Cadeveric Study

Innervation Patterns of the Anterior and Posterior Ligamentous Region of the Sacroiliac Joint: Insights from a Cadaveric Study

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Background: In addition to the sacroiliac joint (SIJ) itself, the anterior and posterior ligaments of the SIJ are also sources of pain in the SIJ complex. Nevertheless, detailed descriptions of the nerves that supply the anterior and posterior ligamentous areas of the SIJ are lacking in the literature.

Objectives: The purpose of this study was to examine the anatomical characteristics of the lumbar and sacral nerve branches, which are primarily responsible for the pain signal pathway in the SIJ complex and are distributed within the anterior and posterior ligaments of the SIJ.

Study Design: A dissection-based study of 10 embalmed human cadavers.

Setting: The research took place at Central Hospital of Dalian University of Technology.

Methods: A total of 20 SIJs were examined in this study. The research focused on measuring the angles formed by the lateral branches of the ventral ramus of L4-L5 and the vertical axis, as well as the angles formed by the lateral branches of the posterior ramus of S1-S4 and the vertical axis. The distance from the lateral branches of the sacral posterior ramus to the posterior median line, specifically at a point 8 mm away from the edge of the posterior sacral foramen (PSFs), was also measured.

Results: The angles formed by the lateral branches of the ventral ramus of L4-L5 and the vertical axis were measured to be 43° ± 6° and 25° ± 2°, respectively. Similarly, the angles formed by the lateral branches of the posterior ramus of S1-S4 and the vertical axis were found to be approximately 39° ± 6°, 48° ± 12°, 43° ± 12°, and 44° ± 6°, respectively. At a distance of 8 mm from the PSFs, the distances from the lateral branches of the sacral posterior ramus to the posterior median line were approximately 20-30 mm.

Limitations: The study is subject to certain constraints, including the utilization of preserved specimens that may have resulted inadvertently in damage to the lateral branches of the sacral ventral ramus during anatomical dissections. Furthermore, the study was limited by a small sample size and difficulties in controlling the movement of nerve fibers during data collection.

Conclusions: In the event that the lateral branch capture rate of the perioral bipolar leapfrog technique attains 100%, it is imperative to delineate bipolar lesions in the superolateral and inferolateral quadrants of each PSF. Moreover, when employing the lateral pathway of the PSFs for lateral branch radiofrequency ablation (RFA), it is recommended that the radiofrequency (RF) needles be positioned at a minimum distance of 30 mm from the posterior midline to mitigate the risk of inadvertent thermal injury to the spinal nerves. The lateral branches of the lumbar posterior ramus should also be denervated during the RFA. If the patient's pain symptoms are still not effectively relieved after completing the above treatment, surgeons may use intra-articular injections to alleviate factors originating from an anterior source.

Key words: Sacroiliac joint, sacroiliac complex pain, anterior and posterior ligaments of the SIJ, lumbar and sacral nerve branches, anatomy, innervation, radiofrequency ablation, intraarticular injections

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The sacroiliac complex is a common source of chronic mechanical low-back pain, accounting for approximately 10% to 27% of potential sources (1,2). This complex includes the sacroiliac joint (SIJ) and the associated ligaments on this joint's anterior and posterior aspects (3,4). Numerous studies have shown that in addition to factors related to the SIJ itself, the anterior and posterior ligaments of the SIJ were also among the potential causes of pain in the SIJ complex (5). Medical professionals may utilize radiofrequency ablation (RFA) as a treatment for mechanical low-back pain (6,7). However, the effectiveness of RFA varies among studies, and long-term outcomes have been found to be suboptimal (8,9).

The main emphasis of the RFA procedure was on the lateral branches of the posterior rami of S1-S4, which mainly innervate the posterior ligaments of the SIJ, including the iliolumbar ligament, the lumbosacral ligament, the interosseous sacroiliac ligament, the short posterior sacroiliac ligament, and the long posterior sacroiliac ligament (5,10,11). Accurate localization of the nerves innervating the posterior ligamentous region of the SIJ was crucial for enhancing the long-term efficacy of these interventions. However, Dreyfuss et al (12) discovered that fluoroscopically guided multisite, multi-depth sacral lateral branch blocks were effective in reducing pain originating from the posterior ligamentous region (extra-articular part) of the SIJ but not in alleviating pain that stemmed from the joint's intra-articular portion or anterior ligamentous region. (The latter includes the iliolumbar and anterior sacroiliac ligaments.) This finding suggests that the nerves innervating the intra-articular portion or anterior ligamentous region of the SIJ from its anterior aspect may also transmit neural signals related to pain in the SIJ complex.

