An Anatomical Analysis of the Dorsoventral Relationship between the Sacral Plexus and the Pudendal Nerve in Man by Use of Computer Aided Three-Dimensional Reconstruction

By

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Summary: In order to investigate the dorsoventral relationship between the sacral plexus and the pudendal nerve in man, morphological examination was performed on one pelvic half of a male cadaver. The second and third spinal nerves were removed en bloc and sectioned serially for three-dimensional reconstruction imaging of the selected sections. Comparison of the sequential images revealed that the root of the pudendal nerve is first situated ventral to the caudal root of the sacral plexus, and that the former and the latter are shifted cranialward and caudalward, respectively, at the point of exit from the second anterior sacral foramen.

Abbreviation

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
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<tr>
<td>Bis</td>
<td>nerve to the short head of the biceps femoris</td>
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<tr>
<td>Br (ex. Br1)</td>
<td>branch of the spinal nerve</td>
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<td>Cfp</td>
<td>posterior femoral cutaneous nerve</td>
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<td>Co</td>
<td>nerve to the coccygeus</td>
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<td>D</td>
<td>dorsal primary rami</td>
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<td>Fx</td>
<td>femoral flexor nerve</td>
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<tr>
<td>Gi</td>
<td>inferior gluteal nerve</td>
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<tr>
<td>Gs</td>
<td>superior gluteal nerve</td>
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<tr>
<td>La</td>
<td>nerve to the levator ani</td>
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<tr>
<td>Oi</td>
<td>nerve to the obturator internus</td>
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<tr>
<td>Per</td>
<td>common peroneal nerve</td>
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<tr>
<td>Pud</td>
<td>pudendal nerve</td>
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<tr>
<td>Qtf</td>
<td>nerve to the quadratus femoris</td>
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<td>Sx</td>
<td>root of the sacral plexus</td>
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<tr>
<td>Tib</td>
<td>tibial nerve</td>
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The nerves innervating the muscles of the pelvic outlet in man principally arise from the pudendal plexus. Although the pudendal plexus has close connections with the sacral plexus which sends primary nerves to the pelvic limb, the stratificational relationship (Akita et al. 1992a) between the sacral plexus and pudendal plexus in man remains unclear. In previous studies (Akita 1992a, b; Akita et al., 1992b, 1995), minute dissection was performed on Lacertilia (Iguanidae Iguana iguana and Varanus dumerillii), Urodele (Cryptobranchidae Megalobatrachus japonicus), Aves (Gallus gallus domesticus) and mammals (Macaca mulatta) in order to determine the detailed relationships between the innervation of the pelvic limb and the pelvic outlet muscles. These findings revealed that the origins of the pudendal nerves were situated ventrocaudal to the sacral plexus.

The present study was undertaken to confirm the dorsoventral relationship between the sacral plexus and the pudendal nerve in man by using computer aided three-dimensional reconstruction imaging of serial sections of the second sacral nerve.

Materials and Methods

The right pelvic half of a male cadaver, typically fixed and preserved for dissection practice (10% formalin and 30% alcohol), was used for this study. In this specimen, 24 presacral vertebrae (C7, Th12, L5) were found. In the dissection procedure, in order to obtain detailed data of the segmental composition of the sacral and pudendal plexuses, the bony elements were completely removed. After identification of the main branches of both plexuses, the plexuses were removed for detailed examination.

The second and third sacral spinal nerves (Fig. 1) were embedded en bloc in paraffin, and then serially sectioned into 10μm thick sections. The sections were stained with hematoxylin-eosin. All sections were photographed and traced; the branches of each...
section were then identified. In order to obtain the reconstruction image, sections at about every 1000 μm were selected and scanned by a Sharp JX-220 color image scanner on a NEC PC-9801RX microcomputer and an Astrodesign VP-1125 video CG system. Sequences of the selected 36 sections were reconstructed using Ratoc System Engineering TRI/P software. Compiled images were photographed directly from a Sony PVM-1442Q color video monitor.

Results

Segmental composition of the nerves from the sacral and pudendal plexuses

In the examination of the ventral primary rami of L4 to S4, the sacral plexus was found to extend between L4 and S2, and the pudendal plexus between S2 and S4.

