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**Implications of the neuroanatomy of the equine thoracolumbar vertebral column with regional anaesthesia and complications following desmotomy of the interspinous ligament**

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**Abstract**

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Impinging/overriding dorsal spinous processes of the thoracolumbar vertebrae are a common cause of poor performance in horses. In the last five decades, numerous surgical treatments have been reported on, from transverse transection of the affected dorsal spinous processes, endoscopic resection of the affected dorsal spinous processes, to transection of the interspinous ligament. Until recently, cosmetic outcomes have been reported as good to excellent in studies. However, a previously unreported complication of neurogenic atrophy of the contralateral epaxial muscle following desmotomy of the interspinous ligament has been recently reported. The authors hypothesised that this was because of a more lateral approach than previously described, resulting in the scissors being too far across midline and transecting a nerve in the region. Considering this finding, we have reviewed the literature on the neuroanatomy of the thoracolumbar region in the horse.

Literature on the neuroanatomy of the horse is lacking when compared to that of humans and companion animals, with most of the work extrapolated from companion animals. Based on the current literature, we hypothesise that transection of an intermediate branch of the dorsal spinal nerve supplying the *m. longissimus* is potentially the cause of the post-operative neurogenic atrophy.

The lack of detailed knowledge of the neural anatomy of the equine back has resulted in the role of local anaesthesia in localising pain in the equine back being poorly understood. The wide variation in techniques used for localising back pain may explain why some horses suffering from poor performance or an abnormal gait because of back pain, improve to local anaesthesia of the back while others do not.

This review article highlights a lack of anatomical knowledge regarding the equine thoracolumbar region in the literature despite diagnostic local anaesthesia, medication, and surgery in this area being relatively common.

## **Introduction**

Impingement of two or more dorsal spinous processes (DSPs) has been reported to be a frequent cause of back pain of horses.<sup>1-6</sup> The first surgical treatment for impinging dorsal spinous processes involved transversely amputating the affected portion of the DSP through a crescentic incision on the dorsal midline.<sup>7</sup> Modifications of this surgery have sought to minimise disruption of soft-tissue by transecting the affected DSPs obliquely,<sup>5,8-11</sup> by resecting only the cranial portion of a DSP at the site of impingement (i.e. cranial wedge subtotal ostectomy),<sup>12</sup> or by endoscopic resection of the impinging portion of the dorsal spinous processes.<sup>13</sup>

Desmotomy of an interspinous ligament between impinging DSPs is a minimally invasive technique, performed through a small incision, used to resolve pain caused by the impingement.<sup>14,15</sup> Desmotomy can be performed quicker than amputation, convalescence after desmotomy is shorter than convalescence after amputation, and desmotomy has been reported to result in a better functional outcome than medical management.<sup>15</sup>

The cosmetic outcome of horses undergoing surgery to resolve pain caused by impinging DSPs, regardless of the technique used, has been deemed “good-to-excellent” in 100% of horses,<sup>12</sup> “excellent” in 96% of horses,<sup>16</sup> or “good” in 98.2% of horses.<sup>15</sup> Permanent<sup>11,12,14</sup> or temporary<sup>5,15</sup> small bumps or depressions have been observed at the surgical sites of some horses undergoing partial ostectomy of the DSPs or desmotomy of the interspinous ligaments, but we can find no studies that state the likelihood of a horse incurring such a blemish after surgery. One study reported that 40% of horses (9/22) undergoing partial amputation of impinging DSPs developed white hairs at the site of cutaneous incision,<sup>12</sup> whereas another study reported that only 14.3% of horses undergoing desmotomy of the interspinous ligament developed this same complication.<sup>14</sup>

In a recent retrospective study, 5% (8/159) of Thoroughbred racehorses developed neurogenic atrophy of a portion of the epaxial musculature after undergoing desmotomy of one or more interspinous ligaments as a treatment for pain caused by impinging DSPs.<sup>1</sup> The authors hypothesised this previously unreported complication occurred because the site of incision for introducing the scissors used to cut the interspinous ligament was more lateral than that described by Coomer *et al.*,<sup>15</sup> who first described the procedure. Though creating the incisions more laterally allowed the scissors to be inserted at a more obtuse angle, making transection of the interspinous ligament easier, it also allowed the tip of the scissors to be introduced inadvertently farther across midline making transection of a motor nerve on the side contralateral to the site of incision more likely. Although neurogenic atrophy of the epaxial musculature did not adversely affect post-operative racing performance of these horses, this adverse cosmetic outcome could be problematic if the cosmetic appearance of the horse is important to the owner (Figure 1 a, b).

