Multiple dimensions of radiographic reconstruction for the optimal operative strategy of sacral meningeal cysts

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Abstract

Background and purpose The contents and subtypes of sacral cysts are sophisticated in many cases. We applied multiple dimensional magnetic resonance imaging (MRI) reconstruction to preoperatively clarify the specific subtype of sacral meningeal cysts.

Materials and methods We preoperatively used multimodal neural reconstruction MRI sequences to evaluate 76 patients with sacral cysts. The linear nerve roots were precisely traced based on sagittal or coronal images processed at various angles and levels which was conducive to the design of the operation strategy.

Results Cysts with nerve passage were detected in 47 cases (62%, 47/76), whereas cysts without nerve roots were detected in 24 cases (32%, 24/76). Five patients had mixed cysts with or without nerve roots. Intraoperative exploration results proved the high accuracy of image reconstruction; only one cyst without a nerve root was misdiagnosed prior to surgery.

Conclusion MRI reconstruction based on the three-dimensional fast imaging employing steady-state acquisition T2 sequence precisely tracked the nerve roots of sacral cysts and guided the optimal strategy during surgery.

Keywords Sacral cysts · Tarlov cyst · Meningeal diverticula · MRI reconstruction

Introduction

Sacral cysts (SCs) are cerebrospinal fluid (CSF)-filled extradural meningeal cysts within the sacral canal that are most commonly found in patients with lower back/lower extremity/perineal pain, paresthesia, paresis, and bowel/bladder/sexual dysfunction [1–3]. Persistent standing/sitting, coughing, and sneezing result in elevated subarachnoid hydrostatic pressure and drive the more rapid CSF flow into the cyst, which ultimately aggravates relevant symptoms [4]. The worldwide prevalence of SCs was reported as 4.6–13.8%; 10–20% of patients with SCs complain unbearable symptoms due to the local compression or nerve root irritation and require effective surgical management [5–7].

According to the origin of pathogenesis, SCs are traditionally categorized based on a classification system by Tarlov, which was updated by Nabor [8, 9]. However, the classical definition fails to provide detailed guidance for clinical practice. The lack of systematic and standardized surgical treatments for SCs leads to common postoperative residual or recurrent cysts, and the clinical symptoms cannot be fully improved or even aggravated, which may negatively impact the general clinical management of this disease. In our previous study, we divided SCs into two cohorts after careful intraoperative exploration. Cysts with nerve root passage (Tarlov cyst) received standardized surgical nerve root sheath reconstruction; cysts without nerve roots (meningeal diverticula) received standardized neck transfixion [1–3]. Tarlov cyst can be singular or multiple with an uneven size. In contrast, meningeal diverticula cysts are typically solitary and large. These cysts directly arise from the dura mater of the spinal sac and cause symptoms through local expansion and compression. In our experience, we traditionally divided meningeal diverticula cysts into three subtypes, classical

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The classical meningeal diverticula cysts exclude any nerve root passage inside the cavity and have typical fistulas which are often detected at the end of dural sac and directly facilitate CSF outflow. The filamentous cysts are considered with terminal filament passage. Terminal filament inside cyst is always thick and infiltrated by adipose tissue, which can be easily distinguished from nerve roots. Arachnoidal diverticula is another subtype which has distinctive arachnoidal structure at cyst neck. The arachnoidal complex is proved to secret CSF from dural sac into cyst cavity.

The classification currently used is based on subjective identification during surgery, which makes it difficult to accurately carry out a comprehensive diagnosis and evaluation prior to surgery. Therefore, a comprehensive evaluation of the existence, number, and direction of nerve roots is necessary before surgery. Conventional magnetic resonance imaging (MRI) can determine the location and size of SCs as well as the existence of large nerve roots. Due to the low resolution and signal contrast, it is impossible to clearly observe detailed information, such as the number, direction, branches, edema, and degeneration of nerve roots.

From the perspective of clinical requirements, this study relied on a special thin-layer scanning sequence and an arbitrary curved surface with high resolution, minimum layer thickness, and spacing to understand the sources, morphology, branches, and composition of the involved nerves inside and outside the SCs from multiple angles and layers. Based on the reconstructed MRI images, surgeons can make appropriate preoperative plans.