The superior gluteal nerve arose from the dorsal surface of L4, L5 and S1 as their proximalmost dorsal branches. The roots of the inferior gluteal nerve arose from the dorsal surfaces of the union of L4 and L5 and S1. The nerves to the piriformis arose from the caudalmost roots of the superior and inferior gluteal nerves. The common peroneal nerve was formed by the union of the dorsal trunks of L4 and L5 and the dorsal trunk of S1. The ventral divisions of L4 to S2 united to form the tibial nerve. Muscular branches to the posterior muscles of the thigh [the femoral flexor nerve (Eisler, 1891, 1892)] arose from the ventral surface of the tibial nerve. The nerve to the quadratus femoris arose from the ventral surfaces of the union of L4 and L5, and S1. The nerve to the obturator internus, which arose from the ventral surfaces of S1 and S2, was situated more caudal than the quadratus femoris nerve.

The pudendal nerve was formed by S2, S3 and S4; the dorsal nerve of penis arose from S2 and S3 as a ventral branch of the pudendal nerve. The perineal nerve and the inferior rectal nerve did not appear to be divided. The nerves to the levator ani arose from the ventral surfaces of S3 and S4, and those to the coccygeus arose from the dorsal surfaces of S2 and S3. The pelvic splanchnic nerve arose as the ventralmost nerve of S3. The roots of the posterior femoral cutaneous nerve arose from the dorsal roots of the inferior gluteal nerve, the common peroneal nerve and the tibial nerve.

Serial sections of the trunk of the second sacral nerve

As the second sacral nerve is involved in both the sacral and pudendal plexuses, this nerve was chosen for the three-dimensional analysis. Figure 2 shows sequential sections of the second sacral nerve. The points of sectioning are indicated in Figure 1.

The nerve trunk was divided into a few branches (Fig. 2a). In this section, the dorsal primary ramus was not divided. The nerve to the coccygeus arose from the caudal surface of the branch designated here as number 5 (Br5). The dorsal primary rami arose from the dorsal region of Br5 (Fig. 2b). After the primary dorsal ramus was given off, the nerve trunk was composed of four large branches and two small branches (Fig. 2c). Br1 and Br3 were united forming Br1 + 3, Br1 + 3, Br2 and Br4 moved caudalward, and Br4 shifted dorsalward. Br6 as well arose from the dorsal region of Br5. As seen in Figure 2d, Br1 + 3, Br2 and Br4 became divided into small branches and shifted more caudalward. Br6 ran craniodorsalward, and was cranio-caudally divided into two branches. The nerves to the levator ani arose from S3 and ran on the ventral surfaces of the branches of S2; Br5 was then divided into three branches (Fig. 2e). The branches from S3 ran cranialward and fused with the branches from S2.

Three-dimensional reconstruction (Fig. 3)

In order to elucidate the spatial course of the main branches of the second spinal nerve, three-dimensional reconstruction images of the nerve were obtained. Sections from approximately every 1000 μm interval were selected from the union of the ventral and dorsal roots of the spinal nerve. The branches are colored according to their final destinations.

The dorsal primary rami (blue) branched off dorsalward. The pudendal nerve (yellow) arose from the ventral surface of the main trunk of the second spinal nerve, and ran caudalward. Br5 (red) gave off some branches, ran slightly cranialward, and formed the caudal root of the sacral plexus. Br6 (sky blue) ran craniodorsalward and became branches of the posterior femoral cutaneous nerve. At the point of exit from the anterior sacral foramen (Fig. 3d), the pudendal nerve (yellow) was situated caudal to the sacral plexus (red).

Discussion

The sacral plexus and the pudendal plexus are generally regarded as the nerve complexes which innervate the muscles of the primary inferior limb and the muscles of the pelvic outlet, respectively. Although numerous reports have discussed the segmental composition of the sacral and pudendal plexuses in man (e.g., Eisler 1891, 1892; Bardeen and Elting 1901a,b; Nakanishi 1967a,b; Takahashi 1980; Sato 1980), few have included a description of the dorsoventral relationship between these two plexuses. In previous comparative anatomical studies (Akita 1992a,b; Akita et al. 1992b, 1995), we reported that
the pudendal nerve (or the nerve which is homologous to the pudendal nerve) is situated caudoventral within the sacral plexus. Akita et al. (1992a) proposed that the stratificational relationship within the limb plexus is one of the most fundamental features in limb formation, and this relationship is common to each species. Kida (1990) speculated that nerve branching pattern is, at least, well associated with a certain relationship between innervation and muscle phylogeny on the basis of findings obtained by typological anatomy. And Kida and Ishida (1988) called the relationship “corrected nerve-muscle specificity”. Tani et al. (1994) reported that the ramification pattern of the intercostal nerve appears to correspond with the arrangement of motoneuron pool in the ventral horn of the thoracic and lumbar spinal cord. Therefore, the dorsoventral ramification patterns of the spinal nerves is one of the most fundamental elements in trunk and limb formation.