Nevertheless, there exists little thorough examination concerning the frequency and course of the nerves that supply the anterior and posterior ligamentous areas of the SIJ. Therefore, the objective of this study was to augment our understanding of the ramus innervating the anterior and posterior ligamentous regions of the SIJ by dissecting cadaveric specimens and collecting anatomical information that may enhance the efficacy of treating pain associated with the SIJ complex.

Methods

The study employed a sample of 10 embalmed cadavers, comprising 2 women and 8 men aged between 48 and 82 years, with a mean age of 72 years. Selection criteria included the absence of any pathological indications.

The dissection process involved careful extraction of the abdominal and pelvic organs, revealing the lumbar spine and pelvis. The exposed ramus, which innervates the anterior ligamentous region of the SIJ, was identified, as were the proximal femoral, obturator, lumbosacral trunk, and adjacent sympathetic trunk. Subsequently, the superficial muscles and blood vessels above the lumbar spine and the posterior ligamentous region of the SIJ were excised to expose the innervating ramus responsible for the SIJ posterior ligamentous region. The dissection was conducted using a surgical microscope (Carl Zeiss, Inc.) to eliminate the surrounding loose connective tissue and adjacent adipose tissue in proximity to the ramus.

The photographic documentation encompassed the course, initial position, and spatial arrangement of the ramus responsible for innervating the anterior and posterior ligamentous region of the SIJ. Furthermore, measurements were conducted on the angles created by the lateral branches of the posterior rami of S1-S4 and the vertical axis (Fig. 1), as well as the angles formed by the lateral branches of the ventral rami of L4-L5 and the vertical axis. A digital caliper with a precision of 0.01 mm was utilized to measure the distance from the lateral branches of the sacral posterior rami to the posterior median line, specifically located 8 mm from the edge of the posterior sacral foramen (PSF). The posterior median line was defined as a perpendicular line running along the spinous processes of each vertebra.

The collected data was analyzed using available software (SPSS 20.0, SPSS Inc.) and is presented in the form of $\bar{x} \pm s$. The angles created by the lateral branches of the ventral rami of L4-L5 and the vertical axis were assessed using the Mann-Whitney U test, while the angles formed by the lateral branches of the posterior rami of S1-S4 and the vertical axis were evaluated using the Kruskal-Wallis test. The Wilcoxon signed-rank test was employed to evaluate the angles created by the vertical axis and a pair of the lateral branches of the ventral rami of L4-L5 (e.g., the left and right lateral branch of the ventral rami of L4). The same test was used to measure the angles formed by the vertical axis and a pair of the lateral branches of the posterior rami of S1-S4 (e.g., the left and right lateral branch of the posterior rami of S1). Furthermore, the one-way analysis of variance (ANOVA) was utilized to assess the distribution of the locations of the lateral branches of the sacral posterior rami at a distance of 8 mm from the

edge of the PSFs. The paired T-test, with a significance level of $P < 0.05$, was employed to evaluate the distribution of the locations of both the left and right lateral branches of the sacral posterior rami at the specified distance from the PSFs.

Results

Anatomic Observation of the Ramus That Innervates the SIJ Posterior Ligamentous Region

The study discovered that the posterior sacral network (PSN), which innervates the posterior ligamentous region of the SIJ, is created by the lateral branches of the posterior rami of L5-S4 (Fig. 2), sometimes also involving the lateral branches of the posterior rami of L4 (Fig. 3).

Statistical Results of the Ramus That Innervates the SIJ Posterior Ligamentous Region

