Introduction: Proprioception is an important mechanism in knee stability and function. After an injury like an anterior cruciate ligament (ACL) rupture changes appear in knee proprioception which play a major role in rehabilitation. There are several methods to measure proprioception; the threshold to detect passive motion (TTDPM) is often used to quantify proprioception. In this study the reliability and validity were tested of an apparatus, which measures the TTDPM based on the Lund technique of Friddén and Roberts (Sweden).

Materials and methods: Sixteen healthy participants were tested on both legs, from start position 20° and 40°, towards extension (TE) and flexion (TF). The same measurement was repeated 12 (6–21) days later.

Results: An overall mean TTDPM of 0.58° (95% confidence interval CI = 0.53–0.62°) was found. Thresholds were different depending on direction of motion and start position. TTDPM in 20° TE (0.51°, CI = 0.48–0.56°) and in 40° TF (0.54°, CI = 0.50–0.58°) were significantly lower than TTDPM in 40° TE (0.68°, CI = 0.63–0.74°) and in 20° TF (0.58°, CI = 0.54–0.63°). Thresholds were rising with age. Women had higher thresholds than men.

Conclusion: The method is a reliable and valid way to measure proprioception. The next step is to use this method on patients with an ACL-rupture and compare these results with healthy subjects.
although this technique seems to be very promising. In the University Medical Center Groningen (UMCG) we have built our own system to assess the TTDPM based on the prototype of Roberts and Fridén, using digital measurements and with more attention to rule out physical disturbances of the measurements. In this study, we want to present the first experience with the measurement of kinesthesia of the knee in healthy adults by testing reliability and validation.

2. Materials and methods

2.1. Participants

Sixteen healthy persons from the Orthopaedic department of the UMCG were recruited as volunteers. They all gave their informed consent to form a test population. All participants did not have any knee problems in their history; their knee stability was confirmed by physical examination with negative Lachman test, anterior drawer sign and pivot shift test.

2.2. Apparatus

We have refined the apparatus as originally developed in Lund in several aspects [5,13]. On a hospital bed a platform was mounted with a revolving sled that was driven by an electric stepper motor. On the sled a splint for positioning and fixation of the distal limb, including the foot, was attached. The sled could be moved in either direction like the hand of a clock along the natural arc of extension or flexion of the knee.

The subject was positioned on his or her side, with the lower leg placed in the splint. The underlying leg was measured while the other leg was laid upon a second smaller platform (Fig. 1).

The centre of rotation of the knee joint was carefully positioned above the axis of the apparatus. On the knee a potentiometer was fixed, which could measure the angle of the movement with 0.023° accuracy. Care was taken to eliminate any external cues to limb movement except those from the knee joint and surrounding structures. During the pre-test series an influence of breathing on the data was encountered. This caused a measurement error up to 0.12°. Therefore, the trunk of the participants was stabilized by a vacuum mattress, which impeded motion of the pelvis and reduced the measurement error to 0.03°. With the subject in the desired position only motion of the knee in the sagittal plane was possible. Participants were blinded for visual information from the leg while auditory cues were suppressed during the test by earphones with instrumental music. The participants were encouraged to immediately press a button to stop the motion of the apparatus at the moment they could sense motion of their knee. Proprioception was quantified by digitally measuring the TTDPM, in this case the angle (in degrees) at which the machine was halted.

2.3. Test protocol

To compare our data with the data from Roberts and Fridén, the standard testing protocol of Lund was followed (validation). First the right leg was tested in the starting position of 20° flexion, secondly at 40°. Thirdly the left leg was tested at 20° and finally at 40°. In each test 10 measurements towards flexion (TF) and 10 towards extension (TE) were done at random. The leg was moved with an angular velocity of 0.5/°s. After each measurement the leg was repositioned and the starting position was automatically checked or corrected. To avoid guessing by the participants the onset of the rotation had a random delay, varying between 5 and 15 s, after the participants were told to be ready. If a person reacted within 0.1 s after the onset of the motion (i.e. TTDPM < 0.05°), this would be considered as a guess because a physiological reaction time was defined to be 0.1 s at least [18].

All participants were retested in the second session to evaluate reliability and learning effects. The retest was planned at 14 days after the first session.

2.4. Statistical analysis

To analyze the data SAS Version 9.1® was used for linear mixed model; a p-value of lower than 0.05 was considered as statistically significant. Normality of the distribution of the data was tested to allow parametric testing.

3. Results

3.1. Participants

The group consisted of eight males and eight females. The mean age of the participants was 28 years without difference between the men (mean age 30, range 22–42 years) and the women (27, range 21–31 years). The mean length of the participants was 178 cm (range 169–193 cm) with a mean weight of 73 kg (range 60–93 kg). All participants completed both testing-sessions. All participants except two were right-sided dominant. The data from left and right limbs were combined because no significant (p = 0.63) difference was measured comparing the data of the both sides.

We tried to perform the retest at 14 days after the first session. Due to logistic reasons the retest took place after 12 (6–21) days.

