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Intradural Communication of L3 and L4 Ventral Nerve Rootlets of Spinal Nerves

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Abstract : Normally, the nerve roots within the dural sac never communicate with one another. Even the fusion of the ventral and dorsal nerve roots to form the spinal nerve occurs outside the dural sac. In dissecting the spinal cords of 54 cadavers, we found one abnormal case in which the ventral nerve rootlet of the L3 spinal nerve gave a branch which joined with the L4 nerve rootlet within the dural sac. This communication consisted only of motor fibers. This pattern is different from patterns of distribution of normal spinal nerves, which are described by their segmentation and peripheral distribution patterns, both of which occur outside the dural sac and comprise of both motor and sensory fibers. Several causes for this abnormality have been proposed. Firstly, some neurons of the L4 anterior horn may have interposed with the L3 anterior horn cells. These neurons may have given axons and which joined with the L3 spinal nerve, then split back to join with the L4 spinal nerve, to ultimately supply the myotome of the L4 somite. Secondly, the fusion of myotomes of several somites to form one specific muscle may have developed sooner than its nerve and may have influenced the communication between the L3 and L4 nerve rootlets within the dural sac. An ultrastructural study of the communication segment by TEM clearly reveals a bundle of myelinated nerve fibers which are all peripheral nerves with their Schwann cells covered externally.

Key words : Nerve rootlets communication, Intradural

เรื่องย่อ : การรวมตัวกันของ Nerve Rootlets ของ Ventral Nerve roots ของ L3 และ L4 ภายใน Dural Sac

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โดยปกติแล้ว เส้นประสาทไขสันหลังที่อยู่ภายใน ดูรัล แซค (dural sac) และเป็นเส้นประสาทประจำของไขสันหลังระดับนั้นๆ จะไม่มีการรวมตัวกัน แม้แต่การรวมตัวกันของรากประสาทด้านหน้าและด้านหลังไปเป็นเส้นประสาทไขสันหลังก็เกิดขึ้นนอกต่อ ดูรัล แซค จากการชำแหละไขสันหลังคนไทย จำนวน 54 ราย พบความผิดปกติ 1 รายที่ nerve rootlet ของ ventral nerve root ของ L3 ให้แขนงไปรวมตัวกับ L4 ภายใน ดูรัล แซค ซึ่งเป็นเส้นประสาทสั่งการเท่านั้น ลักษณะเช่นนี้ต่างไปจากแบบแผนการกระจายของเส้นประสาทไขสันหลัง ซึ่งเคยมีการอธิบายไว้เป็น 2 แบบคือ การกระจายแบบ เซกเมนทัล (segmental) และการกระจายแบบ เปอริเฟอรัล (peripheral) ซึ่งทั้ง 2 แบบดังกล่าว ล้วนเกิดขึ้นภายนอก ดูรัล แซค และเกิดขึ้นทั้งกับประสาทรับความรู้สึกและประสาทสั่งการ สาเหตุของความผิดปกติที่พบนี้อาจเกิดจากเซลล์ประสาทสั่งการของ L4 เหลื่อมขึ้นไปปะปนกับเซลล์ประสาทสั่งการของ L3 เมื่อให้เส้นใยประสาทออกมา จึงออกมาพร้อมกับเส้นประสาทของ L3 แล้วในที่สุดก็แยกตัวออกเพื่อรวมกับเส้นประสาทของ L4 ดังเดิม เพื่อไปเลี้ยงกล้ามเนื้อซึ่งเจริญมาจากไมโอโตม (myotome) ของไขสันหลังที่ 4 (L4 somite) หรืออีกประการหนึ่ง อาจเกิดจากการรวมตัวกันของไมโอโตมของหลายไขสันหลัง (somites) เพื่อเจริญเป็นกล้ามเนื้อมัดหนึ่งๆ เจริญขึ้นเร็วกว่าปกติ ก่อนที่เส้นประสาทของกล้ามเนื้อนั้นจะจัดรูปแบบเสร็จ มีผลเหนี่ยวนำให้เกิดการเชื่อมกันระหว่างเส้นประสาทก่อนถึงช่วงอันควรคือภายใน ดูรัล แซค การศึกษาส่วนที่เชื่อมกันระหว่าง L3 และ L4 โดยวิธีจุลทรรศน์อิเล็กตรอนแบบส่องผ่าน ทำให้แน่ใจได้ว่าส่วนนี้คือ กลุ่มของเส้นใยประสาทซึ่งมีไมอีลิน (myelin) หุ้ม และมี Schwann cell ล้อมอยู่รอบนอกอีกชั้นหนึ่ง

