[Diagnostics]

Regional Correspondence Between the Ventral Portion of the Lumbar Intervertebral Disc and the Groin Mediated by a Spinal Reflex: A Possible Basis of Discogenic Referred Pain

Takahashi, Yuzuru MD*; Sato, Akio MD†; Nakamura, Shin-Ichiro MD*; Suseki, Kaoru MD*; Takahashi, Kazuhisa MD*

Author Information

From the *Department of Orthopaedic Surgery, School of Medicine, Chiba University, Chiba, and the †Department of Autonomic Nervous System, Tokyo Metropolitan Institute of Gynecology, Tokyo, Japan.

Acknowledgment date: July 10, 1997.

First revision date: October 9, 1997.

Acceptance date: January 22, 1998.

Device status category: 1.

Address reprint requests to: Yuzuru Takahashi, MD; Department of Orthopaedic Surgery, School of Medicine; Chiba University; 1-8-1 Inohana, Chuo-ku; Chiba 260-8677; Japan; E-mail: BXM06740@nifty.ne.jp.

Abstract

Study Design. Lumbar peripheral nerves were examined to determine whether they were responsive to electrical stimulation of the ventral portion of the lumbar disc in anesthetized rats.

Objectives. To confirm by electrophysiologic means the neural correspondence between the ventral portion of the lumbar disc and the groin.

Summary of Background Data. Patients with a degenerated lumbar disc occasionally report groin pain. However, its pathogenesis has not been investigated. The authors of the current study found that chemical stimulation of the ventral portion of rat lumbar disc caused cutaneous plasma extravasation in the groin, and thereby hypothesize the neural relation between the lumbar disc and the groin.

Methods. The ventral portion of rat L5-L6 disc was electrically stimulated, and the elicited action potentials were recorded from the iliohypogastric, genitofemoral, lateral femoral cutaneous, sural, and sciatic nerves. The roles of the lumbar sympathetic trunks and spinal cord in the generation of the action potentials were examined.

Results. Action potentials were elicited principally in the genitofemoral nerve; the action potentials of the genitofemoral nerve were not influenced by transection of the cervical spinal cord, whereas they disappeared immediately after death, which indicates that they are induced by a spinal reflex. The action potentials were reduced considerably after destruction of the lumbar sympathetic trunks, suggesting that they comprise an afferent path of the reflex.

Conclusions. The ventral portion of the lumbar disc had spatial relation to the groin area via a spinal reflex. Such a relation suggests that a disorder in the ventral portion of the lumbar disc may be a possible source of groin referred pain.

Pain originating from an abnormal lumbar disc (discogenic pain) is not localized in the low back area over the causative disc, as has been demonstrated by the location of provoked pain in discography, even if spinal nerve roots are not involved. Discogenic pain usually is referred throughout a rather wide area down to the buttock and hip and occasionally to the thigh. Localization of discogenic pain does not seem to be related to the level of the causative disc, and, therefore, few studies on discogenic pain have been undertaken.[13,16,28] Hence, clinicians who treat patients with low back pain have paid little attention to the diagnostic value of the location of discogenic pain.

Patients who have degenerated lumbar discs in lower segments (L4-L5 or L5-S1) occasionally report groin pain, though few clinical reports confirm this.[11,16,28,29] Furthermore, sometimes patients who undergo percutaneous scopic disc surgery performed with the patient under local cutaneous anesthesia report groin pain when the lateral side of the disc is pierced by a probe. Pain in the buttock and lower extremities in cases of lower disc disorders can be regarded as radicular or to be of referred origin. In contrast, groin pain can not be explained by radicular

pain mechanisms or by conventional theories for segmental referred pain that have been elucidated through basic experiments,[2,5,8,20] because the spinal segments of the groin are L1 and L2.[26] Even proponents of the existence of discogenic referred pain believe that it principally follows a dermatomal- or myotomal-like pattern similar to that of radicular pain; this belief is based on the fact that the lumbar disc is innervated segmentally by the sinuvertebral nerves.[19,21] Accordingly, groin pain seems to be the result of another pain mechanism.

Previously, the authors of the current study reported that topical application of capsaicin, a specific stimulant of unmyelinated sensory fibers, to the ventral portion of the rat L5-L6 disc causes plasma extravasation in the groin area innervated by the genitofemoral nerve.[25,27] Based on this observation, the authors speculated that the ventral portion of the lumbar disc corresponds to the groin via dichotomizing sensory fibers that project axons in the genitofemoral nerve and in the nerve to the psoas muscle.[25,27] Using that methodology, however, it is difficult to elucidate the nerve mechanisms connecting the lumbar disc and the groin. The current study was undertaken to clarify the nerve mechanisms using an electrophysiologic technique.

