention. The authors of these studies also failed to draw conclusions concerning the clinical relevance (e.g. indication for surgery) for patients with or without "giving way" symptoms.

The objective of this study was to assess quantitatively hamstring activity and the mechanical characteristics of posterior-anterior tibial movement in response to mechanically induced tibial translation in patients with ACL rupture. In order to identify possible differences in sensorimotor knee function within the patient population, the subjects were divided into a group with "giving way" symptoms and compared to a group without "giving way" symptoms. The aim was to investigate whether the subjective feeling of “giving way” is related to any objective difference in hamstring reflexes. Accordingly, the hypothesis of the study was that giving way symptoms are rather associated with alterations in sensorimotor function than with increased mechanical instability. Furthermore, we presume that this disturbed sensorimotor function is related to significant changes in the hamstring reflex excitability.

**Experimental procedures**

**Patients**

A total of 21 patients (mean age: 25 ± 4.5 years; height: 180 ± 7.5 cm; weight: 83.5 ± 15.2 kg) with isolated ACL ruptures took part in the study. Patients with effusion, pain, blockade, additional capsuloligamentous injuries and meniscus or cartilage injuries were excluded.
While 83 patients with clinically suspected ACL injury were screened. Objective measures were MRI of the knee before classification as coper or non-coper to ensure the isolated injury. 58 patients had to be excluded after MRI of the knee due to additional injuries. The remaining 25 patients underwent the experimental procedure the day before arthroscopy. After reflex measurements arthroscopy was performed and again 4 out of 25 patients were excluded from the analysis due to additional knee injuries. The way how classification was performed in our study was aimed to strictly identify only patients with isolated ACL ruptures as copers, who never had experienced any “giving way” symptom after the acute injury symptoms had been resolved (i.e. after they were free of pain and effusion and had regained full range of knee motion). Patients were asked the following four questions (see table 1) and only if all were answered in the direction of copers, they were classified as copers. Accordingly, from a functional point of view copers in our study were in daily life without “subjective” symptoms. All the remaining patients were classified as non-coper even if they only reported a single subjective feeling of “giving way”. This classification is more strict than the classification by Chmielewski et al. (2005a) who accepted even one episode of giving way for copers. This “subjective self assessment” of the patient was the unique criterion and was performed before the reflex measurement. As the aim of the study was, to discern only on the basis of the subjective feeling of giving way being ever present to classify as a non-coper, the additional physical scores used in other studies were not used for the prospective classification, as even a good score would have not led to a classification as coper. Based on the questionnaire we classified nine patients as copers and 12 patients as non-copers. The classification was performed after a mean of 77+-53 days (range 19-211) after the trauma. There were no differences between copers (75+-32 days range 41–128) and non-copers (79+-64 days, range 19–211, p=0.27). Prior to the tests, the patients had given their written informed consent. The study was approved by the ethics committee of the University of Ulm.
Experimental set-up

The patients were examined in bipedal stance bearing full body weight (at 30° of knee flexion and 5° of external rotation). There was no significant difference in the hamstring baseline EMG activity between the injured and the uninjured legs, and there was also no significant difference in the baseline activity between copers and non-copers. A force of 300 N was applied to the proximal section of the lower leg (10 cm below the popliteal fossa) parallel to the tibial plateau in order to induce posterior-anterior tibial translation in the healthy and injured legs. Before measurements, the height of the patella-supporting plate was individually adjusted to achieve the knee flexion angle of 30°. The patella was pressed against a supporting plate in order to ensure isolated movement of the tibia relative to the femur and prevent movement of the entire leg. A linear potentiometer (independent linearity: ±0.25 - ±0.0075%, repeatability: 0.002 mm, Novotechnik, Ostfildern, Germany) was placed on the tibial tuberosity and measured (functional) tibial translation. The onset of tibial movement was used as a trigger signal for the measurement of reflex latency (Fig. 1). In order to reduce the variability of individual measurements we performed in each patient a total of 50 single measurements in 10 trials, each of which consisted of 5 single measurements. In addition, KT 1000 arthrometer measurements (MEDmetric Corp., San Diego, USA) were conducted to assess anterior tibia translation. While the reliability of this device has been questioned in the literature (Wroble et al. 1990), the more recent studies indicate that KT 1000/2000 measurements have a sufficient reliability to assess anterior tibia translation during lying as performed in the present study (e.g. Huber et al. 1997, Myrer et al. 1996). Knee joint stability was determined in the healthy and injured legs performing three measurements in each leg. In order to ensure reliability of testing, all measurements were performed by the same investigator who is an orthopaedic surgeon and has ample experience in KT 1000 measurements.
Electromyography (EMG)