INTRODUCTION

Adductor and, abductor muscles of the femur as well as the quadriceps femoris muscles, originate from the fusion of myotomes of L2 - L4 somites¹, thus receiving their nerve supply from the ventral rami of L2 - L4 spinal nerves, which communicate to form a certain pattern of lumbar plexus outside the dural sac and the vertebral column. This lumbar plexus, then gives rise to the obturator and femoral nerves to supply all of the above mentioned muscles^{1,2}.

Continuous with the spinal cord is a series of paired dorsal and ventral roots of spinal nerves. These cross the subarachnoid space and traverse the dura mater separately, uniting within or close to their intervertebral foramina to form (mixed) spinal nerves. Because the spinal cord is shorter than the vertebral column, more caudal spinal roots descend various distances beyond the cord to reach their corresponding foramina, thus forming, largely distal to the cord a divergent sheaf of spinal nerve roots, known as the cauda equina (Figure 1). The cauda equina is comprised of the dorsal and ventral nerve roots of L2 through the coccyx, which run separately without any communication before piercing the dura

in the dural sac. Beyond the dural sac, the spinal nerves are formed at the intervertebral foramina and then branch into dorsal and ventral rami. The ventral rami of the L2 - L4 spinal nerves, which contain both sensory and motor fibers, communicate to form the lumbar plexus which then give branches to the adductor muscles (L3,4), abductor muscle (L3,4) and quadriceps femoris (L2,3,4) (Figure 2).

There are two patterns of distribution for the spinal nerves. The first is the segmental distribution, which refers to the spinal nerves of most of the thoracic segment of the embryo. By the time the somites differentiate into muscles, the dermis of the skin and the corresponding bones, the nerves follow the differentiation and migration of the areas they supply. The spinal nerves of the segmental distribution, always supply their own dermatomes or myotomes^{3,4}.

The second is the peripheral nerve plexus distribution, which refers to the spinal nerves of the neck and extremities. One peripheral nerve originates from the combination of several specific spinal nerves. The ventral rami of C1 - C3 communicate to form the cervical plexus; the C4 - T1 communicate to form the brachial plexus; and the L2 - S2

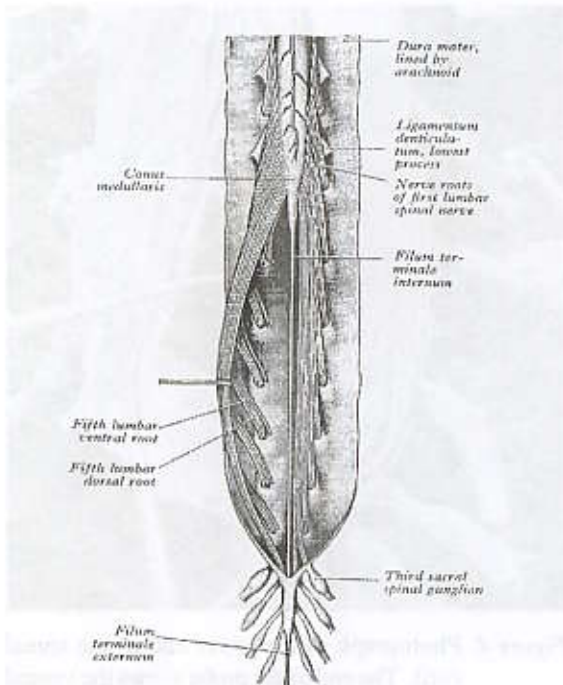


Figure 1. The lower end of the spinal cord, the filum terminale and cauda equina exposed from behind. The dura mater and the arachnoid have been opened and spread out.

communicate to form the lumbosacral plexus^{3,4}. Both patterns of spinal nerve distribution occurs beyond the dura mater, just as in the vertebral column, and both motor and sensory fibers combine in each nerve of both patterns. Intradural communication of the spinal nerve roots or rootlets is extremely rare and there are still no reports about this type of nerve communication.