In this article we review the neuroanatomy of the thoracolumbar portion of the vertebral column of horses, so that surgeons performing desmotomy of one or more of the interspinous ligaments can better understand why this surgery may result in neurogenic atrophy of the epaxial musculature. We also review the diagnostic analgesic techniques currently performed by clinicians to confirm that apparent back pain can be caused by impinging DSPs.

## Neural anatomy of the equine thoracolumbar region

The equine thoracolumbar region consists of 18 pairs of thoracic spinal nerves and 6 pairs of lumbar spinal nerves, each of which carry motor and sensory information to and from the spinal cord.<sup>17-19</sup> As in human beings, dogs, and cats, each spinal nerve of a horse forms from a ventral root and a dorsal root before it exits the intervertebral foramen.<sup>17,18</sup> After exiting the intervertebral foramen, the spinal nerve of horses first gives off a small meningeal branch, then the dorsal ramus, and then the communicating branch of pre- and post-ganglionic sympathetic fibres (*ramus communicans*), before continuing as the ventral ramus<sup>17,19-22</sup> (Figures 2 and 3).

The *ramus communicans* consists of sympathetic efferent and afferent axons that supply visceral structures by way of the splanchnic nerves.<sup>20</sup> The meningeal branch provides motor innervation to the smooth muscles in the meningeal blood vessels and sensory innervation to the *dura mater*.<sup>20</sup> The ventral ramus (*ramus ventralis*) of a spinal nerve supplies motor and sensory innervation to the hypaxial musculature and associated skin.<sup>20,23</sup> The ventral rami of spinal nerves C6-T2 contribute to the brachial plexus.<sup>24-26</sup> The lumbosacral plexus of horses has been described as consisting of the ventral rami of spinal nerves L4-S2<sup>17</sup> or spinal nerves L2-S5.<sup>23</sup> The ventral rami of spinal nerves in the thoracic region are the intercostal nerves (i.e. spinal nerves T3-T17).<sup>17,20,21,27</sup> Each intercostal nerve travels ventrally within the intercostal space, along the caudal aspect of each rib, and then along the superficial surface of the transversus abdominis muscle to provide innervation to that and other muscles of the abdominal wall.<sup>20,23</sup> The intercostal nerve gives rise to the lateral cutaneous branch, which innervates a segment of the body wall and terminates as the ventral cutaneous nerve on the ventrolateral half of the thoracic wall close to the costochondral junction.<sup>28,29</sup> The course of the lateral cutaneous branch of spinal nerve T18 varies slightly to that of the lateral cutaneous branch of the other spinal nerves by terminating ventrally as the costoabdominal nerve (*n. costoabdominalis*), which innervates a band of skin and muscle at the costal arch of the thorax.<sup>21,30</sup> The ventral ramus of lumbar spinal nerve L1, the iliohypogastric nerve (*n. iliohypogastricus*), and that of L2, the ilioinguinal nerve (*n. ilioinguinalis*), supply medial and lateral branches that innervate the abdominal musculature, skin of the flank, and ventral aspect of the abdomen.<sup>18,21,23</sup> The lateral cutaneous femoral nerve arises from L3 and L4 and supplies the skin of the medial aspect of the thigh.<sup>31</sup>

The dorsal ramus (*ramus dorsalis*) of each spinal nerve supplies motor and sensory innervation to the epaxial musculature and associated skin.<sup>20,23</sup> The dorsal ramus divides into

medial and lateral branches (*rami medialis et lateralis*). The medial branch, in the thoracic region, runs dorsolaterally along its corresponding DSP to innervate segments of the *mm. multifidus thoracis*, *mm. rotatores*, *m. longissimus thoracis et lumborum*, *m. spinalis thoracis*, and *m. semispinalis thoracis*. The medial branch, in the lumbar region, runs caudodorsally across the adjacent DSP to innervate segments of the *m. longissimus lumborum*, *mm. multifidi*, and *mm. interspinales*. The lateral branch of the dorsal rami of the spinal nerves in the thoracic and lumbar region runs caudolaterally, at a 45-degree angle to the sagittal plane, coursing between the *m. longissimus* medially and the *m. iliocostalis* laterally, to innervate segments of these muscles.<sup>22,30,32–35</sup> Each lateral branch, after innervating the musculature, perforates the thoracolumbar fascia, and enters the skin where it divides into a short medial cutaneous branch (*ramus cutaneus medialis*) and a longer lateral cutaneous branch (*ramus cutaneus lateralis*), both of which innervate the skin of the thoracolumbar region.