In this study, the positional relationships between the roots of the sacral plexus and the pudendal nerve could be schematically demonstrated (Fig. 4). Based on the present three-dimensional reconstruction (Fig. 4a), the root of the pudendal nerve (yellow in Fig. 3) is first situated ventral to the caudal root of the sacral plexus (red in Fig. 3). Gradually, the former shifts dorsocaudalward and the latter shifts ventrocranialward (Fig. 4b). The roots of the sacral plexus and the pudendal nerve shifts cranialward and caudalward, respectively, at the point of exit from the second anterior sacral foramen (Fig. 4c). Therefore, both roots changed their relative positions within the trunk of the second spinal nerve in the sacrum. The dorsoventral relationship of these two roots is similar in various species (Akita 1992a,b; Akita et al. 1992b, 1995).

Kida (1987) performed a minute investigation of the third and fourth cervical nerves (C3 and C4) using a macroscopical fiber analysis method. He reported that the cutaneous nerves in C3 and C4 display at least two kinds of torsion before and after the cervical plexus, and that it is necessary to investigate the whole length of the spinal nerve in order to explain the true dorsoventral relationships among the branches of a spinal nerve. Although the torsions of the nerve fibers of the second sacral nerve remain unclear, the positional relationships of the main branches can be revealed easily by using three-dimensional reconstruction of serial sections.

Figure 5 shows the schematic representation of

![Diagram showing the shift of the main branches of the second spinal nerve.](image)

Fig. 4. Schematic representation of the shift of the main branches of the second spinal nerve. a) at first the main branches are dorsoventrally arranged, b) the root of the pudendal nerve shifts caudodorsally, and the root of the sacral plexus shifts cranioventrally, c) at the point of exit from the anterior sacral foramen, both roots are craniocaudally arranged.

![Diagram showing the stratificational relationships among the branches of the sacral and pudendal plexuses.](image)

Fig. 5. Schematic representation of the stratificational relationships among the branches of the sacral and pudendal plexuses in this specimen (male, right) (ventral aspect).
the stratificational relationship of the sacral and pudendal plexuses of the present specimen. The stratificational relationship of the dorsal division of the sacral plexus was proposed in Akita et al. (1992a). Sato (1980) proposed the positional relationship among the branches of the pudendal plexus: 1) the nerves to the levator ani, ventral, 2) the pudendal nerve, middle, and 3) the nerves to the coccygeus, dorsal. In the present specimen, the nerve to the coccygeus in S2 arose from the caudal surface of Br5 (Fig. 2a). In this section (Fig. 2a) the dorsal primary ramus was not yet divided. Thus, the nerve to the coccygeus in S2 might be regarded as the dorsalmost branch of the ventral primary ramus.

Although in man there are various patterns of segmental composition (e.g. Bardeen and Elting 1901a,b; Sato 1980), based on the present findings, it could be confirmed that the stratificational pattern is common in man as in all species (Akita 1992a,b; Akita et al. 1992b, 1995).

Acknowledgment

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References


Explanation of Figures
Plate I

Fig. 1. Dorsal aspect of a part of the second and third sacral nerves. Lines a–e correspond to the sections in Figures 2 and 3.
Fig. 2. Sections of the trunk of the second sacral nerve as indicated in Figure 1. a) the trunk is divided into a few branches (Br1 – 5) (x75), b) the dorsal primary rami arises from the dorsal portion of Br5 (x160), c) after the dorsal primary rami is given off, Br6 arises from the dorsal portion of Br5, and Br1 and Br3 fuse (x75), d) Br1 + 3, Br2 and Br4 are divided into small branches, and run caudodorsalward (x75), e) the branches from S2 adjoin the branches from S3 (x37.5).
Fig. 3. Three-dimensional reconstruction images of selected serial sections of the second sacral nerve. The directions of the figures are correspondent to Figure 2. These figures (Figs. 3a–f) show the distal sectioning aspects of the nerve approximately every 5 mm from the beginning. The branches are colored according to the final destinations: yellow, root of the pudendal nerve; red, root of the sacral plexus; blue, dorsal primary rami; sky blue, root of the posterior femoral cutaneous nerve; green, nerve to the coccygeus.