Reflex activity in the hamstring muscles and the vastus medialis was measured using surface EMG. Pairs of self-adhesive bipolar electrodes (Arbo Ag/AgCl sensor, Tyco Healthcare, Neustadt, Germany, interelectrode distance 2 cm) were arranged longitudinally on the muscle bellies in the middle between the knee joint gap and buttocks gap of the femoral biceps muscle (lateral hamstring) and the semimembranosus/semitendinous muscle (medial hamstring). The m. vastus medialis was recorded 2-3 cm medially and 5 cm proximally from the upper patella rim. The reference electrode was placed on the medial malleolus. The skin was shaved, abraded, and cleaned with alcohol before the electrodes were attached. A commercially available EMG measuring and evaluation software (Daisy Lab Biovision, Weilheim, Germany) was used for recording and analysing the muscular activity of the hamstrings (bandpass filter: 10-700 Hz, 6th order Butterworth, preamplification: 1000, sampling rate: 5000 Hz). For further analysis, the EMG signals were rectified and averaged. Normally the recordings of the medial hamstrings were taken for analysis as it has been shown that there are no significant differences between the lateral and medial hamstrings as for the onset latencies of SLR and MLR (Friemert et al. 2005b; Friemert et al. 2005c). Due to artefacts or technical difficulties for the medial hamstring recordings of three subjects, the EMG activity of the lateral hamstrings was analysed.

Data analysis

Two of the authors analysed the EMG data of all subjects. Both were blinded whether the subjects had been classified as copers or non-copers. Onset latencies and the integrated EMGs (iEMGs) of the hamstring muscles were assessed manually on the computer using two cursors. The onset latency of the first response was defined as the time window from the beginning of tibial translation to the first significant muscular activity. In the case of superimposed responses (first response: monosynaptic reflex = SLR, second response:
polysynaptic reflex = MLR), the evaluation algorithm introduced by Friemert et al. (2005b) was used in order to ensure valid data analysis and to clearly differentiate between a SLR and MLR. The MLR evaluation window was defined as a 30-ms period beginning with the onset of the MLR. The iEMG (SLR and MLR) was calculated as the area under the rectified signal. Additionally, the iEMG activity in hamstring and vastus muscles was assessed during the 30ms prior to the beginning of tibia translation. Maximum tibia translation was determined on the basis of the tibial translation curves (Fig. 1).

Statistical analysis

All values are means with standard deviations. Differences between healthy and injured legs were analysed using a paired Student's t-test. The statistical significance of comparisons between the the non-copers and copers was calculated using Wilcoxon's nonparametric test. A p-value of less than 0.05 was considered statistically significant. The Pearson correlation coefficient was calculated to identify a correlation between anterior tibial translation during stance and MLR latency of all injured patients.

Results

Healthy versus injured legs

There was no significant difference in SLR onset latencies between the healthy legs (19.1 ± 3.5 ms) and the injured legs (19.9 ± 3.3 ms) (p=0.21; Fig. 2a). By contrast, significantly longer MLR onset latencies (p<0.001) were measured for the injured legs (56.3 ± 13.3 ms) in comparison with the healthy legs (35.8 ± 3.8 ms). An ACL injury had no significant effect on the integrals for SLRs (p=0.12) and MLRs (p=0.35). A significant increase in tibial translation, which gives an indirect measure of mechanical joint stability in the posterior-anterior direction, was noted for the injured legs. Whereas during stance a maximum tibial translation of 6.4 mm (± 1.5) was measured for healthy legs, a tibia translation of 8.5 mm (± 2.5) was noted for injured
legs (p<0.001). Likewise, the KT 1000 test showed a significant increase in posterior-anterior joint instability in the injured leg when compared with the healthy leg (5.6 ± 1.8 mm versus 9.7 ± 2.2 mm; p<0.001; Fig. 2b). There was also no relationship between tibial translation during stance and MLR response latency if all injured legs were considered. (r² = 0.22, Fig. 3). No difference in the ratio of the iEMG activity 30 ms prior to the tibia translation of the hamstring and quadriceps (vastus medialis) muscles between the unaffected and the affected leg was found (1.39±1.32 vs. 1.45±0.87, p=0.86). In addition, there was also no statistically significant difference if the absolute iEMG of the quadriceps (p=0.215) or the hamstrings (p=0.236) was compared between the healthy and the injured legs.

