Feasibility Study

The Optimal Needle Placement to Access the S1 Dorsal Root Ganglion for Transforaminal Radiofrequency Treatment

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Background: Pulsed radiofrequency (PRF) treatment modulates the dorsal root ganglion (DRG), thereby blocking nociceptive signals. Its success depends on precise electrode placement adjacent to the target DRG. However, proper electrode placement for the S1-DRG is challenging due to uncertainty regarding the S1-DRG's precise location.

Objective: Our study aimed to investigate the S1-DRG's location relative to the S1-dorsal foramen (DF) and to develop a technique to facilitate its targeting for PRF application.

Study Design: Human cadaver feasibility study.

Setting: Cadaver laboratory.

Methods: Twelve S1-DRGs were dissected. A percutaneous needle passing through the S1-DF targeting the "belly" of the S1-DRG was placed to establish the optimal needle trajectory. The optimal needle skin entry point relative to the posterior superior iliac spine and the needle's caudal and oblique angulations were measured.

Results: In each study cadaver, the S1-DRG was located craniomedially to the S1-DF within the sacral canal. The optimal needle trajectory to the S1-DRG "belly" consistently passed through the inferolateral quadrant of the S1-DF.

Limitations: Our study's findings are based on anatomical examinations of a limited number of human cadavers and may not fully represent living human anatomy.

Conclusion: Approaching through the inferolateral quadrant of the S1-DF maximizes access to the S1-DRG. Placing the needle as described in our study can facilitate PRF treatment of the S1-DRG.

Key words: Pulsed radiofrequency, S1, dorsal root ganglion stimulation, treatment, injectable electrode

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Dating back to the nineteenth century, different approaches—including surgical sectioning, chemical destruction, and thermal radiofrequency—have been performed to treat nerves in order to relieve radicular pain (1-3).

Uematsu, et al (3) applied continuous radiofrequency to the dorsal root ganglion (DRG) and selectively destroyed the small pain related fibers by heating them. However, this also damaged large sensory and motor fibers. This procedure was then quickly abandoned due to its causing extensive side effects and its lack of advantage over treatment with local anesthetics (4). In 1980, a small diameter electrode was developed which causes less pain during the procedure and allows more definite access to the DRG (5). Following that advancement, pulsed radiofrequency (PRF) was introduced (6). The PRF method not only allows delivery of high-frequency electric current to the DRG, but it also avoids thermal tissue damage. Since then, studies have demonstrated the efficacy of performing PRF of the DRG with a small electrode, a technique that is gaining popularity (7,8).

Transforaminal PRF of the DRG requires precise electrode placement to be effective. The tip of the needle, which carries an electrode, must be placed close to the DRG to affect DRG nociceptive neurons. In the lateral view, the lumbar DRG is mostly found in the upper third portion of the intervertebral foramen (9). In the anteroposterior plane, the lumbar DRG is generally found beneath the corresponding pedicle (10). Precise needle tip placement at this point is mandatory for the success of lumbar PRF-DRG treatment.

However, for the S1-DRG, placing the needle tip in the S1-dorsal foramen (S1-DF) in the same manner as the lumbar intervertebral foramen does not allow access to the ganglion because the S1-DRG is in the sacral canal. In addition, the traditional transforaminal entrance into the sacral canal through the S1-DF is a successful approach to target the S1-DRG. The exact location of the S1-DRG in the sacral canal relative to the S1-DF should be studied to precisely target the ganglion in transforaminal PRF treatment.

In our study, we aimed to investigate the exact location of the S1-DRG relative to the S1-DF and to develop a technique to accurately target the S1-DRG for PRF treatment.

We dissected the sacral region of cadavers and inserted a needle percutaneously through the S1-DF in order to target the S1-DRG. We measured the skin entry site and needle trajectory angles and used that data to assist in ensuring the optimal placement of the PRF electrode.

Methods

Our study was conducted on donated cadavers in line with the principles of the Declaration of Helsinki. The Institutional Review Board waived required consent. The sacral region was dissected in 6 embalmed cadavers; a total of 12 S1-DRGs were evaluated. Gluteal skin and subcutaneous tissues were separately cut from the midline of the sacral region and deviated laterally to enhance exposure. Dissection was performed to reveal the sacral dorsal foramina. While protecting the bony wall of the sacral foramina, the dorsal sacral plate and L5 vertebral arch were removed. Then, the dural sac was cut, revealing the rootlets and DRG of the sacral spinal nerves (Fig. 1).

The location of the S1-DRG relative to the S1-DF was noted. The gluteal skin and subcutaneous fat tissue were returned to their anatomical position, and a needle was then inserted percutaneously, targeting the S1-DRG and passing through the S1-DF. The final position of the needle tip was recorded, whether it was positioned or not positioned on the “belly” of the S1-DRG. The ideally located needle was defined as a needle whose tip was successfully located on the S1-DRG’s“belly” or at the closest possible site of the S1-DRG’s “belly.”