This study identified a total of 94 lateral branches of the sacral posterior rami in 10 human cadavers, involving, respectively, 25, 25, 27, and 15 lateral branches of the posterior rami of S1-S4. The lateral branches of the posterior rami of S1 (75%) and S4 (93%) typically originate from the inferolateral sacral 1 posterior foramen and sacral 4 posterior foramen, respectively. In some cases, there may coexist 2 nerve fibers, constituting a respective 25% and 7% of occurrences. The morphological characteristics of the lateral branches of the posterior rami of S2 can generally be categorized into 4 types: (i) In approximately 70% of cases, a single nerve fiber emerges from the inferolateral quadrant of the sacral 2 posterior foramen. (ii) In approximately 10% of cases, 2 accompanying nerve fibers emerge from the inferolateral quadrant of the sacral 2 posterior foramen. (iii) In approximately 5% of cases, a single nerve fiber emerges from the superolateral quadrant of the sacral 2 posterior foramen. (iv) In 15% of cases, one nerve fiber originates from the superolateral quadrant of the sacral 2 posterior foramen, while another nerve fiber originates from the inferolateral quadrant of the sacral 2 posterior foramen, as shown in Fig. 4. However, the lateral branches of the posterior rami of S3 exhibit the highest number of branches, and their morphology can typically be classified into another 4 types: (i) In 60% of cases, a solitary nerve fiber emerges from the inferolateral quadrant of the sacral 3 posterior foramen. (ii) In 15% of cases, 2 accompanying nerve fibers emerge from the inferolateral quadrant of the sacral 3 posterior foramen. (iii) In 20% of cases, one nerve fiber emerges from the inferolateral quadrant of the sacral 3 posterior foramen, while another nerve fiber emerges from the superolateral quadrant of the sacral 3 posterior foramen, as shown in Fig. 4. (iv) In 5% of the observed cases, 2 nerve fibers originate from the superolateral quadrant of the sacral 3 posterior foramen, while a third nerve fiber emerges from the inferolateral quadrant of the same foramen. In our

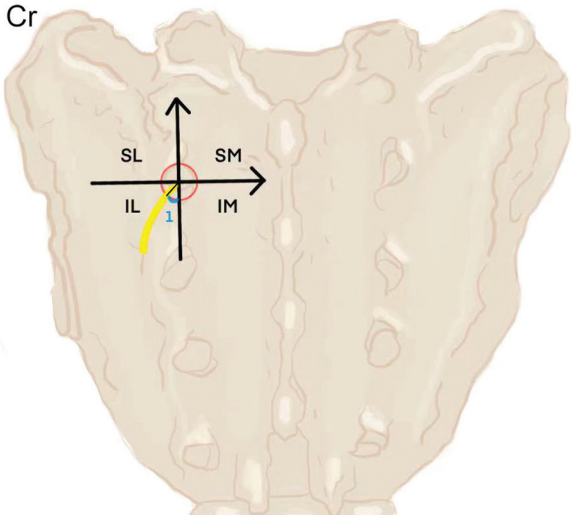


Fig. 1. *The angles formed by the lateral branches of the posterior ramus of S1 and the vertical axis.*
Cr, cranial; Quadrants: SL, superolateral; SM, superomedial; IL, inferolateral; IM, inferomedial. ∠1, the angle formed by the lateral branches of the posterior ramus of S1 and the vertical axis

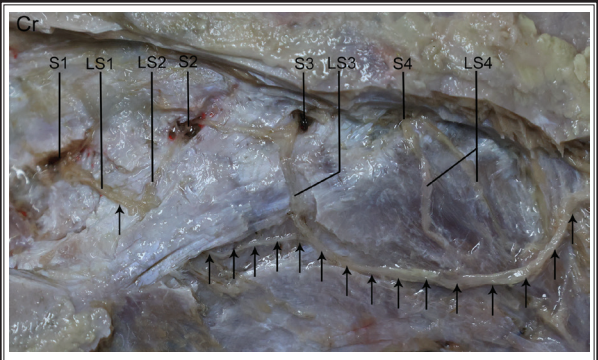


Fig. 2. *The left lateral view of the lateral branches of the posterior ramus of S1-S4.*
Cr, cranial; S1, S2, S3, and S4 represent the PSFs 1-4; LS1, LS2, LS3 and LS4 represent the lateral branches of the posterior ramus of S1-S4; black arrow, the PSN

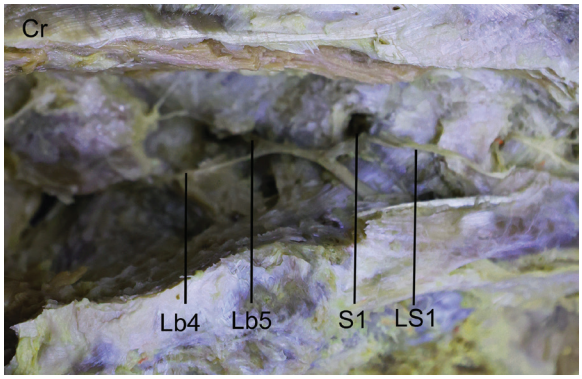


Fig. 3. *The left lateral view of the lateral branches of the posterior ramus of L4-S1.*
Cr, cranial; S1, posterior sacral foramina of S1; Lb4, and Lb5 represent the lateral branches of the posterior ramus of L4-L5; LS1, the lateral branches of the posterior ramus of S1

