MECHANOSENSITIVE AFFERENT UNITS IN THE LATERAL LIGAMENT OF THE ANKLE

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We have studied the mechanoSensitive afferent units in the lateral ligament of the ankle of the cat, with reference to the causes of lateral instability after injury, using electrophysiological recording from the lumbar dorsal rootlets.

We identified 30 mechanoSensitive units in the lateral ligament; 28 (93%) were located near the attachment to the fibula and calcaneus, which included both low-threshold group-II units and low- and high-threshold group-III units. Our results indicate that there are both proprioceptors and nociceptors in the lateral ligament of the cat ankle, and confirm that afferent fibres from the lateral ligament may contribute to the stability of the joint by regulation of position and movement.

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Rupture or sprain of the lateral ligaments of the ankle is common, and has been reported to lead to chronic instability in 20% or more of patients.1-3 One of the causes of recurrent sprains and the sensation of ‘giving way’ is probably a proprioceptive deficit.4-7 Proprioception is considered to be provided by afferent signals from joint, muscle, and skin mechanoreceptors which can determine position, detect motion, and protect against excessive movement.5,9

Mechanoreceptors in the joint capsule have been fully investigated,10-12 but little has been reported about the detailed characteristics of those in ligaments. Mechanoreceptors and sensory nerve endings have been shown histologically to be present in the anterior cruciate ligament of the knee in man and the cat13-15 and electrophysiological responses have been elicited from those in the anterior cruciate ligament of the cat.16 The presence of presumed mechanoreceptors in human ankle ligaments has been demonstrated histologically,17 but their neurophysiological properties have not been determined.

From our studies of mechanoSensitive afferent units in the lumbar spine and shoulder using electrophysiological techniques we proposed that low-threshold group-II and group-III units have a proprioceptive function and high-threshold group-III units, a nociceptive function.18-20 In this study we performed an electrophysiological investigation of mechanoSensitive afferent units in the lateral ligament of the cat ankle.

MATERIALS AND METHODS

Operative technique. We used 13 adult cats weighing 2.3 to 3.1 kg. They were sedated by an intramuscular injection of ketamine hydrochloride (20 mg/kg body-weight) and anaesthetised by an intravenous injection of sodium pentobarbital (25 mg/kg body-weight). The level of anaesthesia was evaluated from pupillary size and additional doses of sodium pentobarbital were given to maintain a deep level during the experiment. Atropine (0.45 mg/kg body-weight) was injected subcutaneously to suppress upper respiratory secretions. The animals were immobilised by intravenous injection of 0.6 mg of pancuronium bromide per hour, and were artificially ventilated by endotracheal intubation. Body temperature was maintained at 37°C with a heated blanket.

The lumbar spine was approached through a midline dorsal longitudinal incision. The longissimus, spinalis and multifidus muscles were removed between L3 and S1 along the spinous processes and laminae. Laminectomy was performed on L4 to L7. The L7 and S1 dorsal roots were exposed by opening the dura. A pool was formed from the skin flaps, and the spinal cord was covered in warm (37°C) mineral oil. The animals were fixed in the prone position with the head immobilised in a holder attached to the operating table. The spine was secured at the L3 and S1 spinous processes and the hip, knee and ankle immobilised by an external fixator.

An incision was made in the skin and subcutaneous tissue to expose the lateral aspect of the left ankle. The lateral ligament was displayed by resecting the peroneal
tendons and cutting the capsule taking care to preserve the cutaneous branch of the superficial peroneal and posterior tibial nerves.