Methods

Experimental Set-Up. Experiments were performed using male adult Wistar rats weighing 200-350 g. Rats were anesthetized with intraperitoneal injection pentobarbital (50 mg/kg), immobilized with gallamine triethodide (20 mg/kg, i.v.), and ventilated artificially via a tracheal cannula. The jugular vein was catheterized to allow for intravenous administration of supplemental anesthetics and other drugs. Additional pentobarbital and gallamine triethodide were injected via the catheter, when necessary. The rectal temperature was maintained at 37.0-38.0°C using an automatically regulated heating pad and lamp. Rats were placed in the supine position, and an abdominal midsagittal incision was made.

The ventral surface of the L5-L6 disc was exposed between the left psoas muscle and the ventral longitudinal ligament by using the transabdominal approach. Approximately 1 mm of the tip of an enameled wire electrode with a diameter of 0.1 mm was bent acutely, and the bent portion was inserted into a 26-gauge needle. With the wire electrode inserted, the needle was introduced into the L5-L6 disc 1 mm left of the midsagittal line. Then the needle was drawn back, leaving the bent part of the wire electrode in the disc, such that the cut end was positioned at the ventral surface of the disc (Figure 1). A surface electrode attached to the right belly was used as the reference electrode (anode) and was grounded. Single, square, pulse stimuli of 5-20 V were delivered monopolarly to the disc every second by using a digital electrical stimulator (SEN-7130, Nihon Koden, Tokyo, Japan) via an isolator. Preliminary experiments revealed that when stimulation of 20 V did not elicit action potentials in the genitofemoral nerve, stimulation with higher voltages up to 100 V also did not elicit action potentials in the genitofemoral nerve or in other nerves.
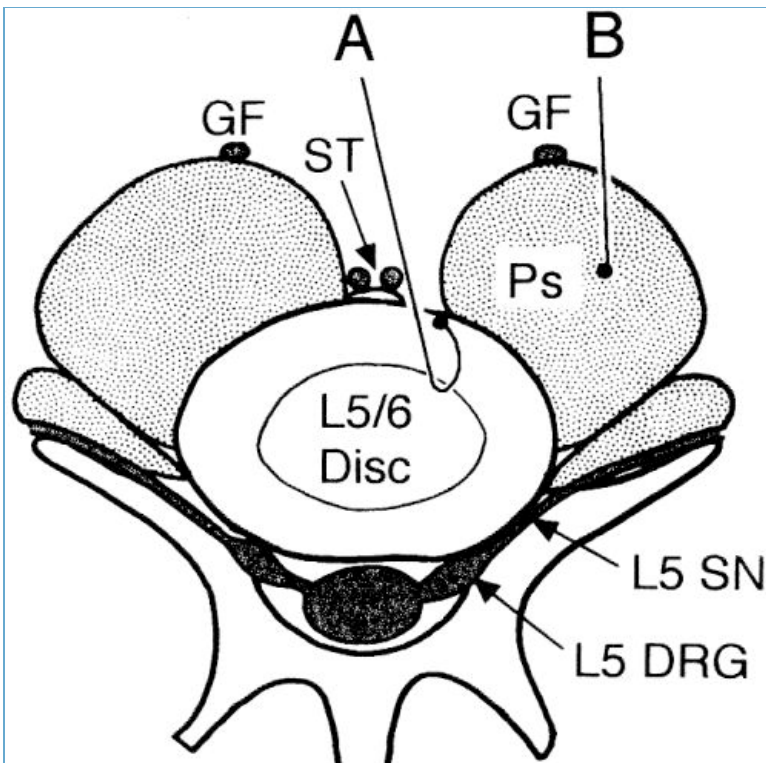

Figure 1. Setting for stimulation electrodes. A = site of electrode placement for stimulation of the L5-L6 disc; B= site of electrode placement for stimulation of the left psoas muscle; GF = genitofemoral nerve; ST = sympathetic trunks; Ps = psoas muscle; L5 SN = L5 spinal nerve; L5 DRG= L5 dorsal root ganglion.

Peripheral nerves originating from the spinal nerves of T13 through L6 segments were isolated for recording. Rats were divided into two groups. For one group, (n = 15), the genitofemoral, iliohypogastric, and lateral femoral cutaneous nerves were exposed in the retroperitoneal space, whereas the saphenous and sciatic nerves were exposed in the mid-thigh. These nerves are branches of the ventral rami of the spinal nerves. For the other group of rats (n= 5), after the wire electrode was placed in the disc, the rat was turned over to the prone position, and a midsagittal incision was made in the back. The cutaneous nerves of the dorsal rami of the left spinal nerves L1 through L6 were exposed between the dorsal fascia and the skin.

Nerves were cut, and the proximal end was draped on a pair of platinum iridium electrodes and covered with warm paraffin oil. Action potentials were recorded using a preamplifier (S-0476, Nihon Koden), and 20 trials of responses were averaged by a computer (ATAC 3700, Nihon Koden). The averaged responses were displayed on a screen, stored on floppy disks, and recorded on an XY plotter(7400A, Hewlett Packard, Palo Alto, CA).