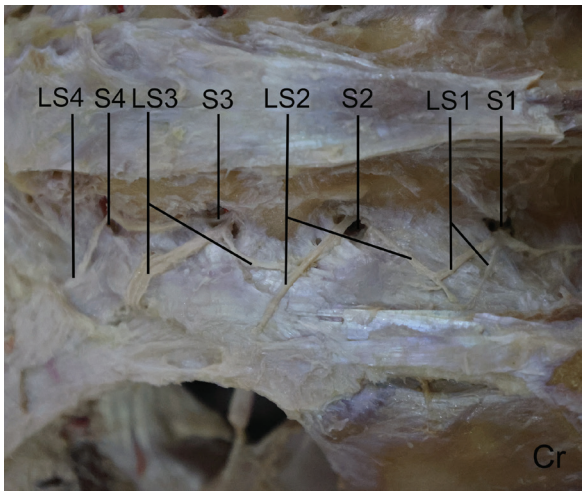


Fig. 4. *The branches of the lateral branches of the sacral posterior ramus.*
Cr, cranial; S1, S2, S3, and S4 represent the PSFs 1-4; LS1, LS2, LS3 and LS4 represent the lateral branches of the posterior ramus of S1-S4

investigation, it was noted that the lateral branches of the posterior rami of S1-S4 originated predominantly as a single nerve fiber from the corresponding inferolateral quadrant of the PSFs.

The angles of inclination of the lateral branches of the posterior rami of S1-S4 in relation to the vertical axis are detailed in Table 1. Given the diminished nerve fiber count in the lateral branches originating from the superolateral quadrant, statistical analyses focused

Table 1. *The measurements of the angle between the lateral branches of sacral posterior ramus and the vertical axis, $\bar{x} \pm s$ (minimum-maximum)*

	LS order	Relative acute angle (°) (minimum-maximum)
Left	LS1	39 ± 6 (30-48)
	LS2	52 ± 13 (38-72)
	LS3	43 ± 15 (20-75)
	LS4	45 ± 4 (38-50)
Right	LS1	38 ± 6 (28-44)
	LS2	44 ± 10 (28-60)
	LS3	43 ± 8 (30-58)
	LS4	44 ± 7 (34-53)

LS, the lateral branches of sacral posterior ramus; relative acute angle, the angles formed by the lateral branches of the posterior ramus of S1-S4 and the vertical axis

solely on the larger root of the lateral branches that originated from the inferolateral quadrant. A statistically significant difference was observed in the angle between the lateral branches of the posterior rami of each sacral nerve and the vertical axis (H = 8.902, $P = 0.031$). A subsequent pairwise comparison indicated a significant difference in the angles formed by the lateral branches of the posterior rami of S1 and S2 in relation to the vertical axis (H = -18.913, $P = 0.032$). No significant difference was observed between the angle formed by vertical axis and the lateral branches of the posterior rami of S1 and the angle that the vertical axis formed with the lateral branches of the posterior rami of S3 (H = -11.400, $P = 0.531$). Similarly, no difference was found between the vertical axis and the angle formed by the lateral branches of the posterior rami of S1 and the angle that the vertical axis formed with the lateral branches of the posterior rami of S4 (H = -16.186, $P = 0.169$). The angle formed by the lateral branches of the posterior rami of S2 and the vertical axis did not differ from the angle formed by the lateral branches of the posterior rami of S3 and the vertical axis (H=7.513, $P > 0.05$) or the angle formed by the vertical axis and the lateral branches of the posterior rami of S4 (H = 2.727, $P > 0.05$). Additionally, no significant difference was observed between the angle formed by the lateral branches of the posterior rami of S3 and the vertical axis and the angle formed by the lateral branches of the posterior rami of S4 and the vertical axis (H = -4.786, $P > 0.05$). Furthermore, the angle formed by the left lateral branches of the sacral posterior rami was not significantly different from that of the corresponding right lateral branches ($P > 0.05$). No statistically significant disparity was observed across

genders in the angle between the vertical axis and the lateral branches of the posterior rami of each sacral nerve ($P > 0.05$). The angles formed by the vertical axis and the lateral branches of the posterior rami of S1-S4 were approximately 39° ± 6°, 48° ± 12°, 43° ± 12°, and 44° ± 6°, respectively.

