We assessed proprioception using threshold levels for the perception of knee movement at slow angular velocities (0.1°/s to 0.85°/s) in 20 patients with unilateral tears of the anterior cruciate ligament (ACL) and 15 age-related control subjects. Failure to detect movement was also analysed.

The threshold levels of detection did not differ between the damaged and undamaged knees in the patients or between the patients and the control group. Failure to appreciate movement, however, was significantly greater in knees with ACL loss compared with the undamaged knees of patients and the control group.

Our findings show a proprioceptive deficit in the absence of the ACL. Measurements of threshold levels of detection of passive movement alone are not suitable for the evaluation of proprioceptive loss in ACL deficiency; assessment of failure to appreciate movement is essential.

Received 4 August 1998; Accepted after revision 12 January 1999

Tears of the anterior cruciate ligament (ACL) are the most common injury to the ligaments of the knee and impair function. Loss of proprioception is also common. Several attempts have been made to demonstrate proprioceptive deficits by means of objective measurements of position and movement.

Detection of passive joint movement has been established as a measure of proprioception in the knee. In most studies, slow passive movement is measured with angular velocities ranging from 0.1°/s, 0.3°/s, 0.4°/s, and 0.5°/s up to 5.0°/s. The differing results of studies on proprioceptive deficits using measurement of the sense of movement at slow angular velocities are believed to be due to variation in the testing devices and the groups of patients tested. Previous studies have shown that, in addition to measurements of threshold levels for the detection of passive movements, assessment of the failure to appreciate movement may be essential for the evaluation of proprioceptive deficits. Further evaluation was needed to attempt to assess the sense of movement by more sophisticated techniques.

We have developed a method for a detailed analysis of proprioception which includes measurement of slow passive knee movement at five different angular velocities as previously used for similar tests. We have analysed proprioceptive deficits in ACL-deficient knees and compared them with normal contralateral knees and with the undamaged knees of a control group.

Patients and Methods

Measurement of the detection of passive movement was carried out as described previously. For measurements of the sense of movement, subjects were seated on a purpose-built testing chair (Fig. 1). In order to minimise cutaneous sensations, the foot and ankle of the test limb were immobilised by a rigid inflated air splint. An internal pressure of 4 kPa (30 mmHg) ensured that the ankle remained fixed, while not occluding the circulation. A similar air-splint was placed underneath the thigh 100 to 150 mm proximal to the knee. Subjects were blindfolded and wore headphones emitting white noise (noise without information to avoid acoustical cues). The air splint around the leg was fixed to a shaft-joint system so that movement only occurred in the knee. This system was directly connected by a wire to a winding drum moved by a stepper motor, the speed and direction of which were controlled by a personal computer to allow passive extension or flexion of the knee. Each test started from a knee-flexion angle of 45°, and consisted of a passive ramp-and-hold movement with an amplitude of 10°. Subjects signalled when they felt the beginning and the end of the movement by pressing a button.

The threshold for the perception of the start of movement (TPSM) was determined, in degrees, by multiplication of the time which passed from the start of the movement to...
the subject’s first press of the button \((t_m[s])\) with the actual angular velocity \(\left(\nu_a[^\circ/s]\right)\):

\[
TPSM \ [^\circ] = t_m [s] \times \nu_a \ [^\circ/s]
\]

We determined from which angle of knee flexion or extension subjects realised the beginning of passive knee movement, and took this as a measure of the sense of movement. The time which passed from the end of the movement to the subject’s final press of the button \((t_s[s])\) was measured. To compare the data at different angular velocities this time was multiplied by the actual angular velocity \(\nu_a[^\circ/s]\) to determine the threshold for the perception of the end of movement (TPEM) in degrees:

\[
TPEM \ [^\circ] = t_s [s] \times \nu_a \ [^\circ/s]
\]

We determined the angle of knee flexion or extension when the subjects appreciated the end of passive knee movement and took this as a measure for the sense of stopping.

If the subject did not press the button after the beginning of the passive knee movement until its end, this part of the test was classified as a failure of detection of movement. Likewise, if no press of the button occurred after the end of the movement a failure of detection of a step was assumed. In contrast to our previous work, we used five different angular velocities in this study to determine both the thresholds for the perception of the start and the end of movement (Table I). The testing protocol included six trials at each of these angular velocities, a total of 30 measurements for each knee.

A group of 15 young healthy volunteers was selected for the evaluation of proprioception in undamaged knees. None had a history of capsular or ligamentous damage to either knee. The mean age of this test group was 25.3 (SD 4.8) years, and there were nine men and six women. Both right and left knees were tested.

Twenty subjects who had isolated ruptures of the ACL were also tested. These tears had been diagnosed arthroscopically within 48 hours of the initial injury. The mean age of this test group was 24.5 (SD 5.2) years, and there were 14 men and six women. Ruptures of the ACL were seen in the right knee in eight patients and in the left knee in 12. All were due to trauma. The mean period after injury at the time of proprioceptive testing was ten weeks (8 to 14). None of these patients had special physiotherapy before the tests.

At the time of testing, all the ACL patients experienced marked instability in their damaged knees, but were free from pain. All had a positive pivot-shift test with a positive Lachman’s sign and anterior subluxation of the tibia on the femur was at least 3 mm greater than on the contralateral uninjured knee, as measured by the KT-1000 arthrometer (MEDmetric Corporation, San Diego, California) at maximum manual draw with the knee flexed to 30°. Patients with additional damage such as meniscal tears or neurological diseases were excluded. All the patients had normal contralateral knees and no history of previous injury, symptoms or treatment.