Experiments. In 15 rats, the distribution of responsive nerves was examined from the genitofemoral nerve (spinal segment, L2; n = 15; in all rats), iliohypogastric nerve (T13 and L1, n = 7), lateral femoral cutaneous nerve (L2, n = 10), saphenous nerve (L3, n = 10), and sciatic nerve(L4-L6, n = 12). The combination of the nerves examined varied among rats. Action potentials were recorded initially from the genitofemoral nerve and then from the other nerves. The magnitude of the response of action potentials of the iliohypogastric, lateral femoral cutaneous, saphenous, and sciatic nerves was expressed as the percent amplitude compared with that of the genitofemoral nerve, which was defined as 100%. In some rats, the sciatic nerve bifurcated to the common peroneal nerve and the tibial nerve in the mid-thigh. In these rats, each nerve was examined, and if action potentials were elicited in either branch, the sciatic nerve was determined to be responsive. In five other rats, the distribution of responsive nerves was examined from the dorsal cutaneous nerves of L1 to L6. In this experiment the authors did not make a reference recording from the genitofernoral nerve because it was difficult to do so with the rat in the prone position.

To clarify whether the action potentials of the genitofemoral nerve were caused by central or peripheral mechanisms, they were recorded before and 10 minutes after transection of the cervical spinal cord at C5-C6 (n = 3) and before and 10 minutes after the rat was killed by administering an overdose of pentobarbital intravenously (n = 3).

To detect the afferent pathways of the action potentials of the genitofemoral nerve, their changes were observed before and after the transection of the bilateral paravertebral sympathetic trunks at L4; these trunks then were cauterized electrically at L3 through L5 (n = 8). The upper limit of cauterization was determined to be L3 so as not to damage other nerves located at L2.

It previously has been theorized that sensory fibers to the L5-L6 disc are derived from the nerves in the psoas muscle, based on the observation that transection of the bilateral paravertebral sympathetic trunks did not affect groin plasma extravasation.[25,27] To confirm this theory, the cut end of the same enameled wire was inserted into the left psoas muscle at L5-L6 (Figure 1), and the action potentials elicited by electrical stimulation of the muscle were compared with those elicited by electrical stimulation of the L5-L6 disc within the same rat(n = 6).

Capsaicin applied to the L5-L6 disc increases the vascular permeability in the groin skin.[25,27] To examine whether the electrical stimulation of the disc causes a vascular permeability increase in the skin, skin color changes were observed in rats that were pretreated with intravenous injection of Evans blue (50 mg/kg, Sigma Chemical Co., St. Louis, MO; n = 3).

Statistical Analysis. Comparison of the amplitude of action potential of the genitofemoral nerve and the other nerves and changes in the action potentials of the genitofemoral nerve for the determination of their neural parhways were analyzed by paired *t* test. *P* < 0.05 was used as the minimum level of significance.

Results

An action potential with a latency of 4 msec or bimodal action potentials with latencies of 4 and 8 msec were elicited in the genitofemoral nerve in 14 of 15 rats. However, the iliohypogastric, lateral femoral cutaneous, saphenous, and dorsal cutaneous nerves of L1-L4 and L6 were not responsive. In 7 of 12 rats in which the sciatic nerve was examined, action potentials with latencies of 3-4 msec were elicited; however, their amplitudes were significantly lower than those of the genitofemoral nerve. One L5 dorsal cutaneous nerve showed a small action potential (Table 1, Figure 2).

Nerves		No.	AP(+)	Comparative Size of AP
Nerves of the ventral ramus (n = 15)				
genitofemoral	(L2)	15	14	—
iliohypogastric	(T13, L1)	7	0	0%*
lateral femoral cutaneous	(L2)	10	0	0%*
saphenous	(L3)	10	0	0%*
sciatic	(L4–L6)	12	7	28.5 ± 33.2%*
Nerves of the dorsal ramus (n = 5)				
dorsal cutaneous	L1	5	0	—
	L2	5	0	—
	L3	5	0	—
	L4	5	0	—
	L5	5	1	—
	L6	5	0	—

No. = number of rats examined; AP(+) = number of rats in which action potential(s) were elicited in the respective nerve; comparative size of AP = the percentage of the amplitude of action potentials compared with that of the genitofemoral nerve as 100%, expressed as mean ± S.D.
* significantly low ($P < 0.01$).

Table 1 Distribution of Nerves in Which Action Potentials Were Elicited by Electrical Stimulation of the L5-L6 Disc
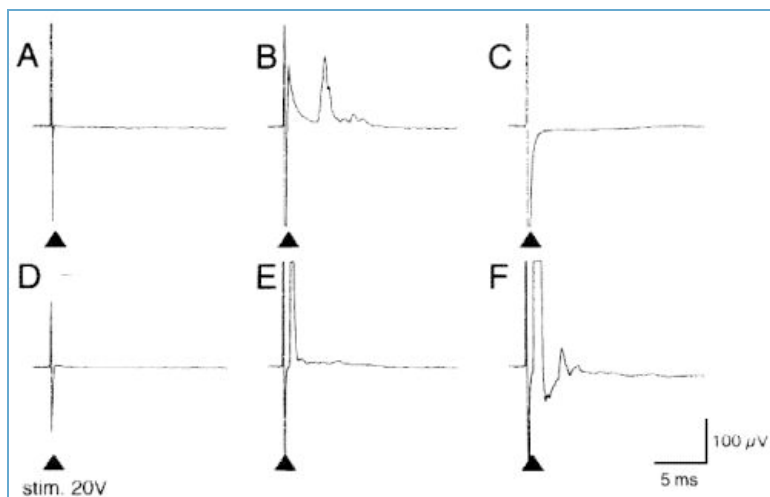