As 16 persons finished both sessions of four series of measurements of 20 thresholds, in total 2560 values of the TTDPM could be available. Eleven values of the threshold
of eight participants were not compatible with a normal reaction time leaving 2549 values to be analyzed.

3.2. Threshold to detect passive motion (TTDPM)

At first look the TTDPM values were not normally distributed (see Fig. 2a and b). Due to the fact that the lower bound was set at 0.05°, the distribution curve was left sided truncated. The positively skewed distribution of TTDPM was normalized via a log transformation (Fig. 3a and b) giving valid argument to continue with the parametric testing in the linear mixed model. To render the definitive estimates the log transformed data were analyzed and the presented estimates were back-transformed (antilog transformation).

Overall the mean threshold (TTDPM) was 0.58° (95% confidence interval CI = 0.53–0.62°). In Table 1, the values of both sessions are summarized comparing different starting positions and different directions of motion. The movement starting from 20° towards extension showed significantly lower thresholds than their counter movements 20° TF or 40° TE (p < 0.001). Flexion starting in 40° (40° TF) gave significant lower thresholds than extension in 40° or flexion starting in 20° (p < 0.001 and p = 0.005, respectively).

The second session showed a tendency to lower values of thresholds compared to the first session, although not statistically significant (p = 0.074). These values are listed in Table 2. Only the movements TE in 20° and in 40° had a significant lower TTDPM in the second test.

Between men and women a small difference in TTDPM was noted. Women had on average a 0.10 higher threshold (p = 0.043) than men. Furthermore age appeared to play a role in the detection of motion. Each year older than 21

<table>
<thead>
<tr>
<th>Direction</th>
<th>20°</th>
<th>95% CI</th>
<th>40°</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean TTDPM in different starting positions</td>
<td>TE</td>
<td>0.51</td>
<td>0.48–0.56</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>TE</td>
<td>0.58</td>
<td>0.54–0.63</td>
<td>0.54</td>
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Movements away from the position of maximal volume (20° TE and 40° TF) give significantly lower thresholds than their counter movements.
rendered a higher threshold of 0.018 (p = 0.011), suggesting that a 31-year-old person would have a TTPDM that is 0.10° higher then when this person would have been 21 years.

Because of the log transformation direct calculations of the variances was not useful. The intra-class correlation between the participants computed after log transformation was 11%.

4. Discussion

Based on the Lund technique our registrations were similar. In this study the mean TTDPM in healthy persons was 0.58°, whereas in the Lund-studies 0.5–1.0° was considered as a normal value for the TTDPM [5,9,12,14,17]. The data in Lund were measured by an analogue scale; the measurement error was 0.25°. Our apparatus used a digital registration with an error of 0.03°. Furthermore in the Lund studies median values were calculated of three measurements. In contrary we have rendered mean values of 10 samples per item with very low inter- (11%) and intra-individual (89%) variances. Our data are much more precise and give the apparatus a high reliability. The apparatus is also a valid method to measure the TTDPM in healthy adults having the Swedish data as the only reference data.

In measuring the TTDPM, it was seen that the participants responded quicker the second time they were tested than the first time. This could be considered as a learning effect, though only the differences in motion towards extension were statistically significant. There was no difference found between right or left legs, so in this study dominance of the leg has no influence on the threshold measurements.

Interesting is the interpretation of the data summarized in Table 1. Movements away from the position of maximal volume of the knee (i.e. Bonnets position) are the test of the TTDPM in 20° TE and in 40° TF. These data showed significantly lower thresholds than the measurements TF in 20° and TE in 40°, respectively. We would postulate that higher tensions on the structures around the knee due to reducing its volume give more important proprioceptive stimuli. In the most recent study of Roberts et al. they introduced the ‘proprioceptive index’ which is the sum of the four TTDPM-results in flexion and extension in both starting positions [12]. Considering the fact that there is a statistically significant difference between the different thresholds, we doubt that this calculation is a valid way to indicate proprioception.

Several studies presented a less sensitive proprioception in women compared to men [2,19]. In this study women also had a discretely but significantly higher threshold than men. This might be one of the explanations why there is a higher incidence of ACL-rupture in women, although the relation between gender and ACL-rupture is multifactorial and not well understood.

Our data showed a higher threshold with rising age, which can be a proof of the natural aging process, also described in previous literature [20,21]. Furthermore this might be one of the reasons why younger people rehabilitate quicker than older people after ACL-reconstruction.

In conclusion, the method used is an accurate and valid way to measure the TTDPM and thereby to indicate proprioception in healthy persons. As most research in clinical settings is done in ACL deficient subjects, the following step will be to assess if patients with an ACL-rupture have a different TTDPM compared to healthy persons.

Acknowledgments

The authors would like to thank the following persons: all the participants for participating on the measurements; David Roberts, department of Orthopaedics, University Hospital Lund, Sweden, for giving us detailed information about their apparatus and the technique of proprioception measurements; Hans Thole, department of Medical Technology UMCG, for the construction of the apparatus used; Orthin Instrumentmakerij for their support in the acquisition of the instruments.

Conflict of interest

None.

References