All subjects gave informed consent and had both the injured and the uninjured knees tested. All experimental

### Table I. Mean (± sd) TPSM (degrees) for 20 patients with ACL-deficient knees and 15 volunteers with undamaged knees

<table>
<thead>
<tr>
<th>Angular velocity (°/s)</th>
<th>Control group</th>
<th>Patient group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>0.1</td>
<td>0.98 ± 0.48</td>
<td>1.01 ± 0.31</td>
</tr>
<tr>
<td>0.15</td>
<td>1.01 ± 0.47</td>
<td>1.10 ± 0.51</td>
</tr>
<tr>
<td>0.35</td>
<td>1.2 ± 0.53</td>
<td>1.25 ± 0.55</td>
</tr>
<tr>
<td>0.6</td>
<td>0.87 ± 0.36</td>
<td>0.99 ± 0.41</td>
</tr>
<tr>
<td>0.85</td>
<td>1.09 ± 0.43</td>
<td>1.15 ± 0.39</td>
</tr>
</tbody>
</table>
procedures were approved by the local ethical committee.

ANOVA was carried out for comparison between groups, with p values of <0.05 being considered significant.

Results

In the control group, the mean detection of TPSM ranged from 0.87° to 1.25°, with no differences between right and left knees. In the patients, the mean detection was from 0.89° to 1.24°. We did not find any significant differences between the ACL-deficient and uninjured knees of the patients at each of the five angular velocities (Table I).

Analysis of the TPEM revealed similar results. It ranged from 0.79° to 1.15° in the control group and from 0.85° to 1.11° in the patient group. It did not differ between either of the knees of the control group or between the ACL-deficient and the uninvolved knees of the patients. There were no significant differences between the control group and the knees of the patients at each of the five angular velocities (Table II).

Analysis of failure to detect movement showed a significant decrease with increasing angular velocities in each group tested (Fig. 2). There were significant differences in the rate of failure between the control group and the ACL group. In the undamaged knees of the patients, the rates were lower than for the damaged knees, but still significantly exceeded those for the control group (Fig. 2). There were no differences between the right and left knees of the control group.

Analysis of failure to detect stopping had similar results. We found decreasing rates of failure with increasing angular velocities in all knees tested. The rates of detection of stopping did not differ significantly between the right and left knees of the control group. They were seen significantly more often in the ACL-deficient knees than in the uninjured knees. In the control group, the rate of failure to detect stopping was much lower compared with both the ACL-deficient and the uninjured knees of the patients (Fig. 3).

Discussion

Assessment of sense of movement in our study included measurements of both TPSM and TPEM.

We chose 45° of knee flexion as a starting position for measurements because mid-range angles of knee flexion of 30° to 60° have been used frequently for similar measure-
Since several studies indicate that proprioception in the knee is more sensitive in the end ranges of extension, further studies will have to include angles of knee flexion between 0° and 20°. So far all studies have compared absolute values for detection of the threshold without regard to the influence of failure of detection. In previous studies we showed that the registration of failure of detection may be of special importance in the analysis of measurement of the sense of movement. Therefore, in this study, we analysed failure of detection of movement and stopping at each of the five different angular velocities used.

We found increasing rates of failure for detection of both the start and the end of movement with slower angular velocities. This is in accordance with previous studies, in which proprioceptive acuity was found to improve with increasing velocities of joint movement.

Analysis of failures of detection of movement showed significant differences between the ACL-deficient and the uninvolved knees of the patients, and the knees of the control group. The increase in rates of failure of detection of movement in ACL-deficient knees suggest a marked proprioceptive deficit.

Analysis of failure to detect stopping showed significantly higher rates in ACL-deficient knees compared with the uninjured knees and the control group. By contrast, measurements of the sense of movement showed no differences in TPSM between ACL-deficient and uninjured knees of the patients or between knees of the patients and the control group. TPEM did not differ between either group. These results agree with the findings of Wright et al., who did not find elevated thresholds of detection of movement with ACL injury. Even in studies in which such changes in the sense of movement were found in patients with ACL-deficient knees, differences between the ACL-deficient and uninjured knees could not be observed in several of the individual subjects.

The lack of uniform results in these studies has been explained by the observation that some individuals may rely to a greater extent or receive a greater proportional afferent input from the ACL and other associated damaged capsular ligaments. This is related to the variability in the pattern of innervation of the ACL and differences in the number of mechanoreceptors among different knees. Despite this anatomical variability in the innervation of the knee, the threshold levels for the perception of both the start and the end of movement did not differ between injured and uninjured knees in our study. Differences in innervation, either on the basis of anatomical variability or due to injury, are not necessarily reflected by elevated levels of detection of threshold movement.

It has been suggested that muscle spindles play an important role in detection of movement. Inhibition of the quadriceps muscle can contribute to the functional disability in ACL-deficient knees and has to be considered in relation to the proprioceptive loss. Individual differences in the ability to compensate for loss of the ACL through input from muscle or tendon receptors could be responsible for these different findings. Supraspinal processing of afferent signals may vary from person to person depending, for example, on their concentration.

Many intra-articular and extra-articular factors have an influence on the development and extent of the proprioceptive deficit associated with loss of the ACL.
ments of the threshold levels of detection of passive movement alone do not seem to be suitable for the evaluation of proprioceptive loss in ACL-deficient knees. Instead, analysis of failure of detection of movement is essential since differences between damaged and undamaged knees can be seen in a wide range of different angular velocities.

This work was supported in part by Deutsche Forschungsgemeinschaft AW 5/2-1.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References