MATERIALS AND METHODS

Spinal cords and meninges were dissected in 54 cadavers used by second year medical students at the Department of Anatomy, Faculty of Medicine Siriraj Hospital. The dura and arachnoid matter were opened along the median plane longitudinally to expose the spinal cord, the nerve roots and the cauda equina. The cauda equina of all the cords were

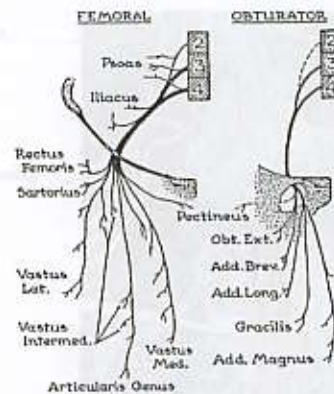


Figure 2. The motor distribution of the obturator and femoral nerves.

studied carefully, by separating the nerve root of each segment. This was done by following the rootlets of both the dorsal and ventral parts of each segment until they came together before penetrating the dura mater.

The communication segment described in this paper, was further studied ultrastructurally by TEM, to confirm that it was indeed a nerve fiber. The segment was cut 5 mm long and transferred to 2.5% glutaraldehyde in 0.1 M sodium cacodylate buffer, pH 7.2 at 4°C for 2 hours. It was then washed three times with the same buffer, post fixed in 1% osmium tetroxide (OsO_4) in 0.1 M sodium cacodylate buffer, pH 7.2 at 4°C for one hour, and washed three times with distilled water. After tertiary fixation and staining with 1% uranyl acetate in distilled water for 20 minutes, the segment was washed three times with distilled water. It was dehydrated in a graded series of ethanol (50-100%) for 15 minutes at each step and then infiltrated twice in propylene oxide for 20 minutes each. The solution was replaced twice with a mixture of propylene oxide and absolute alcohol at 1:2 and 2:1, respectively, and left in the 2:1 mixture overnight. It was then embedded in Araldite. Thin sections showing silver to gold interference were mounted on formvar-coated copper grids and further stained with uranyl acetate and lead citrate for 10 minutes each, and observed by transmission electron microscope.

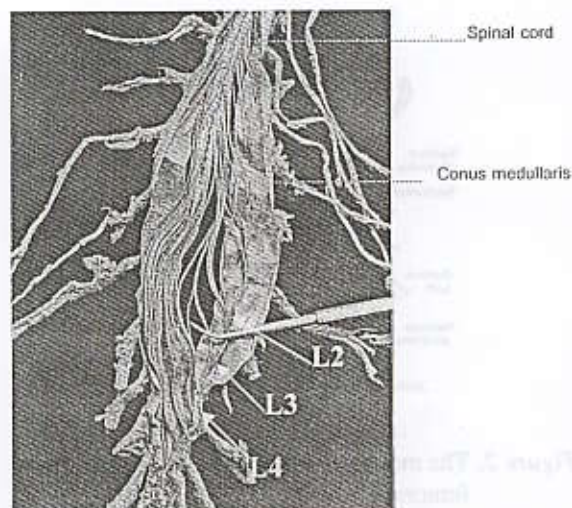


Figure 3. Photograph of the lower end of the spinal cord, the filum terminale and cauda equina exposed from the front. The dura and arachnoid mater have been opened and spread out. The arrows show the left ventral nerve rootlets of L2, L3 and L4 spinal nerves. The end of the probe shows the ventral nerve rootlet of the L3 segment giving a branch to join with the rootlet of the L4 segment within the dural sac.