The diameters of the lateral branches of the posterior rami of S1-S4, measured at a distance of 8 mm from the PSFs, were found to be approximately 1.26 ± 0.22 mm, 1.19 ± 0.39 mm, 1.29 ± 0.20 mm, and 1.14 ± 0.27 mm, respectively. The distances from the lateral branches of the sacral posterior rami to the posterior median line at the 8 mm distance from the PSFs are presented in Table 2 and illustrated in Fig. 5. At a distance of 8 mm from the PSFs, no statistically significant variation was observed in the distance between the posterior midline and the lateral branches of the posterior rami of each sacral nerve ($F = 1.830$, $P = 0.150$). Furthermore, a paired T-test indicated that at the same distance, the distance between the posterior midline and the left lateral branches of the sacral posterior rami did not differ from that of the corresponding right lateral branches of the sacral posterior rami ($P > 0.05$). No statistically significant disparity was observed in the spatial separation between the posterior midline and the lateral branches of the posterior rami of each sacral nerve, specifically at a distance of 8 mm from the PSFs, when comparing individuals of different genders ($P > 0.05$).

In this study, a total of 14 lateral branches of the posterior ramus of L4 and 20 lateral branches of the posterior ramus of L5 were also found to join the PSN. Among them, 6 the lateral branches of the posterior ramus of L4 were not added to the PSN, with a main length of approximately 27.20 ± 2.97 mm. The length of the main trunk of the lateral branches of the posterior ramus of L5 was approximately 24.71 ± 5.66 mm. The lateral branches of the posterior ramus of L4 were added to the PSN by anastomosing with the lateral branches of the posterior ramus of L5. Meanwhile, the lateral branches of the posterior ramus of L5 were added to the PSN by anastomosing with the lateral branches of the posterior ramus of S1 and then participated in the innervation of the posterior ligament area of the SIJ.

Table 2. *The measurements of the distance and diameter between the lateral branches of sacral posterior ramus and the posterior midline at a distance of 8 mm from the PSFs, $\bar{x} \pm s$ (minimum-maximum).*

	LS order	Diameter (mm) (minimum-maximum)	Distance (mm) (minimum-maximum)
Left	LS1	1.25 ± 0.25 (0.80-1.60)	21.21 ± 2.20 (18.10-24.70)
	LS2	1.18 ± 0.43 (0.30-1.70)	23.48 ± 3.80 (17.00-29.40)
	LS3	1.30 ± 0.19 (1.00-1.60)	21.37 ± 3.00 (17.30-27.60)
	LS4	1.11 ± 0.27 (0.60-1.50)	21.60 ± 4.67 (14.70-27.80)
Right	LS1	1.27 ± 0.21 (0.80-1.60)	22.24 ± 3.72 (17.50-29.50)
	LS2	1.20 ± 0.37 (0.50-1.70)	24.44 ± 3.03 (18.40-28.70)
	LS3	1.28 ± 0.21 (1.00-1.50)	22.87 ± 3.18 (16.10-26.10)
	LS4	1.17 ± 0.29 (0.80-1.60)	22.79 ± 2.60 (20.30-26.40)

LS, the lateral branches of sacral posterior ramus; Diameter, at a distance of 8 mm from the PSFs, the diameter of the lateral branches of sacral posterior ramus; Distance, at a distance of 8 mm from the PSFs, the distance between the lateral branches of sacral posterior ramus and the posterior midlin

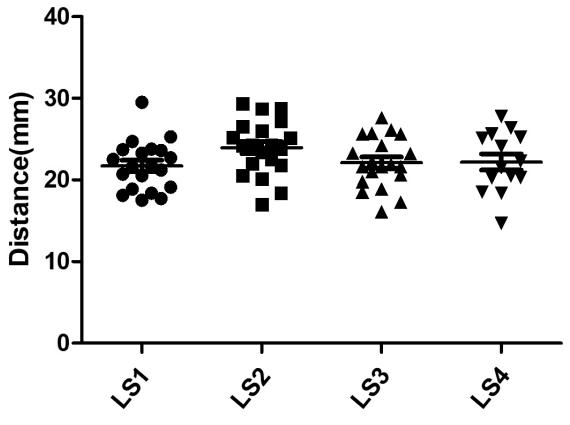


Fig. 5. *The location of the lateral branches of sacral posterior ramus at a distance of 8 mm from the PSFs.* Distance, at a distance of 8 mm from the PSFs, the distance between the lateral branches of sacral posterior ramus and the posterior midline

Anatomic Observation of the Ramus That Innervates the SIJ Anterior Ligamentous Region