The ideally located needle entry site on the skin was measured relative to the most inferomedial tip of the posterior superior iliac spine (PSIS) using a soft tape measure. A perpendicular guiding pin was inserted on the ganglion to correctly measure the angles of the needle. Then, the trajectory of the ideally located needle was photographed in lateral and superior views. The needle’s caudal angle (in lateral view) and oblique angle (in superior view) were measured using ImageJ software (National Institutes of Health).

Results

In each study cadaver, the S1-DRG was located craniomedially to the S1-DF within the sacral canal. To access the S1-DRG, the needle tip had to be directed cranially and medially within the sacral canal, which was enabled when the needle tip passed through the inferolateral quadrant of the foramen (Fig. 1).

In 6 study cadavers, the needle tip was precisely placed on the “belly” of the S1-DRG. However, in the other 6 study cadavers, the needle tip could only reach the inferior border of the ganglion, not the ganglion’s “belly.” The primary reason for this was the PSIS’s location in the needle's trajectory, which substantially restricted establishing the needle's position. Realigning the needle trajectory to overcome this obstacle made it possible to access the inferior border of the DRG.

The mean skin entry site of the ideally located needle was 13.6 ± 7.6 mm lateral and 24.7 ± 10.2 mm inferior to the PSIS. The mean caudal angulation of the needle (needle tip directed cranially) was 16.1° ± 8.9°, and the mean oblique angulation in the transverse plane (needle tip directed medially) was 28.6° ± 10° (Fig. 2).

Discussion

The most important finding of our study is that the S1-DRG is located within the sacral canal; it was found craniomedially relative to the S1-DF in all study cadavers. Therefore, the RF needle should be advanced through the inferolateral quadrant of the S1-DF in order to successfully target the craniomedially located S1-DRG. Furthermore, we defined the optimal skin entry site and angular orientation for targeting the "belly" of the S1-DRG. Accordingly, initially placing the needle at a point 13.6 mm lateral and 24.7 mm inferior to the PSIS, with 16.1° caudal and 28.6° oblique angles, can facilitate establishing the optimal needle trajectory for PRF treatment of the S1-DRG (Fig. 2).

Since the position and the size of the DRG in the intervertebral foramen may differ throughout the vertebral column, different approaches for the cervical, thoracic, and lumbar intervertebral foramen have been described in order to precisely reach the DRG (10,11). However, the exact location of the S1-DRG and its location relative to the S1-DF have not been fully investigated. Identifying the exact location of the S1-DRG is crucial for the success of transforaminal PRF treatments (10). A needle placed inadvertently too close to the spinal nerve can result in both motor and sensory deficits (12). Conversely, placing the electrode too far from the DRG can substantially reduce PRF's efficacy (13). Therefore, knowing the S1-DRG's location relative to the S1-DF can improve the efficacy of RF treatment.

In the lumbar region, the RF needle should be placed below the pedicle in order to target the lumbar DRG (10,14,15). However, applying this technique to the S1-DF for S1-DRG treatment may not result in a successful outcome. Because the S1-DRG is located within the sacral canal and is located craniomedially relative to the S1-DF, the tip of the needle should be advanced into the sacral canal through the inferolateral quadrant of the S1-DF ("4:30 clock position" on the right and "7:30 clock position" on the left S1-DF). Doing this successfully targets the craniomedially located S1-DRG. This approach can maximize optimal needle placement in transforaminal S1-RF treatment (Fig. 1).

Fig. 1. *Cadaveric dissection of the sacral ganglia. The dorsal sacral plate was removed in order to visualize the sacral canal and its content. Yellow circles indicate the boundaries of the sacral dorsal foramina. Sacral ganglia were in the sacral canal and found craniomedially according to the corresponding dorsal foramina. The green area emphasizes the inferolateral quadrant of the S1-dorsal foramen through which the access of the needle tip to the S1-dorsal root ganglion can be optimized. The right-side inferolateral quadrant is located between the 3:00-6:00 o'clock positions. * sign indicates the "belly" of the S1-dorsal root ganglion. PSIS, posterior superior iliac spine.*

The foramen restricts needle adjustment, such that only a limited space can be used to access the DRG, making it difficult to establish the ideal needle trajectory. We believe that anticipating the optimal entry site and needle trajectory can overcome this difficulty. For this purpose, we inserted a percutaneous needle passed it through the inferolateral quadrant of the S1-DF which was directed as craniomedially as possible in order to target the S1-DRG's "belly." After establishing an optimally placed needle, we measured the skin entry site and trajectory angles. Initially placing the needle at the skin entry site and the angles described in our study can facilitate establishing the optimal needle position. During treatment, depending on any minor morphological differences the patient