Materials and methods

Patients

In this postoperative study, 76 patients with symptomatic SCs underwent comprehensive neurological and MRI evaluations at an outpatient center between March and October 2021. All patients were diagnosed with indications for surgery and underwent surgical management.

MRI reconstruction

The patients underwent sacral MRI (GE Discovery MR750 3.0 T). All original axial/sagittal/coronal T1-weighted images (WI), T2WI, and other images were transferred to a GE Advantage Workstation 4.6 reformat (General Electric, Schenectady, NY, USA) or three-dimensional (3D) maximum intensity projection workstation for reconstruction. Spinal nerve roots within cysts were located on axial T2WI images, and sagittal or coronal images were reconstructed at various angles and levels based on the axial cross-section of the nerve root. Every axial section with nerve roots was reconstructed (layer thickness: 1 mm). Linear nerve roots with multiple directions or branches were outlined in the reconstructed sagittal images, and every nerve trunk or branch received double reconstruction in parallel and vertical directions to create coronal images. The detailed direction of the nerve roots and branches within the cysts was further evaluated on coronal images. Processed images were uploaded to the Picture Archiving and Communication Systems database.

Preoperative evaluation

Based on the reconstruction procedure, the detailed direction and branches of the nerve root and the specific position and angle of the nerve root entering or exiting the cyst were clearly presented in the processed MR images. If no nerve root was detected in the cyst, reconstruction was performed to locate the leakage point. Individualized skin incisions and sacral laminectomy were designed according to the results of the MRI reconstruction. The laminectomy window covered the full travel length of the nerve roots or the leakage point. Different operative strategies were used for different types of SCs.

Microsurgical management

Each patient underwent a single-stage microsurgical operation with a gross total resection of the cysts. The involved sacral laminae were then exposed, and complete laminectomy was performed via piezosurgery with care to preserve the integrity of the cyst wall. The terminal thecal sac was identified and dissected from the overlying cysts. The sensory and motor functions of the affected nerve roots in the sacral canal were determined via the electrophysiological monitoring of the somatosensory and motor evoked potential levels and curve changes. Preoperative MRI findings were confirmed under a microscope. Cysts with nerve root passage underwent nerve root sheath reconstruction, and cysts without nerve roots received neck transfixion. The posterior wall of sacral canal was reconstructed with CranioFix Absorbable.

Follow-up

All patients were followed up at the outpatient center or via telephone questionnaires. The clinical outcome of each patient was evaluated using the International Journal of Obstetric Anesthesia score. Clinical symptoms were assessed as improved or deteriorated via interrogation and physical examination, respectively.
Table 1: Presentation of 76 cases

| Types                        | Gender | Age (years, average ± SD) | Number of cysts | Maximum diameter |
|------------------------------|--------|---------------------------|-----------------|------------------|
| With nerve root              | Male (25, 33%) | 40 ± 16.3                  | 105             | 4 ± 6.5          |
| Without nerve root           | Female (51, 67%) | 41 ± 13.4                  | 25              | 5 ± 2.1          |
| with mixed cysts with or without nerve roots | 1 (20%) | 46 ± 14.5                  | 14(8 + 6)       | 3 ± 1.2          |

Statistical analysis

Data analysis was performed using SPSS 17.0. Data were compared using a two-sample t-test or one-way analysis of variance for parametric data and the Mann–Whitney or Wilcoxon tests for non-parametric data. Data were expressed as mean ± standard error. Statistical significance was set at \( P < 0.05 \).

Ethics committee approval

This study was approved by the ethics committee of our hospital and conducted according to the principles of the Declaration of Helsinki.