Figure 2. Specimen records of action potentials from peripheral nerves of the ventral rami T13 through L6 elicited by electrical stimulation of the L5-L6 disc. A = iliohypogastric nerve (T13, L1); B = genitofemoral nerve (L2); C = lateral femoral cutaneous nerve (L2); D = saphenous nerve (L3); E = peroneal nerve (L4, L5); F = tibial nerve (L5, L6). Waves over electrical stimulation ([black up pointing small triangle]) represent artifact potentials. An action potential with a latency of 4 msec is elicited in the genitofemoral nerve. A small action potential with a latency of 3 ms is shown in the tibial nerve.

The amplitude of action potentials of the genitofemoral nerve was reduced to 95.4 ± 21.2% (mean ± SD), which was not a significant reduction, 10 minutes after the transection of the cervical spinal cord. The action potentials of the genitofemoral nerve were abolished completely after death in all rats (Figure 3).
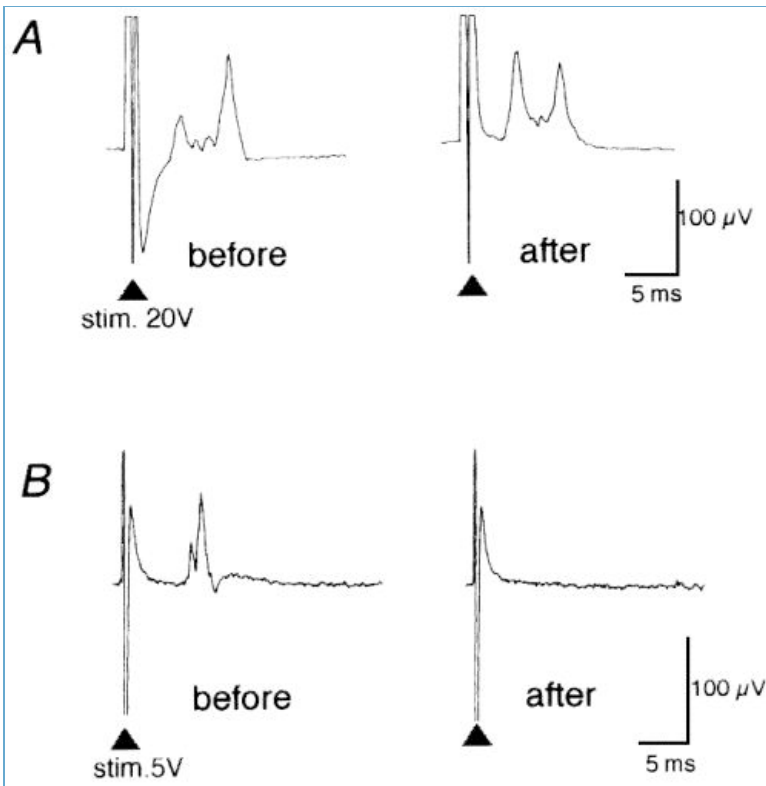
Figure 3. Specimen records of the action potentials in the genitofemoral nerve (**A**) before and 10 minutes after the transection of the cervical spinal cord at C5-C6 and (**B**) before and 10 minutes after the death.