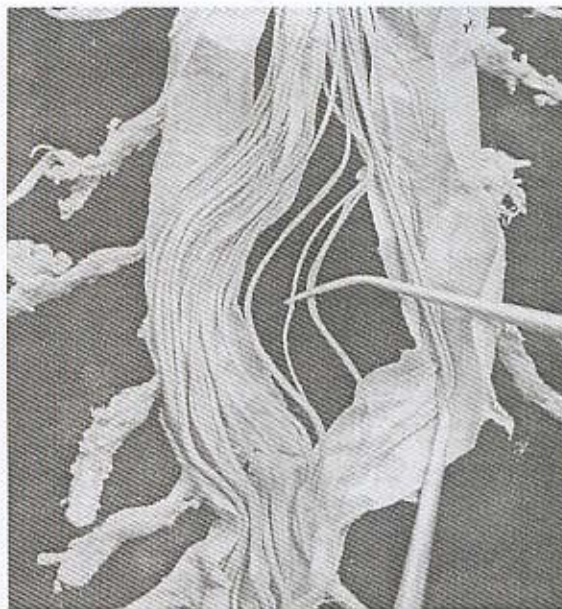


Figure 4. Photograph of the lower end of the spinal cord. The end of the probe shows the ventral nerve rootlet of the L3 segment giving a branch to join with the rootlet of the L4 segment within the dural sac.

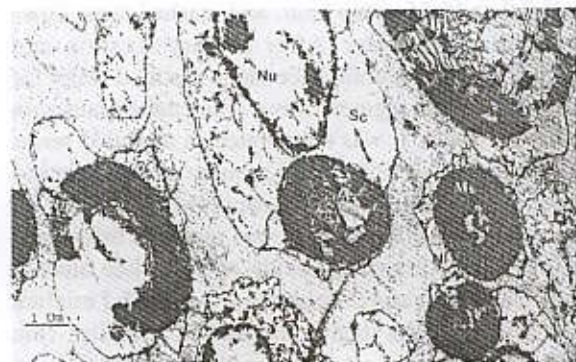


Figure 5. TEM of a bundle of myelinated nerve fibers. The axis cylinders (Ax) are covered with myelin sheath (Ms) and neurilemma sheath (NI). This micrograph also shows a Schwann cell body (Sc) and nucleus (Nu).

RESULTS

Of the 54 spinal cords studied, 53 spinal cords were classified as normal spinal cords and a remaining spinal cord was considered abnormal. In the normal spinal cords, the paired dorsal and ventral roots of the spinal nerves crossed the subarachnoid space and traversed the dura mater separately, then joined together at each intervertebral foramen to form the spinal nerve. At the region of the cauda equina, each comprised of the dorsal and ventral nerve roots of L2 through to the coccyx, which ran separately without any communication before piercing the dura of the dural sac. Beyond the dural sac the spinal nerves were formed at the intervertebral foramina.

In the one abnormal spinal cord, we found that one of the ventral nerve rootlets of the L3 segment gave a branch to communicate with the rootlet of the L4 segment (Figure 3, 4) before piercing the dura mater and within the dural sac. This abnormality occurred specifically with the ventral rootlets within the dural sac.

TEM of the rootlet communication of L3 and L4, revealed that the rootlet comprised of many axons which were all myelinated nerve fibers. The axis cylinders were covered with a myelin sheath consisting of regular layers of membrane, darker lines (or major dense lines) and the intervening intraperiod lines. The bulk of the Schwann cell cytoplasm and nucleus encircled the myelin sheath. Most axons showed thin layers of Schwann cell cytoplasm immediately surrounding the axons. Most myelin sheaths in the section showed various degrees of degeneration as the layers of periodicity became more or less separate from one another and some did not completely encircle the axons. This indicated the poor preservation of the tissue as the tissue was cut directly from the cadaver.

DISCUSSION

Motor nerve fibers arise from cells in the basal plate of the developing neural tube and begin to appear at the end of the fourth week of gestation⁵. The nerve fibers emerge as a continuous series of rootlets along the ventrolateral surface of the spinal cord and are destined for a particular developing muscle group. Before they pierce the muscle mass, the ventral and dorsal nerve roots of each segment join together to form the (mixed) spinal nerve, then separate to form the dorsal and ventral branches, which pierce the dorsal and ventral muscle masses respectively. The dorsal and ventral muscle masses develop from the myotome of each segment and eventually develop into the extensor and flexor groups of the striated muscle of the trunk.