The innervation of the anterior ligamentous region of the SIJ is primarily provided by the lateral branches of the ventral rami of L4-L5, as observed in a study involving 20 patients. Specifically, the lateral branches of the ventral rami of L4 originate from the posterior aspect of the ventral rami of L4 and terminate in the

iliolumbar ligament region (Fig. 6). Similarly, the lateral branches of the ventral rami of L5 originate from the posterior aspect of the ventral rami of L5 and terminate in the sacroiliac anterior ligament region (Fig. 7). Furthermore, the examination of 20 sides revealed the absence of femoral, obturator, or lumbosacral trunk branches that were directed toward the anterior SIJ. Additionally, no sympathetic nerve fibers originating from the neighboring lumbar sympathetic trunk were detected. Moreover, this study did not observe any branches originating from the lateral branches of the sacral ventral rami that were distributed within the anterior ligamentous region of the SIJ.

Statistical Results of the Ramus that Innervates the SIJ's Anterior Ligamentous Region

In this study, a total of 18 lateral branches of the ventral rami of L4 and 20 lateral branches of the ventral rami of L5 were observed in 10 human cadavers. Among those, 2 lateral branches of the ventral rami of L4 were found to be absent, with an average length of approximately 24.02 ± 4.38 mm. The main trunk of the lateral branches of the ventral rami of L5 had an average length of approximately 38.40 ± 3.97 mm. The angles formed by the lateral branches of the ventral rami of L4-L5 and the vertical axis are detailed in Table 3. No statistically significant difference was observed in the angle between the left and corresponding right lateral branches of the ventral rami of L4 and the vertical axis (Z = -1.472, P = 0.141). Similarly, no statistically significant difference was found in the angle between the left and corresponding right lateral branches of the ventral rami of L5 and the vertical axis (Z = -0.952, P = 0.341). Furthermore, no statistically significant difference was observed in the angle between the lateral branches of the ventral rami of L4-L5 and the vertical axis when comparing different genders (P > 0.05). However, when the angle formed by the vertical axis and the lateral branches of the ventral rami of L4 is compared to the angle formed by the vertical axis and the lateral branches of the ventral rami of L5, there is a significant statistical difference (Z = -4.839, P = 0.000).

Discussion

Histological examination and immunohistochemical staining have verified the presence of nociceptive nerve components associated with pain in the SIJ complex (5,13). In patients experiencing pain in the SIJ complex, these components are found not only in the



Fig. 6. *The left ventral lateral view of the lateral branches of the ventral ramus of L4. Cr, cranial; ST, lumbar sympathetic trunk; Lb3 and Lb4 represent the lateral branches of the ventral ramus of L3-L4; N4, the L4 ventral ramus; IL, iliolumbar ligament; *, lumbar sympathetic ganglions*

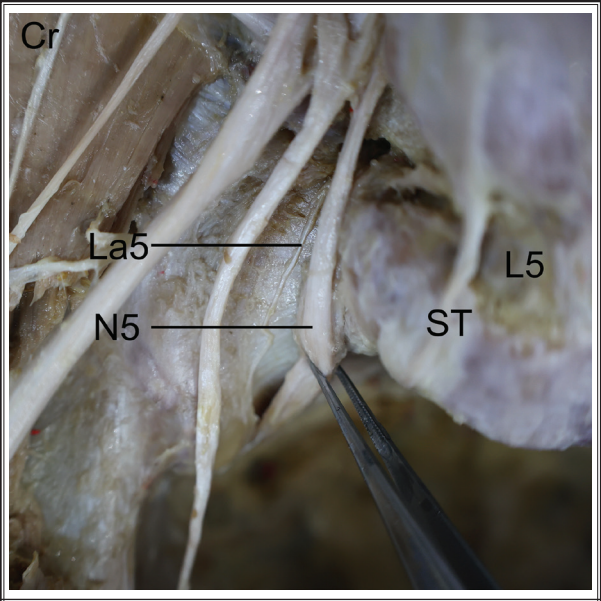


Fig. 7. *The right ventral lateral view of the lateral branches of the ventral ramus of L5.*
Cr, cranial; ST, lumbar sympathetic trunk; Lb5, the lateral branches of the ventral ramus of L5; N5, the L5 ventral ramus

posterior ligamentous region of the joint but also in its anterior ligamentous region. However, when RFA is applied to the lateral branches of the sacral posterior ramus, the procedure targets only the nerve innervation in the posterior ligamentous region of the SIJ, which may be a reason why clinical trials and data have shown that the efficacy of this technology is good in the short term but not ideal in the long term (8,10,14-16). Additionally, the anatomical characteristics of the lateral branches of the sacral posterior ramus are also factors that affect the effectiveness of RFA (7,17,18). Therefore, to improve the treatment outcomes for patients with pain in their SIJ complexes, this study observed the anatomical characteristics of the nerve innervation of the anterior and posterior ligamentous region of the SIJ, and measure the angles created by the lateral branches of the posterior rami of S1-S4 and the vertical axis, the angles formed by the lateral branches of the ventral rami of L4-L5 and the vertical axis, as well as the distance from the lateral branches of the sacral posterior rami to the posterior median line, specifically located 8mm from the edge of the PSF.