The transection of the bilateral paravertebral sympathetic trunks at L4 reduced the amplitude of action potentials of the genitofemoral nerve, but to a significant degree. After destruction of the bilateral paravertebral sympathetic trunks at L3 through L5, the response was significantly reduced (Figure 4).
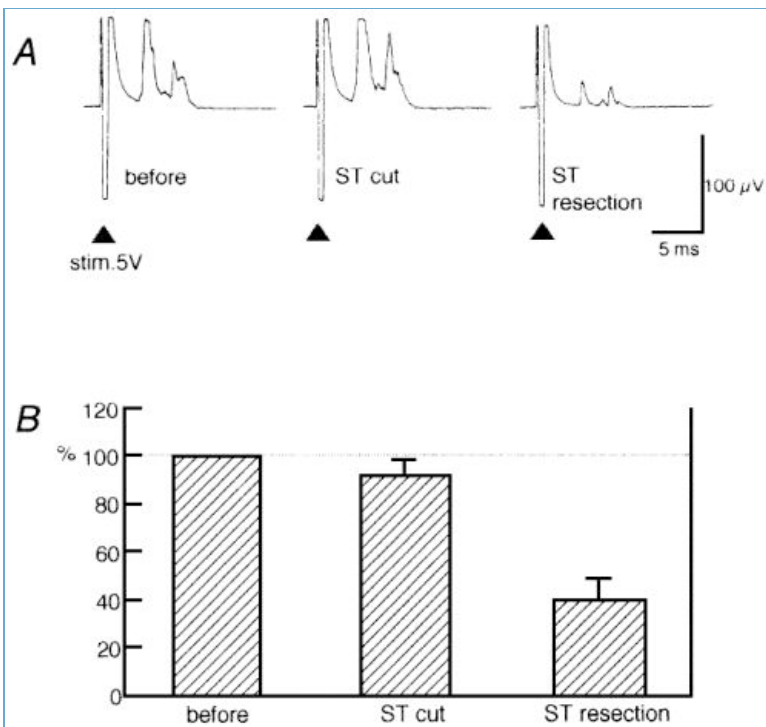
Figure 4. Changes in the action potentials in the genitofemoral nerve elicited by surgical manipulation of the bilateral sympathetic trunks. **A,** Specimen records of potentials obtained before and after transection at L4, which occurred after resection at L3-L5 of the bilateral sympathetic trunks. Bimodal action potentials with latencies of 4 and 8 msec were elicited before surgery. They were unaffected by transection, but markedly reduced after resection. **B,** Changes in the size of action potentials recorded from the genitofemoral nerve before and after transection, which occurred after resection of the bilateral sympathetic trunks, with the potentials before surgery taken to be 100%. Columns and bars represent means± SEM (n = 8).

The genitofemoral nerve showed no response in five rats and only a small action potential in one rat by

electrical stimulation of the left psoas muscle, whereas in the same six rats, the genitofemoral nerve showed action potentials by electrical stimulation of the L5-L6 disc. The percent amplitude of the action potentials elicited by the psoas muscle compared with that elicited by the disc was significantly smaller (1.7 ± 41%).

Plasma extravasation did not appear in the skin after electrical stimulation of the disc in all three Evans bluetreated rats, despite the fact that an action potential was elicited in the genitofemoral nerve.

Discussion

Action Potentials in the Genitofemoral Nerve

The action potentials recorded from the genitofemoral nerve disappeared immediately after the rat was killed, which means that the action potentials were induced by some reflex mechanisms involving the central nervous system, not by peripheral mechanisms such as antidromic propagation of action potentials via dichotomizing primary sensory fibers or by direct activation of the genitofemoral nerve resulting from spread current. The action potentials of the genitofemoral nerve were not influenced by transection of the cervical spinal cord, indicating that the reflex arc is present in the thoracic or lumbar spinal cord. Therefore, hereafter the authors of this report will refer to the response elicited in the genitofemoral nerve as a spinal reflex.

The amplitude of the reflex wave was significantly reduced after the paravertebral sympathetic trunks were destroyed from L3 through L5. Electrical stimulation of the psoas muscle did not induce the reflex. These results indicate that an afferent pathway of the reflex, *i.e.,* sensory fibers to the lumbar disc, is present in the paravertebral sympathetic trunks. This inference also is based on a previously reported histologic study of a human fetus,[9] recent histologic studies on the innervation of the L5-L6 disc in rats,[15,17] and a clinical study on the efficacy of selective infiltration of the L2 spinal nerve in the management of discogenic low back pain.[18] However, pathways other than the sympathetic trunks may exist, because resection of these trunks at L3 through L5 did not abolish the reflex completely. Sensory fibers that are derived from the sympathetic trunks above L3 and that run along the ventral longitudinal ligament may exist. However, the existence of sensory nerves that run via the psoas muscle, as described in the current authors' previous report,[25] are unlikely based on the results of this study.

Regional Correspondence Between the Ventral Portion of the Lumbar Discs and the Groin