The dorsal rami of the lumbar spinal nerves, also known as the cranial clunial nerves (*nn. clunium cranialis*), give rise to medial branches, which innervate the epaxial muscles in this region, and lateral branches, which innervate the lumbar skin and cranial part of the croup.<sup>23</sup> In small domestic animals such as dogs and cats, the dorsal rami and their branches, of the thoracic spinal nerves, do not communicate with adjacent, resulting in longitudinal segmental innervation of the skin of the dorsum.<sup>21,27,30</sup> The skin of horses usually has sensory innervation from multiple nerves (i.e. a zone of overlap).<sup>20,36</sup>

The medial branch of the dorsal rami of the lumbar region of horses diverges into two branches which travel dorsocaudally toward the surface of the vertebral lamina, before exiting the intertransverse space.<sup>22</sup> An intermediate branch arises at various locations from the dorsal ramus of the thoracic and lumbar spinal nerves of human beings, cats, and dogs,<sup>32–34,37</sup> and this branch has been identified recently in the lumbar region of horses.<sup>22</sup> An intermediate branch arising from the dorsal ramus of spinal nerves T7-L2 of human beings originates at the site where the dorsal ramus diverges into medial and lateral branches. The intermediate branch of spinal nerves T4, T5, and L3-L5 of human beings arises more distally from the lateral branch of the dorsal ramus. An intermediate branch of spinal nerve T6 has not been found.<sup>33,38</sup> An intermediate branch, originating from the lateral branch of the dorsal ramus at the level of the intertransverse ligament where the dorsal ramus divides into its medial and lateral branches, has been observed consistently in the lumbar region of the cat.<sup>34,39</sup>

When present in the lumbar region, regardless of its origin, the intermediate nerve of human beings, cats, dogs, and horses consistently innervates the *m. longissimus dorsi*. The presence of an intermediate branch in the thoracic region of the horse has yet to be confirmed. The *m. longissimus dorsi* in the thoracic region of the horse, if not innervated by an intermediate branch, is probably innervated by the medial branch of the dorsal spinal nerve.<sup>17</sup>

The articular process joints of the thoracolumbar vertebrae of horses, dogs, and human beings have dual segmental innervation supplied by the medial branch of the dorsal ramus,<sup>20,22,32,40,41</sup> this has been demonstrated in the cervical vertebrae of horses except at cervical vertebrae C2-C3.<sup>42</sup> In dogs, this dual innervation is provided by small, terminal branches from the medial branch that innervate the caudal aspect of the articular process joint at that level, and small terminal branches that innervate the cranial aspect of the articular process joint of the next caudal vertebrae. In horses, however, this dual innervation is supplied by two separate branches of the medial branch.<sup>22</sup> As the medial branch emerges from the intertransverse space, it divides into 4 distinct branches in the cervical region,<sup>42</sup> and 2 distinct branches in the thoracolumbar region, one of which courses caudodorsally around the process of the articular process joint at the same level to innervate the caudal aspect of the articular process joint, while the second branch continues caudally to innervate the cranial aspect of the articular process joint of the next caudal vertebra.<sup>22</sup>

The interspinous ligament of horses contain dense sensory innervation,<sup>43</sup> which likely arises from the medial branch of the dorsal ramus, as it does in human beings.<sup>35</sup> The density of these sensory nerves in the interspinous ligament between impinging DSPs has been observed to be significantly greater than that between non-impinging DSPs.<sup>44</sup>