Currently, multiple research studies have shown that the primary innervation of the posterior ligamentous region of the sacroiliac joint is derived from nerve branches originating from L5-S4, with intermittent contribution from L4 (19-21). Yin et al (14) identified that the lateral branches of the posterior ramus of S1-S3 emerge from specific positions on the right (2 o'clock to 6 o'clock) or left (6 o'clock to 10 o'clock) side, when conceptualizing the posterior sacral foramina as a clock face. Additionally, Robert et al (22) offered a detailed account stating that the SIJ was innervated by the PSN. It was noted that most PSN branches traveled through the lateral sacral crest located between the transverse sacral tubercles (TSTs) 1-3, with the greatest density found between TSTs 2-3. Furthermore, Zhu et al (11) categorized the posterior ligamentous region of the SIJ into 4 specific zones, labeled as areas 0–3 in a sequential manner along the sagittal plane. The researchers noted that zones 0–1 received direct innervation from the lateral branches of the posterior rami of the fourth and fifth lumbar vertebrae (L4–L5), whereas zones 2–3 were innervated by both lumbar and sacral nerves via the PSN. Those researchers found a significantly greater number of identifiable terminal nerve branches in regions 2–3 than in regions 0–1. The findings of the aforementioned studies were consistent with those of this study. In this investigation, measurements were taken of the angles created by the lateral branches of the posterior ramus of S1-S4 in relation to the vertical axis. The results indicated that the majority of these angles fell within the range of 35° to 55°. Specifically, the lateral branches of the posterior ramus of S1-S4 predominantly originated from the 4 o'clock-to-6 o'clock position on the right or the 6 o'clock-to-8 o'clock position on the left. Although there was a significant difference in the angles formed by the lateral branches of the posterior rami of S1 and S2 in relation to the vertical axis, that difference might have been attributable to anatomical variations and a small sample size. In addition, this study also found that the number of the lateral branches of the sacral posterior ramus and the PSN branches were most abundant between TSTs 1-3, especially between TSTs 2-3. The above areas correspond to the regions 2–3 described by Zhu et al (11).

Table 3. *The measurements of the angle between the lateral branches of the ventral ramus of L4-L5 and the vertical axis* $\bar{x} \pm s$ *(minimum-maximum).*

	La order	La (%)	Relative acute angle (°) (minimum-maximum)
Left	La4	9 (90)	42 ± 7 (35-54)
	La5	10 (100)	24 ± 2 (22-28)
Right	La4	9 (90)	43 ± 5 (36-50)
	La5	10 (100)	25 ± 2 (22-28)

La, the lateral branches of lumbar ventral ramus; Relative acute angle, the angle between the lateral branches of the ventral ramus of L4-L5 and the vertical axis

This study additionally assessed the separation between the lateral branches of the posterior rami of each sacral nerve and the posterior midline at a distance of 8 mm from the PSFs, a distance deemed safe for the RFA procedures (4,12,23-25). Although previous studies have successfully identified the specific locations of the initial origins of the lateral branches of the posterior ramus of S1-S4, accurately locating these nerve fibers at a distance of 8 mm from the PSFs remains a challenging task. To further clarify the positioning of the lateral branches of the posterior ramus of S1-S4, a study was conducted to measure the distance between the left lateral branches of the sacral posterior ramus and the posterior midline at a point 8 mm away from the PSFs. The results indicated that there was no statistically significant difference in the spatial separation between the lateral branches of the posterior ramus of each sacral nerve and the posterior midline. Additionally, there was no significant difference observed in the distance between the left lateral branches of the sacral posterior ramus and the posterior midline when compared to the corresponding

right lateral branches of the sacral posterior ramus. This finding suggests that the distance between the lateral branches of the posterior ramus of each sacral nerve and the posterior midline, specifically at a distance of 8 mm from the PSFs, consistently measured approximately 20-30 mm. Furthermore, the contralateral ramus of the lateral branches of the sacral posterior ramus displayed similar positions when located at a distance of 8mm from the PSFs.