**Recording and identification of afferent units.** The L7 and S1 dorsal rootlets were separated and cut at their proximal ends. Each was draped over a bipolar platinum electrode. Afferent impulses from the nerve fibres were amplified, monitored on an oscilloscope and audio monitor, and recorded on an FM tape recorder. The receptive fields of the mechanosensitive units in the lateral ligament of the ankle were located with 1 mm diameter glass probes, and then stimulated electrically with a bipolar electrode. In the search for units, we used a 10 to 25 V stimulus of duration 0.5 ms. To calculate the conduction velocities the distance (in mm) between the stimulating and recording electrodes was measured and divided by the onset latency (in ms) of the evoked response. We classified fibres that had a conduction velocity of less than 2.5 m/s as group-IV units, those with a velocity of between 2.5 and 20 m/s as group-III units, and those of more than 20 m/s as group-II units. The receptive fields were stimulated with a set of 17 nylon filaments to determine the threshold of mechanical stimulation. The filaments, 38 mm long with a force ranging from 0.008 to 279.4 g (Semmes-Weinstein Monofilaments; North Coast Medical Inc, San Jose, California), were applied vertically to the receptive fields until they buckled slightly, and held in that position for at least 1.5 s. Each was applied at least three times to each receptive field.

**RESULTS**

**Receptive fields of the units.** We identified 30 discrete mechanosensitive units in the lateral ligament of the ankle. Most receptive fields had a single circular area of 1 to 2 mm in diameter and were not uniformly distributed throughout the lateral ligament. Ten of the 30 discrete units were located in the proximal third of the lateral ligament (near the fibular attachment), two in the middle third and 18 in the distal third (near the calcaneal attachment). Overall, 28 (93%) of the units were found either near the proximal or distal ends of the ligament, adjacent to the bone attachment (Fig. 1).

**Conduction velocities of the units.** Figure 2 shows the pattern of the potential in a rootlet evoked by electrical stimulation of a single receptive field in the lateral ligament. Of the 30 units in the lateral ligament 24 (80%) were group II and six were group III. The mean conduction velocity of the group-II units was 47.2 ± 17.4 m/s (20.4 to 77.0) and that of the group-III units 14.5 ± 4.49 m/s (5.85 to 18.3). The conduction velocity of the units in the proximal, middle and distal parts of the ligament is shown in Table I. In the proximal (fibular) part, 30% of the units were group III and 70% were group II, while in the distal part 11% of the units were group III and 89% were group II. In the middle part one unit was in each group. No group-IV units were found in the lateral ligament. There was no significant difference in the conduction velocity in the three parts.

**Mechanical thresholds of the units.** The response of the units in the lateral ligament to mechanical stimulation is shown in Figure 3. The mean mechanical threshold of the 30 units in the lateral ligament was 4.43 ± 4.58 g (0.75 to 20.9); 25 (83%) of these units had a threshold of less than 7.0 g.

<table>
<thead>
<tr>
<th>Location</th>
<th>Group III (2.5 to 20 m/s)</th>
<th>Group II (&gt;20 m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal (fibular side)</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Middle</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Distal (calcaneal side)</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>

**Table I.** The number of group-II and group-III units in the three different parts of the ligament as determined by measurement of the conduction velocity.
Figure 4 shows the mechanical threshold of the units plotted against the conduction velocity. Of the 30 units, 24 in group II had a mean threshold of 3.35 ± 2.6 g (0.75 to 12.5); 22 (92%) had a threshold of less than 7.0 g. Six group-III units had a mean threshold of 8.75 ± 7.92 g (0.98 to 20.9) and three had a threshold of more than 7.0 g. The mean threshold of the group-III units was significantly higher than that of the group-II units (p < 0.01, Student’s t-test).

DISCUSSION

Although histological and electrophysiological studies on the mechanoreceptors in other ligaments, such as the anterior cruciate ligament of the knee, have been reported, there has been no electrophysiological study of mechano-sensitive afferent units in the ligament of the ankle of the cat.

One of the problems in neurophysiology is the link between anatomically-defined structures at the end of nerve fibres, and the impulses recorded from nerves and nerve fibres in physiological studies.