### **Neurogenic atrophy of the epaxial muscles**

A recent study reported the occurrence of focal atrophy of the epaxial musculature of horses as a complication of transection of the interspinous ligament for treatment of horses for impinging DSPs.<sup>1</sup> Though the appearance of the affected horses was suggestive of atrophy of the *m. longissimus dorsi*, the authors failed to determine which epaxial muscles had atrophied. Based on the reported apparent lack of effect of neurogenic atrophy of a short segment of the epaxial musculature on athletic function, we assume that the atrophy was localised to the superficial epaxial muscles (e.g. *m. trapezius thoracalis* and *m. latissimus dorsi*) and perhaps to the deeper lying *m. longissimus dorsi*. The *mm. multifidi*, which are found in the deepest portion of the epaxial musculature, plays an important role in stabilising the vertebral column of human beings

and horses.<sup>45–47</sup> Humans who have incurred atrophy of the *Mm. multifidi* are reported to experience reduced athletic performance.<sup>48</sup> In a study by Sihvonen *et al.* examining the outcome of human patients undergoing laminectomy of one or more lumbar vertebrae, 39.9% of patients experienced post-operative muscular atrophy and 11.7% of those suffered loss of strength, coordination, and function, characterised by an inability to perform normal working movements and to walk at normal speed.<sup>48</sup> Those authors theorised muscular atrophy was due to damage to the medial branch of the dorsal ramus of the spinal nerve as it coursed along the dorsal surface of the transverse processes. It must be noted that horses may have better ways of compensating for the loss of function in a segment of muscle in comparison to human beings.

Transection of the medial branch of the dorsal ramus of a spinal nerve at the level of the transverse process, denervates a substantial portion of the deep, stabilising muscles of the back, such as the *mm. multifidi*, causing these muscles to atrophy within a few days.<sup>49,50</sup> When performing laminectomies of the thoracolumbar vertebrae of human patients, approaches lateral to the lateral end of the transverse process should be avoided to prevent transection of the medial branch of the dorsal ramus of the spinal nerve and subsequent neurogenic atrophy of the *mm. multifidi* are avoided.<sup>51</sup>

As demonstrated in anatomical studies of cats, human beings, and more recently horses, the intermediate branch of the dorsal ramus of the lumbar spinal nerves consistently innervates the *m. longissimus dorsi*,<sup>22,33–35,39</sup> and we believe this to be the nerve transected in the horses that developed focal atrophy of the epaxial musculature reported by Derham *et al.* (2019)<sup>1</sup>. In that study, eight of 159 horses (5%) developed atrophy of the epaxial musculature after undergoing desmotomy of one or more interspinous ligaments. The reason for this low percentage of affected horses may be because the intermediate branch of the dorsal ramus of the thoracolumbar spinal nerves of most horses arises distally from the lateral branch of the dorsal ramus, making it unlikely to be subjected to trauma during transection of the interspinous ligament. The origin of the intermediate branch observed in human beings varies,<sup>33,35</sup> and the same may be true of horses. More anatomical studies are required to describe the presence, origin, and course of the intermediate branch of the dorsal ramus of the thoracolumbar spinal nerves of horses.

### **Local analgesia of the thoracolumbar region**

Diagnostic analgesia plays an important role in veterinary practice.<sup>52</sup> Thorough knowledge of the neuroanatomy of the equine limbs is considered mandatory for correct placement and



evaluation of such nerve blocks. Though perineural nerve blocks of limbs play a major role in localising pain causing lameness of horses,<sup>52-55</sup> the lack of detailed knowledge of the neural anatomy of the thoracolumbar region has resulted in the role of local anaesthesia in localising pain in the equine back being poorly understood. The performance of some horses with back pain improves markedly, after a local anaesthetic is instilled into the suspected site of back pain, whereas the performance of others with back pain fails to improve, leading to the hypothesis that horses, like human beings, have different thresholds of pain,<sup>4</sup> or the deposition of local anaesthetic does not sufficiently block the nerve that is innervating the cause of pain.

Using diagnostic analgesia to confirm or eliminate back pain as the cause of poor performance of horses has been strongly advocated by some clinicians,<sup>16,56,57</sup> but a standardised protocol has not been established. Some studies describe administering local anaesthetic adjacent to the impinging DSPs, whereas others describe administering the local anaesthetic into or adjacent to the interspinous spaces.<sup>12,16,57-59</sup> Some studies describe administering local anaesthetic on only one side of the back, whereas others advocate infiltrating local anaesthetic near to lesions detected during radiographic examination of the back. Volumes of local anaesthetic used and time before testing after injection vary among studies.<sup>9,12,13,16,57-59</sup>