However, studies have shown that the ramus within the anterior ligamentous region of the SIJ is also important in understanding SIJ complex pain (5,26,27). Multiple studies have suggested the presence of neural elements within the anterior ligamentous region of the SIJ (28). These studies collectively support the notion that the predominant innervation of the SIJ anterior ligamentous region is derived from the nerve branches of L4-S2, with possible contributions from L2 and L3 in specific instances (27,29). Nevertheless, research by Szadek et al (27) suggests that the ventral ramus of L4 and L5 may also play a role in providing innervation to the SIJ anterior ligamentous region, implying the potential participation of L4 and L5 nerves in transmitting pain signals from this area, aligning with the findings of this study. In our study, we found that the innervation of the anterior ligamentous region of the SIJ lateral branches came predominantly from the ventral ramus of L4 and L5. We did not observe any branches from the femoral, obturator, or lumbosacral trunk supplying the anterior SIJ, nor did we detect sympathetic nerve fibers from the nearby lumbar sympathetic trunk. Additionally, our investigation uncovered no evidence that branches originating from the lateral branches of the sacral ventral ramus were distributed within the anterior ligaments of the SIJ. Furthermore, measurements were conducted to ascertain the angles created by the lateral branches of the ventral ramus of L4-L5 in relation to the vertical axis. The results revealed that these angles were recorded at 43° ± 6° and 25° ± 2°, respectively. A potential rationale for this occurrence is that the innervation of the iliolumbar ligaments region is predominantly linked to the lateral branches of the ventral ramus of L4, while the sacroiliac anterior ligaments region is primarily innervated by the lateral branches of the ventral ramus of L5. In other words, these angle measurements might be due to the different ligaments innervated by the lateral branches of the ventral branches of L4 and L5.

Undoubtedly, developing an understanding of the nerve innervation in the anterior and posterior ligamentous areas of the SIJ was beneficial for clinical doctors' ability to treat pain in the SIJ complex, especially for the commonly used minimally invasive technique of lateral branch RFA. According to the observation results of this study, if the lateral branch capture rate of the perioral bipolar leapfrog technique reaches 100%, bipolar lesions must be mapped around the superolateral and inferolateral quadrant of each PSF. Because the anatomical features of these lateral branches originate from the PSFs and extend outward, it is advisable to position RF needles at least 30 mm from the posterior midline when utilizing the lateral pathway of the PSFs so the lateral branch RFA can avoid unintended thermal effects on the spinal nerves. In addition, to improve the therapeutic effects on pain in the SIJ complex, the lateral branches of the posterior ramus of L4-L5 should also be denervated during lateral branch RFA. Finally, this study also suggested that surgeons could consider utilizing intra-articular injections to administer medications directly into the joint cavity to alleviate symptoms stemming from an anterior origin in patients who continue to experience unresolved pain after lateral branch RFA.

The study is subject to certain constraints, including the utilization of preserved specimens that may have resulted in inadvertent damage to the lateral branches of the sacral ventral rami during anatomical dissections. Furthermore, the study was limited by a small sample size and difficulties in controlling the movement of nerve fibers during data collection. Despite these limitations, the thorough examination of the innervation of the anterior and posterior ligamentous regions of the SIJ promises to enhance treatment strategies for pain related to the SIJ complex.

Conclusion

If the lateral branch capture rate of the perioral bipolar leapfrog technique attains 100%, it is imperative to delineate bipolar lesions in the superolateral and inferolateral quadrants of each PSF. Moreover, when employing the lateral pathway of the PSFs for lateral branch RFA, it is recommended that the RF needles be positioned at least 30 mm from the posterior midline to mitigate the risk of inadvertent thermal injury to the spinal nerves. The lateral branches of the lumbar posterior ramus should also be denervated during the RFA. If the patient's pain symptoms are still not effectively relieved after completing the above treatment, surgeons may use intra-articular injections to alleviate factors originating from an anterior source.

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Author Contributions

Yubo Sun is the first author of this work.

Yubo Sun: Conceptualized and designed the study, acquired, analyzed, and interpreted the data, drafted and proofread the manuscript.

Nizhou Jiang: Conceptualized and designed the study, acquired, analyzed, and interpreted the data, drafted and proofread the manuscript.

Zhijin Wang: Acquired, analyzed, and interpreted the data.

Yu Liu: Acquired, analyzed.

Jian Jiang: Drafted and proofread the manuscript, gave final approval of the manuscript.

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