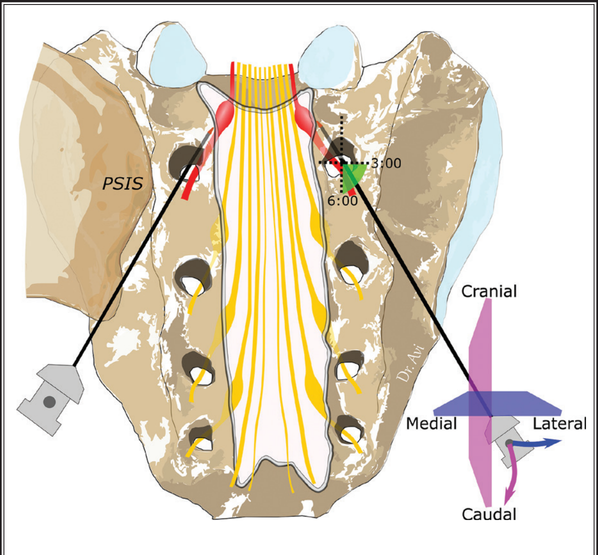

Fig. 2. *Approach to the S1-dorsal root ganglion. The S1-dorsal root ganglion and S1 nerves are in red. The green area indicates the inferolateral quadrant of the S1-dorsal foramen. The right-side inferolateral quadrant is located between the 3:00-6:00 o'clock positions (on the left side, mirror symmetry, between 9:00-6:00 o'clock). The optimal needle trajectory is established by pulling the base of the needle caudally in the sagittal plane(in pink) and laterally in the oblique (transverse) plane (in blue) so that the needle tip is directed craniomedially to the S1-dorsal root ganglion. In some cases the posterior superior iliac spine can overhang and be large enough to block the needle tip's trajectory and thus access to the S1-dorsal foramen. In that case, a more medial approach may be required to target the ganglion.*

has, the interventionalist can further modify the needle's angle as needed in order to reach the S1-DRG through the inferolateral quadrant of the S1-DF.

In 6 study cadavers, the needle tip was ideally placed on the "belly" of the DRG; however, in the other 6 study cadavers, the needle tip was barely placed at the inferior border of the DRG. Even with maximal craniomedial direction in those 6 study cadavers, the "belly" of the S1-DRG could not be fully reached. The main reason for this was the presence of the massive PSIS. Indeed, the PSIS may substantially limit the caudal angulation of the needle, which in turn can limit higher (more cranial) access of the needle tip within the sacral canal (Fig. 2).

If the electrode does not reach the proximity of the DRG, the treatment will not be fully effective; furthermore, a misplaced electrode can cause injury to the spinal nerve. However, as reported previously, using finite-element calculations, a needle tip with an exposed electrode can produce an effect on a DRG in an area measuring 4 mm wide and 7 mm long (16). Therefore, an electrode that reaches even the inferior border of the S1-DRG may still yield effective results. The key to successful optimal electrode placement is directing the needle tip as craniomedially as possible, which requires a needle approach through the inferolateral quadrant of the S1-DF.

Our study was conducted on formalin-fixated cadavers. Tissue thickness, including the subcutaneous adipose layer, may differ in living patients. Hence, the specific skin entry site and optimal needle angle described in our study may not be fully applicable to all patients. However, our study defined the location of the S1-DRG relative to the S1-DF and showed that reaching the S1-DRG requires a needle approach through the inferolateral quadrant of the S1-DF. Applying this principle can facilitate access to the S1-DRG and reduce the number of attempts needed to establish an optimal needle trajectory, which in turn can reduce the patient's pain experience during the treatment.

Conclusion

Approaching through the inferolateral quadrant of the S1-DF will maximize access to the S1-DRG. Initially placing the needle at the skin entry site and angles described in our study can facilitate PRF treatment of the S1-DRG and reduce the number of attempts required to locate the S1-DRG.

Ethical Approval

This study was conducted on donated cadavers in line with the principles of the Declaration of Helsinki.

Author Contributions

S.S. and O.H.G. conceived and designed the study based upon their interventional pain medicine experience; they encouraged A.V.I. to investigate. A.V.I. and A.S. carried out dissections based on S.S., S.K., and O.H.G.'s clinical experience. A.V.I. took the lead in writing the manuscript and drawing the illustrations. O.H.G., S.S., and S.K. supervised the research findings and contributed to their interpretation, while U.S.S. and O.H.G. provided overall project supervision. U.S.S. and O.H.G. helped supervise the project. All authors discussed the results and contributed to the final manuscript. The manuscript has been read and approved by all authors, and each author believes that the manuscript represents honest work. There has been no duplicate submission or publication elsewhere of any part of the work.

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