Results

Presentation

In total, 76 patients (25 men and 51 women) with SCs were included in this study. Among them, 47 (62%) cases were identified as Tarlov cysts with nerve roots inside, 24 (32%) as meningeal diverticula cysts without nerve roots, and only 5 (6%) as mixed type with both Tarlov and meningeal diverticula cysts. Female patients with Tarlov cysts were more common. The average length of the precise skin incision was 4–5 cm, the average operation time was 1.5–2.5 h, and the

Fig. 1 A. Precise skin incisions and sacral laminectomy were designed according to the MRI image (green line). B. Skin incisions. C. The posterior wall of sacral canal was reconstructed with CranioFix Absorbable. D. Postoperative MRI showed total resection of cyst.
Fig. 2  A, B. Patient with SCs received regular MRI scanning. Double cysts were presented at the end of dural sac and nerve root was indistinctly detected inside cyst (red arrow). C, D. The reconstructive MRI image (Coronal T2) clearly showed triple cysts (blue box) around the end of dural sac (red box). The middle cyst was traversed by single nerve root (red arrow). E. Single nerve root (black arrow) was detected under microscope which was consistent with the preoperative MRI image. F. Cyst with nerve root received nerve root sheath reconstruction (black box). G. Postoperative MRI proved total resection of cysts

Fig. 3  A. Preoperative MRI scanning showed one small cyst and one large cyst at the end of dural sac. Nerve root with indistinctly bifurcations inside cyst (red arrow). B, C. The reconstructive MRI image (Sagittal T2) clearly showed the relationship between cysts and dural sac. One of the cyst was traversed by single nerve root which was bifurcated inside cyst (red arrow). D. Intraoperative exploration found similar structure of nerve root as MRI images (black arrow). E. Postoperative MRI proved total resection of cysts
blood loss during each operation was 10–30 mL (Table 1, and Fig. 1).

Of the 47 patients with Tarlov cysts, 17 (36%) were male and 30 (64%) were female, with a mean age of 40 ± 16.3 y. In total, 105 cysts were detected, with a maximum length of 40 ± 6.5 mm. Of the 24 patients with meningeal diverticula, 7 (29%) were men and 17 (71%) were women, with a mean age of 41 ± 13.4 y. In total, 25 cysts were found, with a maximum length of 50 ± 21.3 mm. Of the five mixed cases, one (20%) was male and four (80%) were female, with an average age of 46 ± 14.5 y. All 14 cysts were explored; 8 were found to have nerve roots and 6, without, with a maximum length of 30 ± 12.2 mm. Tarlov cysts with nerve roots were typically multiple and small, and meningeal diverticula were usually solitary and large. No significant differences were found in the age, sex, or maximum diameter of the cysts. The mean diameter of a single cyst among the mixed cysts was relatively small (Table 1).

In 47 Tarlov cysts, the MRI reconstruction results were measured during the operation, and the accuracy of the preoperative prediction was nearly 98% (46/47). Only one case with a huge cyst was incorrectly identified as having no nerve root passage. In 47 cases of Tarlov cysts and 5 cases of mixed cysts, a total of 113 (105 + 8) cysts underwent further analysis. Among 91 (81%, 91/113) cysts with a single nerve root input, 69 (75.8%, 69/91) cysts had a single nerve root output (Fig. 2), 16 cysts (17.6%, 16/91) had a double root output (Fig. 3) and 6 cases (6.6%, 6/91) had multiple outputs (Fig. 4); among 15 cysts (13%, 15/113) with a double root inputs, 13 (86.7%, 13/15) cysts had a double nerve root output (Fig. 5), and 2 cysts (13.3%, 2/15) had a triple root output; among 7 (6%, 7/113) cysts with triple root input, 6 (85.7%, 6/7) cysts had a triple output (Fig. 6), and 1 cyst had multiple outputs (Table 2). All cases received standard nerve root reconstruction during surgery, the complete resection rate in this cohort was 100% according to postoperative MRI examination. In long-term follow-up, only one case reported recurrence of cyst (Table 3).

A total of 31 (25 + 6) cysts were found in 24 cases of meningeal diverticula and 5 cases of mixed cysts. There were 23 cysts with a maximum diameter of 50 ± 20.1 mm, with 19 cysts were located in the middle of the sacral canal, and 4 cysts located on the side. The mean diameter of the eight multiple or mixed cysts was 30 ± 12.6 mm, with two cysts located in the middle, while the others were located on the side. As no nerve root was found in the meningeal diverticula, this type of cyst was further evaluated according to the CSF source. We found that 11 (35%) were filiformous cysts (Fig. 7), 11 (35%) were classical meningeal cysts with simple fistulas at the end of the dural sac (Fig. 8), and 9 (29%) were arachnoid diverticula with an arachnoid structure herniated into the neck of the cyst (Fig. 9, Table 4).
Every case received cyst neck transfixion in surgery, the complete resection rate in this cohort was 100% according to postoperative MRI scan. No case reported recurrence of cyst in long term follow-up (Table 5).