_Copers versus non-copers_

A comparison between the healthy legs of copers and non-copers revealed no significant differences in MLR onset latency (36 ± 4.1 ms versus 35.8 ± 3.9 ms; p=0.81), maximum tibial translation (p=0.59) or the KT 1000 test (p=0.67). A significantly longer MLR onset latency, however, was measured for the injured legs of the non-copers (p=0.01; Fig. 4a). Whereas the copers had an MLR onset latency of 47.9 ± 8.1 ms, the non-copers showed a reflex response after anterior tibial translation that occurred considerably later (62.6 ± 13.2 ms). Neither the KT 1000 test (p=0.97) nor functional posterior-anterior tibial translation (p=0.31) showed significant differences between the two groups (Fig. 4b). The integrals revealed no significant between-group differences, neither for the healthy legs (SLR p=0.95, MLR p=0.37) nor for the injured legs (SLR p=0.18, MLR p=0.78). We found no difference in the iEMG hamstrings/quadriceps ratio for the patients classified as copers and non-copers (1.46±0.77 vs. 1.44±1.07, p=0.62). Finally, there was no difference in the mechanical stability (assessed by both, KT 1000 and by maximum tibia translation during stance) between these two groups although there was a clear increase of tibia translation in the affected legs compared with the unaffected legs in both copers and non-copers.
Discussion

Our study shows that a rupture of the anterior cruciate ligament was associated with a significantly longer latency of the hamstring MLR. In addition, a significant increase in anterior tibial translation was found. On the basis of the present findings ‘giving way’ symptoms appear to be associated with altered stretch reflex excitability of the MLR but not with mechanical knee instability.

Previous studies agree that an ACL rupture leads to a loss of proprioception in the knee-stabilizing muscles of the thigh (Hogervorst and Brand 1998), but they fail to identify the cause of this neurophysiological disorder. Di Fabio et al (1992) reported changes in hamstring activity in subjects with ACL insufficiency. After an anterior posterior sway no hamstring activity was found in the compensatory leg EMG activity in healthy legs while they found hamstring activity in the ACL deficient leg after 100 ms coupled with the automatic postural responses of quadriceps and tibialis muscle. Moreover, reflex activity of muscles was significantly increased in the ACL-deficient leg in unilateral stance indicating an integration of the capsular-hamstring reflex in postural control in order to stiffen the knee joint after ACL rupture (Di Fabio et al. 1992). The authors suggested that a capsular hamstring reflex is integrated into the existing structure of a preprogrammed postural synergy in order to compensate for ligamentous laxity. Accordingly, increased knee laxity seems to modulate central programming to compensate joint laxity and to maintain erect posture. If this is the case for long loop reflexes it may also be the case for the MLRs with shorter latencies. Beard et al. (1993) and Bruhn (1999) found during stance a significant increase in the latency of the hamstring reflex induced by anterior tibia translation which may be induced by a deficient proprioception. Our results confirm these studies and show that only the second component of the response (e.g. MLR), which is probably mediated by secondary muscle spindle (group II) afferents as shown in the soleus muscle during stance and gait (Schieppati et al. 1997, Grey et
al. 2001), plays a major role in the sensorimotor function of the knee joint. Onset latencies of the MLR on the affected side with values around 63ms could be close to the fastest long latency responses. For the soleus (Taube et al. 2006) as well as for the tibialis anterior muscle (Petersen et al. 1998, Christensen et al. 2001) the fastest transcortical responses have been shown to be earliest at around 85ms. Given the longer travel distance of 2*30-45cm, i.e. 60-90cm one may expect the fastest transcortical responses in the hamstrings 10-15ms earlier, i.e. earliest at 70-75ms. Accordingly, a transcortical component cannot be excluded for the upper range of the response latencies classified as “MLR” latencies. However, it seems unlikely that some of the non-copers show delayed MLR responses and no “fast” LLRs while other non-copers only show fast LLRs. It seems more likely that this is a continuous delay of the MLRs. On the other hand, if it should be the case that in the non-copers the MLRs are suppressed and this is associated with the subjective feeling of instability, then one may still hypothesize that the MLR may play a major role for this subjective knee joint stability.