Electrical stimulation of the L5-L6 disc induced a spinal reflex principally in the genitofernoral nerve, one of the branches of the L2 spinal nerve. The other nerves, except for the sciatic nerve and the L5 dorsal cutaneous nerve, did not respond to stimulation. Interestingly, the lateral femoral cutaneous nerve and the L2 dorsal cutaneous nerve, which are other branches of the L2 spinal nerve, also did not respond. The spinal reflex elicited predominantly in the genitofemoral nerve should not be called merely a segmental spinal reflex, because it appeared in the nerve that innervated a more localized area than the L2 segment. In rats, the groin is located in the most ventral region of the L2 spinal segment.[26] Therefore, it may be more proper to refer to this reflex as a regional spinal reflex (Figure 5).
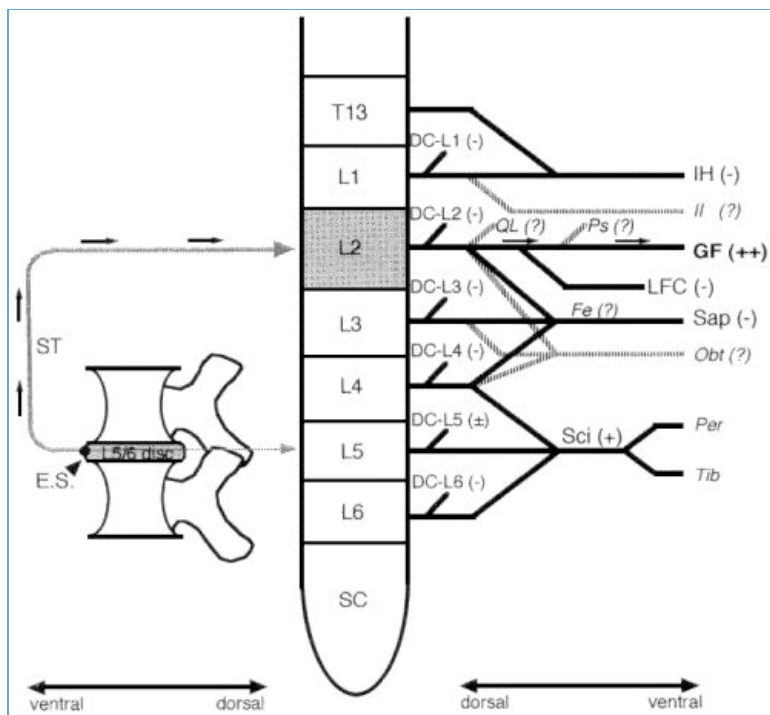
Figure 5. Illustration of a regional spinal reflex in the genitofemoral nerve elicited by the electrical stimulation of the L5-L6 disc in rats. E.S. = electrical stimulation; ST = sympathetic trunks; SC = spinal cord; DC = dorsal cutaneous nerve; IH = iliohypogastric nerve; QL = nerve to the quadratus lumborum muscle; Ps = nerve to the psoas muscle; II = ilioinguinal nerve; GF = genitofemoral nerve; LFC = lateral femoral cutaneous nerve; Fe = femoral nerve; Obt = obturator nerve; Sap = saphenous nerve; Sci = sciatic nerve; Per = peroneal nerve; Tib = tibial nerve. Nerves drawn with broken lines or denoted in italics were not examined in the current study. Symbols in parentheses represent the degree of response.

It should be noted that the genitofemoral nerve and the dorsal cutaneous nerves were not examined simultaneously. One can not disregard the possibility that the genitofemoral nerve also was not responsive in the rats. Furthermore, the authors did not investigate the nature of the action potentials recorded from the sciatic nerve and from the L5 dorsal cutaneous nerve, because the amplitudes of these action potentials were unstable in repeated determinations. Although it has been demonstrated in this study that sympathetic sensory fibers predominately innervate the ventral [15] and dorsal portions [17] of the disc, the authors can not completely deny the possible contribution of the sinuvertebral nerve in the innervation of the lumbar disc. Action potentials in the branches of the L5 spinal nerve still may be explained by a segmental spinal reflex mechanism (Figure 5).

Investigations on referred pain in spinal disorders have focused only on the craniocaudal spatial relation between the pain source and the location of perceived pain;[12,21] the dorsoventral spatial relation has not been considered. Recently, Aizawa [1] reported, based on detailed anatomic observation of human cadavers, that the nerve bundles in spinal nerves of L1 through L4 segments show a dorsoventral layer pattern in accordance with the localization of the innervating tissue. He demonstrated that, in the ventral ramus of the L2 spinal nerve, the nerve bundles to the genitofemoral nerve and psoas muscle, to the lateral femoral cutaneous nerve, and to the quadratus lumborum muscles are arranged in order from ventral to dorsal.[1] A dorsoventral arrangement of the nerves in the lower limb also is expressed as a mediolateral arrangement in the lumbar dorsal horn.[4,24] Therefore, the sensory nerves to the lumbar disc originating from the L2 ventral ramus may have such a dorsoventral layer arrangement. The L5-L6 facet joint in rats is innervated in part by sympathetic sensory fibers from the L2 segment.[22,23] Considering the dorsoventral location of the facet joint, sympathetic sensory nerves projecting to the facet joint are likely to pass through the dorsal layer of the L2 spinal nerve. If such a dorsoventral arrangement in the sympathetic sensory nerves to the lumbar spine exists, the ventral portion of the lumbar disc would seem to be related more closely to the groin area than to other lumbar structures.

Diagnostic Significance of Referred Pain of the Lumbar Disc

Referred pain is thought to be generated by 1) convergence of sensory input from separate parts of the body to the same dorsal horn neuron,[2-8] 2) sensory convergence to the identical dorsal root ganglion neuron via dichotomizing primary sensory fibers,[5] and 3) secondary pain resulting from muscle spasm [20] or sympathetic activity elicited by a spinal reflex [10] or by antidromically produced pain-generating substances.[3]

The action potentials in the genitofemoral nerve elicited by electrical stimulation of the disc did not produce plasma extravasation in the skin, whereas chemical stimulation of the disc did produce such extravasation.[25,27]

The authors of the current report estimate that the groin plasma extravasation that followed chemical stimulation of the disc was caused by a combined mechanism of the antidromic axon reflex of sensory C-fibers and a spinal vasodilatation reflex.27 However, the fact that the action potentials of the genitofemoral nerve were measured by the whole nerve-recording technique indicates that the action potentials are derived from myelinated fibers, conceivably muscular motor fibers. Electrical stimulation applied under the conditions used in the current study may not activate C-fibers or induce a spinal reflex causing vasodilatation or plasma extravasation.