Four (4.5%, 4/76) patients had SCs accompanied by presacral pelvic cysts. Both cysts were interlinked by a narrow bridge within the anterior wall of the sacral canal. Leakage at the end of the dural sac was considered as the source of CSF fluid in this kind of dumbbell-shaped cyst. The gradual enlargement of the huge SCs eroded the bony structure of the sacral canal, and once the anterior wall was broken, the CSF invaded anteriorly and formed cysts within the pelvic cavity. In this group of cases, two contained nerve roots, whereas two had no nerve roots (Figs. 10, 11, and Table 6). Cases with nerve roots received standard nerve root reconstruction, while cases without nerve root received transfixion of cyst neck, the complete resection rate in this cohort was 100% and no case reported recurrence of cyst (Table 7).

Nine patients came to our department to undergo secondary surgery. One case had recurrent SCs, and another had rare and complex cysts. The other seven patients were treated by physicians in other hospitals and did not undergo standard treatment for sacral cysts. Another patient was found to have advanced squamous cell carcinoma after repeated puncture and fat and muscle packing operations in another hospital and finally died due to the systemic spread of the tumor embolus. The operative
strategy for recurrent SCs was similar to that of our standardized surgery: cysts with nerve root passage underwent nerve root sheath reconstruction, and cysts without nerve roots received neck transfixion (Table 8).

**Discussion**

In 2013, based on our preliminary clinical experience, we classified SCs into two types: nerve root type (Tarlov cyst) and non-nerve root type (meningeal diverticula) [1–3]. This classification system provides guidance on the relevant surgical strategy and clinical prognosis. Weigel et al. cited the comparative analysis of the SC classification by our group and emphasized that assessment played an effective role in guiding clinical treatment [11]. The basic principle of the SC operation is to restore the normal anatomical structure of the nerve root sheath and terminal cistern via surgical nerve root reconstruction or fistula suture [12–16]. For the surgical treatment of SCs with nerve roots, some scholars selected surgical methods, such as puncture aspiration or glue injection, which disregard nerve root sheath restoration [16]. In addition, blind punctures often stimulate and damage the nerve roots, leading to residual and recurrent cysts [17, 18]. Such failed surgical attempts were fully verified in nine of our patients who underwent reoperation. Repeated injection or aspiration and multiple cramming of fat and muscle failed to fundamentally solve the problem of residual and recurrent cysts.

Successful root sheath reconstruction included accurate incision design, overlapping nerve roots with the cyst wall, redundant cyst wall excision, and strengthening of the reconstructed nerve sheath with an artificial dura mater, all of which required a comprehensive understanding of the number, branches, and direction prior to surgery [19]. No previous study has analyzed the input and output of nerve roots

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**Table 2** Presentation of cysts with nerve roots

| Cysts with nerve roots | Single nerve root input | Double nerve root inputs | Triple nerve root inputs | Number of cysts |
|------------------------|-------------------------|--------------------------|--------------------------|-----------------|
| No branch              | 69 (single output)      | 13 (double outputs)      | 6 (triple outputs)       | 88              |
| Single branch          | 16 (double outputs)     | 2 (triple outputs)       | 1 (multiple outputs)     | 19              |
| Double branch          | 6 (triple outputs)      | 0                        | 0                        | 6               |
within Tarlov cysts in detail. In our study, we found that most Tarlov cysts entered with a single root input (91/113, 81%). Among the 91 cysts, 75.8% (69/91) had a single root output, 17.6% (16/91) had a double root output, and 6.6% (6/91) had a triple root output. Moreover, in 13% (15/113) of cysts with a double root input, 86.7% (13/15) had a double output and only 13.3% (2/15) had a triple output. Only 6% (7/113) of the cysts had triple roots.