The wide variation in technique may explain why some horses suffering from poor performance or an abnormal gait because of back pain, improve to local anaesthesia of the back while others do not. Caution should be observed when evaluating the effects of a local anaesthetic administered at sites where the neural pathways are poorly understood. Injecting a local anaesthetic on both sides of the interspinous space produces a significant increase in range-of-motion in dorsoventral flexion and extension at all measured segments in horses clinically free of back pain, perhaps because analgesia of the injected areas alters proprioception.<sup>58,60</sup>

In some instances, local anaesthesia of the articular process joints in the thoracolumbar region of the back can be helpful in determining if an abnormality causing signs of back pain, such as osteoarthritis of the articular process joints is present.<sup>3</sup> Intra-articular anaesthesia of the articular process joints however can lead to diffusion of local anaesthetic to affect the nerves of the dorsal and ventral rami.<sup>61</sup> Studies describing injecting the articular process joints of horses with local anaesthetic using ultrasound-guidance, show that the anaesthetic diffuses far beyond the joint.<sup>62,63</sup> One study demonstrated repeatable landmarks for injecting the medial branch of the *ramus dorsalis* of the lumbar spinal nerves of horses at a point far enough removed from the

intervertebral foramen (*foramen intervertebrale*) to avoid the local anaesthetic diffusing to the ventral ramus.

A recent retrospective study by Prisk and García-López<sup>14</sup> describing the outcome of 56 horses that had undergone desmotomy of the interspinous ligament as treatment for back pain caused by impinging DSPs, found that 91% (51/56) returned to performance but disappointingly only 52% (27/51) returned to a level of performance equal to or greater than that before treatment, presumably because these horses still experienced back pain. That one-third of the horses in that study continued to suffer from persistent back pain after surgery is in stark contrast to the success of desmotomy of the interspinous ligament as a treatment for poor performance caused by impinging DSPs, reported in previous studies.<sup>1,14,15</sup> The horses in the study by Prisk and García-López<sup>14</sup> may have continued to suffer from back pain after desmotomy because of concurrent abnormalities of the back, such as osteoarthritis of the thoracolumbar process joints, which is reported to be present in 25% of horses with impinging DSPs,<sup>3</sup> or a soft-tissue injury of the thoracolumbar region, which is reported to be present in 38% of horses with back pain.<sup>4</sup> The corticosteroid injected into the musculature of the back to treat the horses in this study for back pain and to confirm that back pain was the cause of poor performance may have diffused to sites other than the site of impingement, perhaps resulting in the erroneous observation that impinging DSPs were the sole cause of back pain.

## **Conclusion**

Descriptive anatomical studies of the spinal nerves of human beings, cats, and dogs have shown that the presence and course of the intermediate branch of the dorsal ramus of the thoracolumbar spinal nerves varies among spinal nerves of the thoracic, mid-thoracic, and lumbar regions. The intermediate branch of the dorsal ramus of the thoracolumbar spinal nerves of the horse also may vary in its existence, origin, and course, and this variability is likely the reason for the inconsistent development of neurogenic atrophy of the epaxial musculature in the cohort of horses reported by Derham *et al.* (2019)<sup>1</sup>. We advise that care should be taken to avoid inserting the tip of the scissors into the contralateral epaxial musculature when inserting scissors to transect the interspinous ligament at an angle more obtuse than that described by Coomer *et al.* (2012)<sup>15</sup>. We also recommend that further studies be carried out to assess the effectiveness of direct

injection of the interspinous ligament with local anaesthetic in horses thought to be suffering from pain due to impinging DSP. The neuroanatomy of the equine thoracolumbar vertebral column of horses should be studied thoroughly, and the sites to which injections of local anaesthetic or a corticosteroid injected into the epaxial musculature, interspinous space, or intra-articular process joint diffuse should be evaluated.

#### **Authors' declarations of interest**

No competing interests have been declared.

#### **Ethical animal research**

Not applicable.

#### **Informed consent**

Not applicable.

#### **Data accessibility statement**

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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All authors contributed to the writing, editing, and revision of this manuscript. All authors approved the final version of the manuscript.

