Chapter 8

Summary and Conclusion
The role of a large number of structures are reported in the aetiology of low back pain. Also, during the last 130 years several mechanisms to protect the spinal nerve against traction have been described. All these structures were located in the spinal canal proximal to the intervertebral foramen. Tissue bands outside the intervertebral foramen are also described.\textsuperscript{12}

In \textbf{Chapter 2} it is shown that the lumbar spinal nerves are attached to the lumbar spine. However, this study also outlines the anatomy of a not previously described extraforaminal attachment of the spinal nerves in the extraforaminal region. Per lumbar level, these extraforaminal ligament attachments consist of a superior and an inferior ligament. The superior ligament originates from the intervertebral disc and the ventral crista of the intervertebral foramen. It inserts into the articular capsule of the facet joint with an attachment to the spinal nerve laterally. All the superior and inferior ligaments on levels Th12-L1 have a ventrocaudal-dorsocranial direction in relation to the spinal nerve, attaching the spinal nerve medially. At levels L2-L5, the direction of the inferior extraforaminal ligament is ventrocranial-dorsocaudal, attaching the spinal nerve ventrally and laterally. Although previous studies have described the anatomy of the extraforaminal region,\textsuperscript{3,11} to the best of our knowledge these studies do not mention attachments to the spinal nerve. One study described ligament attachments to the nerve root, but these attachments were within the intervertebral foramen.\textsuperscript{12}

The present study shows that not only are there extraforaminal ligaments, but that these structures at all lumbar levels also have attachments with the spinal nerve. We call this specific part of the extraforaminal attachment to the spinal nerve the ‘extraforaminal ligament’ (efl). Thoracic ligamentous attachments are described in \textbf{Chapter 3}. From the 2nd to the 9th thoracic level, the efl consist of a superior and an inferior part. The superior efl originates from the costovertebral joint and the superior transverse process. It inserts on the inferior transverse process. The superior part is identified as the superior costotransverse ligament. This ligament is ventrally attached to the spinal nerves. The inferior ligament attaches the nerve dorsally and originates and inserts on the superior and inferior transverse process, respectively. In the literature, no such ligament has been described. All the superior and inferior ligaments have a laterocranialdorsal to mediocaudalventral orientation in relation to the spinal nerves. On the 10th and 11th levels, we see the same attachments to the thoracic spinal nerves. The features of the efl at the thoracic levels correspond to the 12th thoracic and the 1st lumbar levels. At these levels, the extraforaminal ligaments connect the spinal nerves to the intervertebral foramen and disc.

\textbf{Chapter 4} describes the anatomy of extraforaminal ligaments from the second cervical to the first thoracic spinal nerves in the extraforaminal region. From the second cervical to the first thoracic spinal nerve the efl consist of a ventral and dorsal superior and inferior part. The
ventral superior efl originates from the anterior tubercle of the transverse process. It inserts on the posterior tubercle of the transverse process. The ventral side of this ligament is attached to the spinal nerves. The dorsal superior efl attaches the nerve dorsally and originates at the dorsal part of the transverse process. It inserts on the epineurium of the spinal nerves. The literature describes protection of the peripheral nerves against nerve traction damage by pre-, intra- and extraforaminal structures, such as the ligaments of Trolard\textsuperscript{13}, Hofmann\textsuperscript{5}, Spencer\textsuperscript{2}, suspensor radial ligaments\textsuperscript{14} and the denticular ligaments.

The lumbar extraforaminal ligaments form a first line of defence to protect the spinal nerve roots against traction (Chapter 5). It appears that a large portion of extraforaminal traction can be diverted by the lumbar efl. When subjected to traction, the spinal nerve shows more elongation distally than proximally to the efl. In addition, there is a load-reducing capacity of tensile forces in ventral direction of the lumbar spinal nerves. The spinal nerve proximal to the efl stays centred when the nerve is pulled at an angle. Thus, the spinal nerves are protected against compression when moving the nerves in ventral and dorsal directions. Furthermore, we found that the load-reducing capacity in the longitudinal direction of the nerve increases from L1 to L4.

It appears that a large portion of extraforaminal spinal nerve traction can be diverted by the thoracic efls (Chapter 6). Some differences were seen in the mechanical properties between the thoracic and lumbar level. At the lumbar level, when subjected to traction, the spinal nerve shows more elongation distally than proximally to the efl. This is in contrast to the thoracic level, where more elongation is seen proximally than distally of the efl. This is a remarkable finding, because we expected more elongation of the nerve distal to the efl, as seen in the lumbar region. The spinal thoracic nerves proximal to the efl stay centred in the intervertebral foramen when the nerve is pulled at an angle. When the efl is transected, the proximal part of the efl shows an increase in movement in the cranial and caudal direction when pulled in the cranial and caudal direction, respectively.

**CONCLUSIONS**

In conclusion the studies presented in this thesis describe how extraforaminal ligaments connect the spinal nerve to the extraforaminal region. This with features characteristic for each level. The lumbar extraforaminal ligaments convey traction to the disc and fibrous capsule of the lumbar vertebrae, and thereby distract tensile forces from the intraforaminal nerve roots. Therefore, we conclude that the lumbar extraforaminal ligaments have a mechanical function in preventing spinal root compression.