Dhaher et al. (2003) were able to show that in healthy subjects a mechanical valgus stimulation consistently elicits reflex responses in knee joint muscles with a latency of 83-92 ms while stretch reflexes of the same target muscles showed latencies around 30 ms. They hypothesized that the muscle responses may originate from mechanoreceptors lying in periarticular tissues such as joint ligaments and capsule. A more recent study of the same group indicates that excitation of such reflexes from periarticular tissue afferents results in a significant increase of the joint adduction-abduction stiffness (Dhaher et al. 2005). They discussed that this reflex stiffness may have significance during functional tasks. The reflexes investigated in the present study showed onset latencies clearly below 80 ms, even in the non-coper group. Accordingly, they can also contribute to the knee joint stiffness. The fact that the onset latency in the non-copers was clearly delayed compared to the copers and even more delayed compared to subjects with healthy knees may indicate a disturbance or delay in the processing of the afferent information arising from the knee during posterior-anterior tibia
translation. This may be interpreted as a disturbance of the sensorimotor integration associated with isolated ACL injury. As the subjective feeling of “giving way” was only reported by non-copers, i.e. patients with a rather long delay of the MLR response, while the copers only showed a moderate delay, one may hypothesize that this delay in MLR may also affect knee joint stiffness. In a recent study, it has been shown by intraoperative direct mechanical stimulation of the ACL that receptors within the ACL may be able to contribute to the hamstring MLR, although this contribution may be weak (Friemert et al. 2005c). However, there is a discrepancy between the latencies (SLR, MLR) of the present study as well as in our previous paper (Friemert et al. 2005b) and those measured after intraoperative ACL stimulation (Friemert et al. 2005c) in healthy legs. A reason for the observations may be that intraoperative stimulation took place distal of the femur by direct mechanical stimulation of the ACL, while in the present experiments and in our previous study (Friemert et al. 2005b) the stimulation was an anterior tibia translation that affects the hamstring muscles to the knee, i.e. not only the muscle spindles in the distal but also in the proximal part of the muscle are stimulated at the same time. Accordingly, the distance from the afferent sensor to the spinal cord may be on average up to 25 cm shorter than during isolated stimulation of the ACL. If the conduction velocity of the contributing afferents was up to 60 m/s and one postulates that the information from the ACL is also mediated via afferents with similar conduction velocity, this would mean that the onset latency can be expected to be approximately 4 ms shorter. The changes in onset reflex latency observed in the present study are most probably due to changes in the sensorimotor integration of this reflex component on the spinal level. This is particularly noteworthy, because information from these afferent pathways arising from the hamstring muscle spindles is additionally modulated by the central nervous system via gamma motor neurons (Johansson et al. 1990). It is therefore possible that appropriate training stimuli may induce motor learning and consequently may improve knee sensorimotor function. These findings confirm previous assumptions about a supraspinal integration of this
reflex (Fischer-Rasmussen et al. 2002; Johansson et al. 1990; Krauspe et al. 1992; Sojka et al. 1989). Beard et al. (1994) reported that the onset latencies of hamstring reflexes which were increased after ACL lesions improved after a 12 week physiotherapy program. This may indicate that sensorimotor training, rehabilitative weight training or functional training can help to restore sensorimotor control of the knee as recommended by Chmielewski et al. (2005b). Such beneficial effects were shown in a study by Friemert et al (2005a), where postoperative functional training within the first postoperative week decreased the proprioceptive deficit significantly.

"Giving way"

It has to be noted that the criteria described in the methods section ensured that only patients who reported to never have experienced any symptoms of “giving way” were classified as copers. Our results on "giving way" of the knee provide quantitative evidence for the first time that the subjective feeling of instability is directly associated with the disturbance of the MLR pathway while the SLR pathway is not affected and the mechanical stability of the knee was similar in copers and non-copers. This indicates that the altered stretch reflex excitability may be more important for the development of "giving way", than the mechanical instability of the knee. Kennedy et al. (1982) also postulated that a proprioceptive deficit rather than primary instability of the knee was the cause of "giving way". While Beard et al. (1993) already reported a connection between "giving way" and loss of proprioception, they did not investigate whether there was also a correlation between instability and altered stretch reflex excitability. Using a passive angle reproduction test, Roberts et al. (1999) were able to detect significantly poorer proprioception in patients with "giving way" symptoms. By contrast, they found no differences in proprioception between symptomatic and asymptomatic patients in the active and visual angle reproduction tests. Our results support the findings reported by Kaalund et al. (1990). They described an altered timing of the hamstring activity under
functional conditions when ACL deficient patients walked uphill. A disturbed or delayed timing of the MLR may induce changes in the activation pattern. It has been argued that there are changes in sensorimotor integration after ACL lesions on the basis of altered sensorimotor evoked potentials (SEPs) (Valeriani et al. 1996), and in a small number of patients it has been argued that differences in strategies of hamstring activation between copers and non-copers may be due to changes in somatosensory integration (Courtney et al. 2005). While in the present study the changes in MLR onset latency were significantly more marked in non-copers, the study of Courtney et al. (2005) found changes in SEPs only in one out of four copers but all three non-copers they investigated. Unfortunately, it is not stated whether the changes were located in the periphery or the central nervous system and, furthermore, the patients were investigated 7-214 months after the lesion, i.e. they were rather chronic patients. Future studies will have to investigate both MLRs and SEPs in the same patient at the same time to elucidate this question. Apart from SEPs also aberrant muscle recruitment and a decrease in quadriceps activity have been described in non-copers which may contribute to their instability of the knee (Chmielewski et al. 2005a; Williams et al. 2005). Our results suggest that the subjective feeling of instability (e.g. “giving way” symptom) is not associated with an increase in knee joint laxity. It is more likely that the “giving way” symptoms are related to alterations in stretch reflex excitability. This relationship should be considered in future evaluation of patients with knee instability and in the measurement of patient satisfaction, for example on the basis of knee scores as Tegner activity level and Lysholm score (Tegner and Lysholm 1985) and the International Knee Documentation Committee (IKDC) knee rating system (Hefti et al. 1993).