If the regional spinal reflex in the genitofemoral nerve results in muscle spasms, a lesion in the ventral portion of the lumbar disc may cause groin pain by the secondary pain mechanisms. Considering the regional relation between the groin and the ventral portion of the disc, sensory impulses from the disc and those from the groin may input onto the same neuron in the dorsal root ganglion or in the dorsal horn. Groin pain may indicate the presence of a lesion in the ventral portion of the lumbar disc.

However, Yukawa et al 29 reported that most patients with groin pain have a central disc herniation in the posterior portion of the L4-L5 disc. Referred groin pain has been described in association with positive pain provocation test results on the sacroiliac joint 7 and the lower lumbar facet joint.6,14 Furthermore, it is well known that diseases of the viscera, which are located ventral to the lumbar spine, occasionally cause referred low back pain. Although the ventral portion of the lumbar disc may be related more closely to the groin area than to other lumbar structures, the diagnostic validity of groin pain should be verified through meticulous clinical studies.

Conclusions

The authors of this report conclude, as have the authors of previous studies, that the ventral portion of the L5-L6 disc is neurally connected with the groin in rats. Disorders in the ventral portion of the lumbar disc may be related more closely to referred groin pain than to other lumbar structures. However, this hypothesis must be verified through future clinical studies.

References

1.Aizawa Y. The constitution of the nerves to the thigh originating from the lumbar plexus. In: Sato T, Horiguchi M, Kida M, Kodama K. Massho Shinkei Kaibo-gaku (Anatomy of the Peripheral Nervous System) (in Japanese). 1st ed. Tokyo: Science Communications International, 1995:215-24. [Context Link]

2. Akeyson EW, Schramm LP. Processing of splanchnic and somatic input in thoracic spinal cord of the rat. Am J Physiol 1994;266:R257-67. Bibliographic Links │[Context Link]

3. Bonica JJ. Referred pain. In: Bonica JJ. The Management of Pain. Vol. 1. 2nd ed. Philadelphia, London: Lea& Febiger, 1990:169-74. [Context Link]

4. Bryan RN, Trevino DL, Coulter JD, Willis WD. Location and somatotopic organization of the cells of origin of the spinocervical tract. Exp Brain Res 1973;17:177-89. [Context Link]

5.Dawson NJ, Schmid H, Pierau Fr.-K. Pre-spinal convergence between thoracic and visceral nerves of the rat. Neurosci Lett 1992;138:149-52. [Context Link]

6.Fairbank JCT, Park WM, McCall IW, O'Brien JP. Apophyseal injection of local anesthetic as a diagnostic aid in primary low-back pain syndromes. Spine 1981;6:598-605. Ovid Full Text│ Bibliographic Links │[Context Link]

7. Fortin JD, Dwyer AP, West S, Pier J. Sacroiliac joint: Pain referral maps upon applying a new injection/arthrography technique. Part I: Asymptomatic volunteers. Spine 1994;19:1475-82. [Context Link]

8. Gillette RG, Kramis RC, Roberts WJ. Characterization of spinal somatosensory neurons having receptive fields in lumbar tissues of cats. Pain 1993;54:85-98. ATSU │ Bibliographic Links │[Context Link]

9. Groen GJ, Baljet B, Drukker J. Nerves and nerve plexuses of the human vertebral column. Am J Anat

1990;188:282-96. **Bibliographic Links** | [Context Link]

10. Jinkins JR, Whittemore AR, Bradley WG. The anatomic basis of vertebrogenic pain and the autonomic syndrome associated with lumbar disc extrusion. Am J Roentgenol 1989;152:1277-89. [Context Link]

11. Kaneoka K, Kunogi J, Miyoshi K, Hasue M. Usefulness of pain distribution for the level diagnosis of lumbar radiculopathy (in Japanese). Seikeigeka 1993;44:761-4. [Context Link]

12. Kirkaldy-Willis WH. Referred pain and radicular pain. In: Kirkaldy-Willis WH, ed. Managing Low Back Pain (in Japanese). Tokyo: Igaku-shoin, 1990:120-1. [Context Link]

13. Ljunggren AE, Jacobsen T, Osvik A. Pain descriptions and surgical findings in patients with herniated intervertebral lumbar discs. Pain 1988;35:39-46. **ATSU** | **Bibliographic Links** | [Context Link]

14. McCall IW, Park WM, O'Brien JP. Induced pain referral from posterior lumbar elements in normal subjects. Spine 1979;4:441-6. **Ovid Full Text** | **Bibliographic Links** | [Context Link]