The myotomes of several specific somites also give rise to the striated muscles of the limbs. As each limb bud develops during the 4th-6th weeks of gestation, the nerves from the spinal cord segments opposite to the bud elongate and grow into the bud. The nerve fibers distribute into their muscles, which originate from the myogenic cells (myoblasts) of the myotome of the somites. From the dermomyotome regions of the somites, myogenic precursor cells migrate into the limb bud and later differentiate into myoblasts⁶. The myoblasts of the lumbar myotomes

form the quadratus lumborum muscles. The molecular mechanisms that initiate and control the migration of the myogenic precursor cells from the somites to the limb buds, and subsequent muscle formation remain largely unknown^{7,8}.

Segmental innervation of the limb muscles comes from more than one segment of the spinal cord. Each spinal nerve originally supplies the musculature of its axon myotome. Where myotomal derivatives remain entities, they retain their original segmental supplies, but when derivatives formed by adjoining myotomes, the resulting muscles are occasionally, but not always supplied by their corresponding spinal nerves.

The muscles of the lower limb are supplied by the lumbar plexus which is formed by the first three or four ventral rami of the lumbar spinal nerves. The lumbar plexus is in the posterior part of the psoas major muscle and anterior to the lumbar transverse processes. The second, third and a part of the fourth rami join the plexus and divided into the ventral and dorsal branches. The ventral branches of the second to fourth rami form the obturator nerve. Each dorsal branch of the second and the third rami divided into small and large parts. The small parts unite to form the femoral cutaneous nerve, while the larger parts join with the dorsal branch of the fourth rami to form the femoral nerve. The accessory obturator nerve, when evident, arises from the third and the fourth ventral branches.

In this abnormal case, the ventral nerve rootlet of the L3 segment gives a branch to join with the rootlet of the L4 segment within the dural sac. This finding is extremely rare and there are no previous reports about this type of nerve communication. We propose two different causes for this abnormality. The first possible cause concerns the neurons of the anterior horn of the spinal cord. Some neurons of the L4 anterior horn may have interposed with the L3 anterior horn cells. These neurons may have given axons and joined with the L3 spinal nerve, then split back to join with the L4 spinal nerve to supply the myotome of the L4 somite. The second possible cause concerns the developing somite. The fusion of myotomes of several somites

to form one specific muscle may have developed sooner than its nerve and may have influenced the communication between the nerve rootlets of L3 and L4 within the dural sac.

This may be more distinct when the anterior horn cells are compared with the neurons of the caudal part of nucleus ambiguus, which is the origin of the bulbar part of N. XI. At its onset, it traverses together with the spinal part of N. XI, which originates from the accessory nucleus at the level of C1 - C5 spinal cord segments and is a part of the same column with the nucleus ambiguus. When N. XI emerges from the skull through the jugular foramen, the bulbar part of N. XI splits back to join with the vagus nerve, however this occurs outside the dural sac.

The TEM study of the rootlet revealed that the segment was really a bundle of nerve fibers. The rootlet comprised many myelinated nerve fibers with neurilemma sheaths, along with the cell body of the Schwann cell and its nucleus. Unfortunately, the preserved specimen for TEM, was cut from the formalin preserved cadaver, which was not the standard way to preserve the tissue for TEM study. Most of the myelin sheath in this section, showed various degrees of degeneration as the layers of periodicity became more or less separated from one another. Some of the sheath did not completely encircle the axons. While the micrograph was not of perfect quality, it did confirm the presence of a communicating segment between L3 and L4, that was in fact a bundle of myelinated nerve fibers.

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CONCLUSION

In dissecting the spinal cords of 54 cadavers, we found one abnormal case, in which the ventral nerve rootlet of the L3 spinal nerve gave a branch to join with the L4 nerve rootlet within the dural sac. This pattern is different from normal spinal nerves, which can be described by the segmentation and peripheral distribution patterns. Both patterns occur outside the dorsal sac and are comprised of both motor and sensory fibers. We considered two possible causes for this aberration. The first cause may be due to some neurons of the L4 anterior horn interposing with the L3 anterior horn cells. These neurons may have yielded axons with the L3 spinal nerve, then later split back to join with the L4 spinal nerve to supply the myotome of the L4 somite. The second cause may have been related to the fusion of myotomes of several somites to form one muscle which developed sooner than its nerve, and may have influenced the communication between the L3 and L4 nerve rootlets within the dural sac. TEM study revealed clearly that the communication segment was in fact a bundle of myelinated nerve fibers.

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