Conclusions

Our study shows that ACL rupture causes considerable changes in stretch reflex excitability. "Giving way" of the knee is not simply related to the decrease in mechanical joint stability,
but closely associated with altered stretch reflex excitability that most probably takes place on
the spinal level. Since sensorimotor function may be influenced by appropriate training
stimuli, sensorimotor training early after ACL rupture with a focus on neuromuscular training
may be promising for a rapid restoration of joint function.

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References


Schieppati M, Nardone A. Medium-latency stretch reflexes of foot and leg muscles analysed by cooling the lower limb in standing humans. *J Physiol* 503: 691-698, 1997


Figure legends

Fig. 1
Examples of posterior-anterior tibial translation and the corresponding reflex response of the hamstrings, affected and unaffected side of a non-coper (single subject, mean of 15 individual trials). The onset of the SLR marks the beginning of the monosynaptic reflex, (20.3 ms for the healthy leg, 19.7 ms for injured leg), the onset of the MLR is the beginning of the polysynaptic reflex (37.8 ms for the healthy leg). A clear increase in latency of the MLR can be seen for the injured leg (62.9 ms).

Fig. 2
A, comparison of SLR and MLR onset latencies measured for the healthy and injured legs (n=21). Whereas there are no significant differences in the SLR onsets (p=0.219), the figure shows a significant increase in the MLR onset latencies measured for the injured legs (** p=0.00012).

B, comparison of tibial translation for the healthy and injured legs as assessed by mechanical tibia translation during standing and KT 1000 (n=21). ACL rupture leads to significant knee instability. Both tests revealed significant differences between healthy and injured legs (*** p=0.00042 and p=0.00013, respectively).

Fig. 3
Latency and tibial translation for all injured legs investigated. There was no relationship between tibial translation and the MLR latency responses.

Fig. 4
A, comparison of MLR onset latency between copers and non-copers. A significant increase in MLR onset latencies was found for ACL patients with "giving way" symptoms (non-copers, n=12) compared to patients without (copers, n=9; ** p=0.006).

B, neither the assessment of maximum tibial translation nor the KT 1000 test showed significant differences in joint stability between ACL patients with "giving way" symptoms (non-copers) and without "giving way" symptoms (copers) (p=0.365 and p=0.798, respectively).
Table legend

Tab. 1
Questionnaire for differentiation between coper versus non-coper
Examples of posterior-anterior tibial translation and the corresponding reflex response of the hamstrings, affected and unaffected side of a non-coper (single subject, mean of 15 individual trials). The onset of the SLR marks the beginning of the monosynaptic reflex, (20.3 ms for the healthy leg, 19.7 ms for injured leg), the onset of the MLR is the beginning of the polysynaptic reflex (37.8 ms for the healthy leg). A clear increase in latency of the MLR can be seen for the injured leg (62.9 ms).
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<th>Question</th>
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<td>1</td>
<td>Did you ever have feeling of knee instability since your accident?</td>
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<td>2</td>
<td>Were you able to do your normal daily activity (stair climbing up and down, etc.) without any restrictions?</td>
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<tr>
<td>3</td>
<td>Since ACL rupture did you ever have experienced that your knee was dislocated?</td>
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<td>4</td>
<td>Did you ever have the feeling that you lost knee control?</td>
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**Questionnaire for differentiation between coper versus non-coper**