Our study found that 80% of the units had group-II and 20% had group-III conduction velocities. Of the group-III sensory fibres the myelinated fibres of small diameter conduct nociceptive sensation. Burgess and Perl demonstrated group-III fibres in the skin of the cat with a mechanical threshold of more than 3.3 g and in the skin of the monkey of more than 7.2 g. The three group-III units with a high threshold (more than 7.0 g) which we found may have had a nociceptive function. From this we suggest that the lateral ligament may be a source of pain in the ankle. By contrast, group-II units are thought to be innervated by thick myelinated fibres and to have a proprioceptive function as do the low-threshold group-III units. We consider that the 24 group-II units and three group-III units which had a low threshold (less than 7.0 g) may be proprioceptors. The distinction between the two threshold groups may be an indication that afferent fibres from the lateral ligament of the ankle have a role in transmitting proprioception as well as nociception.

Yamashita et al reported that group-II units were present in only 29% of sensory receptors in the spinal facet joint of the rabbit and Gentle showed that approximately 20% of capsular sensory receptors in the ankle of the chicken were group II. Krauspe et al reported that 79% of mechanosensitive units in the anterior cruciate ligament of the knee of the cat were group II. The mechanical thresholds of these units ranged from 0.7 to 15 g, with most being in the range of 1.7 to 3.5 g. We also showed that 80% of the identified units were group II and 83% of these had low mechanical thresholds. Mechanosensitive units in the lateral ligament of the ankle therefore probably consist of more group-II units with a low mechanical threshold compared with other tissues and probably have a proprioceptive rather than a nociceptive function.

Krauspe et al reported that in the cat most of the receptive fields of the mechanosensitive afferent units in the anterior cruciate ligament were found near its femoral attachment. In the human knee they are located near the surface of the ligament. We found that 93% of the mechanosensitive units were located in the proximal and distal thirds of the lateral ligament near the fibula and calcaneus, respectively. We suggest that the polar distribution of mechanoreceptors allows them to act more sensitively as monitors of tension applied to the ligament than those in the centre of the ligament.

Clinical experience suggests that a proprioceptive deficit may be one of the causes of functional lateral instability of the ankle, resulting in a feeling of ‘giving way’ and recurrent sprains. In patients with chronic lateral instability of the ankle the EMG response of the peroneus longus and the tibialis anterior muscles to sudden angular displacement of the ankle is more delayed in unstable ankles than in stable contralateral ankles. These findings may be attributed to impairment of the proprioceptive reflex system, including joint mechanoreceptors, which makes it impossible to regulate effectively appropriate muscular activity to
prevent sudden movement of the ankle. In simulated ankle strain with an ankle-inverting platform,2 the reaction time of the peroneal muscles was slower in unstable ankles than in normal ankles. The joint afferents transmitting proprioception can directly activate γ-motoneurones.26 Through the effect of the γ loop on the α-motoneurone discharge activating muscles the proprioceptive reflex system may contribute to postural stability and co-ordination of movement of the ankle.27,28 This theory is based on the assumption that there are proprioceptive units in the joint within the ligaments and capsule. Our study has added to evidence supporting the existence of proprioception in the lateral ligament of the ankle, and corroborated clinical suggestions concerning the causal relationship between proprioception and instability of the ankle.

Chronic lateral instability of the ankle may cause severe disability and may result in progressive degenerative arthritis of the ankle.29 Several different surgical procedures have been reported for treating this instability.30-3 As most of the mechanosensitive units identified in our study were located near both poles of the lateral ligament some of those surgical procedures may need to be amended to preserve the attachment of the lateral ligament to bone.

Although we suggest that low-threshold units may serve as proprioceptors and high-threshold units as nociceptors, further physiological studies are needed to analyse the response of mechanosensitive units to controlled loading and movement. Investigation of mechanoreceptors in other ligaments of the ankle is also required, to advance the treatment of ligament injuries and instability of the ankle on a physiological as well as the current anatomical basis.

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REFERENCES