15. Morinaga T, Takahashi K, Yamagata M, et al. Sensory innervation to the anterior portion of the lumbar intervertebral disc. Spine 1996;21:1848-51. **Ovid Full Text** | **Bibliographic Links** | [Context Link]

16. Murphey F. Sources and patterns of pain in disc disease. Clin Neurosurg 1968;15:343-51. **Bibliographic Links** | [Context Link]

17. Nakamura S, Takahashi K, Takahashi Y, Morinaga T, Shimada Y, Moriya H. Origin of nerves supplying the posterior portion of lumbar intervertebral discs in rats. Spine 1996;21:917-24. **Ovid Full Text** | **Bibliographic Links** | [Context Link]

18. Nakamura S, Takahashi K, Takahashi Y, Yamagata M, Moriya H. The afferent pathways of discogenic low-back pain: Evaluation of L2 spinal nerve infiltration. J Bone Joint Surg [Br] 1996;78:606-12. **Bibliographic Links** | [Context Link]

19. Pederson HE, Blunck CFJ, Gardner E. The anatomy of lumbosacral posterior rami and meningeal branches of spinal nerves(Sinu-vertebral nerves) with an experimental study of their functions. J Bone Joint Surg [Am] 1956;38:377-91. [Context Link]

20. Schmidt RF. Fundamentals of Sensory Physiology (in Japanese). Tokyo: Kinpodo, 1980:120-5. [Context Link]

21. Simmons Jr JW, Ricketson R, McMillin JN. Painful lumbosacral sensory distribution pattern: Embryogenesis to adulthood. Orthop Rev 1993;22:1110-8. **Bibliographic Links** | [Context Link]

22. Suseki K, Takahashi Y, Takahashi K, Chiba T, Tanaka K, Moriya H. CGRP-immunoreactive nerve fibers projecting to lumbar facet joints through the paravertebral sympathetic trunk in rats. Neurosci Lett 1996;221:41-4. **ATSU** | **Bibliographic Links** | [Context Link]

23. Suseki K, Takahashi Y, Takahashi K, et al. Innervation of the lumbar facet joints: Origins and functions. Spine 1997;22:477-85. **Ovid Full Text** | **Bibliographic Links** | [Context Link]

24. Swett JE, Woolf CJ. The somatotopic organization of primary afferent terminals in the superficial laminae of the dorsal horn of the rat spinal cord. J Comp Neurol 1985;231:66-77. **Bibliographic Links** | [Context Link]

25. Takahashi Y, Nakajima Y, Sakamoto T, Moriya H, Takahashi K. Capsaicin applied to rat lumbar intervertebral disc causes extravasation in the groin skin: A possible mechanism of referred pain of the intervertebral disc. Neurosci Lett 1993;161:1-3. **ATSU** | **Bibliographic Links** | [Context Link]

26. Takahashi Y, Takahashi K, Moriya H. Mapping of dermatomes of the lower extremities based on an animal model. J Neurosurg 1995;82:1030-4. **Bibliographic Links** | [Context Link]

27. Takahashi Y, Morinaga T, Nakamura S, Suseki K, Takahashi K, Nakajima Y. Neural connection between the ventral portion of the lumbar intervertebral disc and the groin skin. J Neurosurg 1996;85:323-8. **Bibliographic Links** | [Context Link]

28. Takahashi Y, Nakamura S, Suseki K, Takahashi K, Yamagata M. Pain distribution in lumbar disc lesions (in Japanese). Rinsho Seikei Geka 1997;32:69-75. [Context Link]

29. Yukawa Y, Kato F, Kajino G, Nakamura S, Nitta H. Groin pain associated with lower lumbar disc herniation. Spine 1997;22:1736-9. **Ovid Full Text** | **Bibliographic Links** | [Context Link]

Key words: electrical stimulation; groin; lumbar intervertebral disc; rats; spinal reflex

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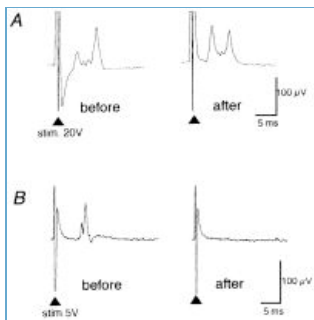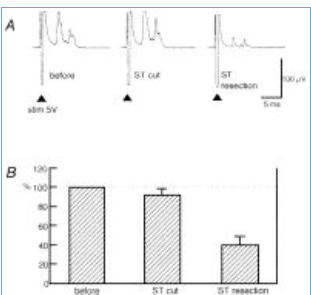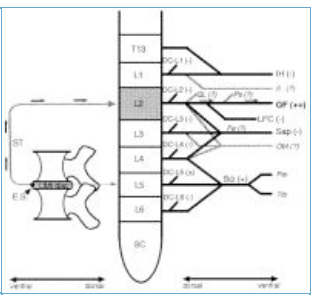

☐ Figure 1

☐ Table 1

☐ Figure 2

☐ Figure 3

☐ Figure 4

☐ Figure 5

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