#### **Figure Legend:**

**Figure 1 a, b:** 6 weeks post-operative image of a horse following desmotomy of the interspinous ligament that developed focal muscle atrophy of the epaxial muscles on the contralateral side to the surgical site (a). Close-up of the focal region of muscle atrophy is encircled (b)

**Figure 2:** Diagram demonstrating the anatomy of the spinal nerve path in the thoracolumbar region. (Reproduced from 'Miller's Anatomy of the Dog' Eds: H.E. Evans and A. DeLahunta<sup>30</sup> with permission from Elsevier.)<sup>1</sup>

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<sup>1</sup> This diagram was published in Miller's Anatomy of the Dog, Evans HE, de Lahunta A: Spinal Nerves page 612 Elsevier (2012)

**Figure 3:** Schematic diagram of the divisions of a typical spinal nerve. (Reproduced from ‘Miller’s Anatomy of the Dog’ Eds: H.E. Evans and A. DeLahunta<sup>30</sup> with permission from Elsevier.)<sup>2</sup>

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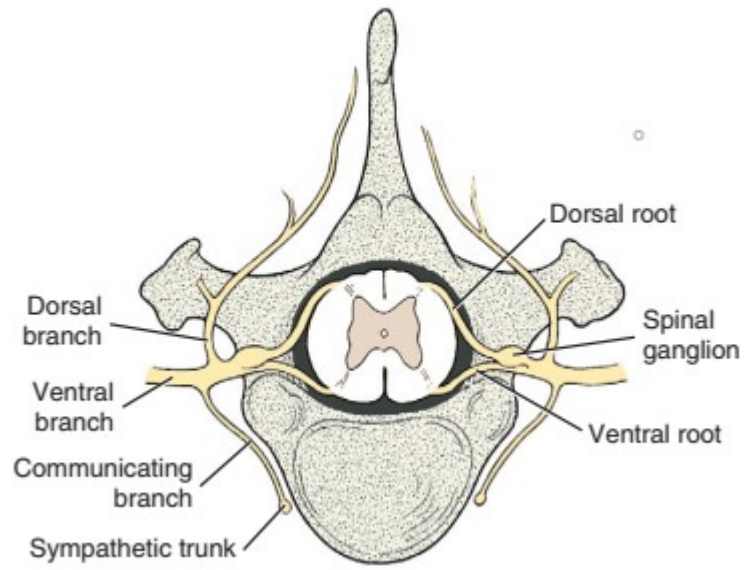
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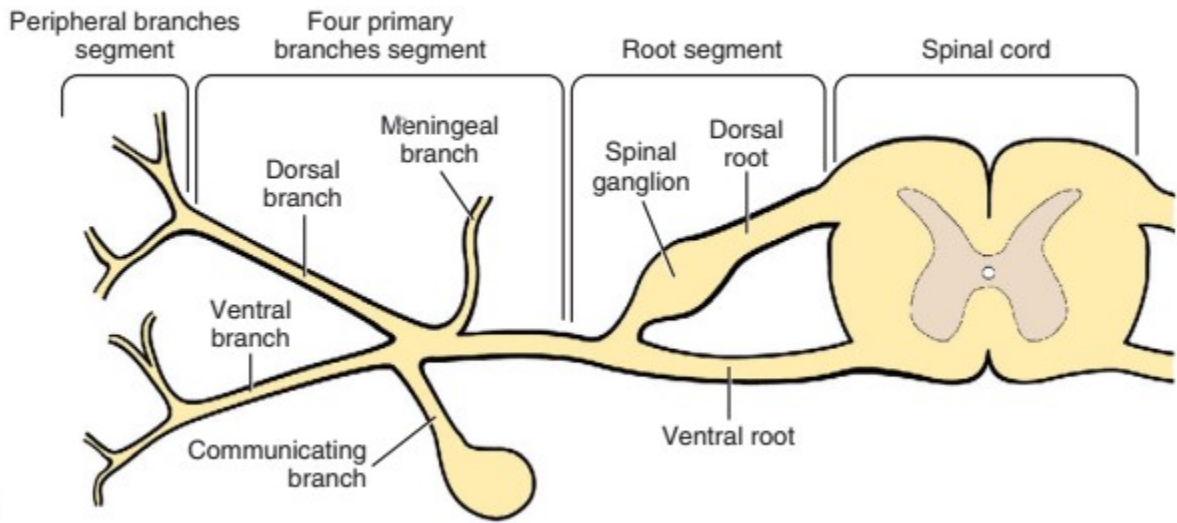
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