A precise transfixion cyst neck is critical for the operative treatment of meningeal diverticulum cysts without internal nerve roots. The remaining cyst wall could be left without excessive dissection to avoid potential damage to the adjacent nerve root attached to the external cyst wall. Preoperative leakage source detection greatly influences the exploration and transfixion of the cyst neck during surgery [20]. With the accumulation of clinical cases, we recently found that SCs without nerve roots can be further classified into classical (35%), filamentous (35%), and arachnoidal diverticula (29%). All such cysts we encountered were relatively solitary and large and were always discovered in the middle of the sacral canal.

Four special cases were accompanied by presacral pelvic cysts. The presacral portion was connected to the sacral portion by a narrow bony defect (isthmus) in the anterior wall of the sacral canal. Continuous leakage of CSF from the dural sac leads to the enlargement of the cysts, which resulted in the gradual erosion of the bony structure of the sacral canal. After breaking through the anterior wall of the sacrum, CSF flowed into the pelvic cavity through the isthmus to form pelvic cysts. The isthmus may or may not have had nerve roots inside them. In our group, two cases contained nerve roots in the isthmus, and two cases had no nerve roots. In addition, the solitary presacral cysts did not communicate with the dural sac.

Fig. 7  
A, B. Preoperative MRI scanning showed huge cyst at S2-4 level with thick terminal filament passage. C (Sagittal T2), D (Coronal T2). Reconstructive MRI image further presented the location of terminal filament with fat infiltration (red arrow). E. Intraoperative image proved the presence of terminal filament within cyst cavity (black arrow). F. Terminal filament was incised and the left part received sheath reconstruction (black box). G. Postoperative MRI image.
**Fig. 8** A. Preoperative MRI scanning showed cyst within sacral canal without detailed information on the leakage point. B (Sagittal T2), C (Coronal T2). Reconstructive MRI image clearly presented the relationship between dural sac (red box) and the neck of cyst (red arrow). D. Intraoperative detection of the leakage point which received transfixion (black arrow). E. Postoperative MRI image

**Fig. 9** A. Preoperative MRI scanning showed huge cyst at S2–4. B (Axial T2), C (Sagittal T2). Reconstructive MRI image showed the arachnoidal structure within cyst (red arrow). D. Intraoperative detection found the presence of arachnoidal diverticula which proved as the source of CSF and received transfixion (black arrow). E. Postoperative MRI image
Table 3  Follow up information (Tarlov cyst, 47 cases)

| Clinical features                                      | Numbers of cases |
|--------------------------------------------------------|------------------|
| Initiation presenting symptoms                         |                  |
| Lower extremity weakness                               | 4 (8.5%)         |
| Lower extremity numbness                               | 9 (19.1%)        |
| Perineum and external genitalia numbness               | 8 (17.0%)        |
| Bowel/bladder and sexual dysfunction                   | 5 (10.6%)        |
| Pain                                                   | 15 (31.9%)       |
| More than one symptom                                  | 10 (21.3%)       |
| Follow-up symptoms                                     |                  |
| Lower extremity weakness                               | 0                |
| Lower extremity numbness                               | 1 (2.1%)         |
| Perineum and external genitalia numbness               | 2 (4.3%)         |
| Bowel/bladder and sexual dysfunction                   | 1 (2.1%)         |
| Pain                                                   | 2 (4.3%)         |
| More than one symptom                                  | 2 (4.3%)         |
| Complete resection rate                                | 100%             |
| Long-term recurrence                                   | 1 (2.1%)         |

Ultrasound-guided puncture and aspiration have limited advantages. Based on our experience, regarding this type of solitary presacral cyst, the precise location of the leakage source should be detected and appropriate surgical treatment should be given according to the presence or absence of the nerve roots.

The clinical application value of MRI 3D-fast imaging employing steady-state acquisition (3D-FIESTA) technology is widely recognized. The 3D-FIESTA-C is an improved version of the 3D FIESTA sequence. Combined with the anatomical features of SCs, the 3D-FIESTA-C sequence greatly improves the contrast deficiency of traditional T2 or T1 fluid-attenuated inversion recovery sequences. Nerve roots inside SCs present with relatively low signals, which is in remarkable contrast to the high CSF signal inside the cyst. The 3D images can be reconstructed in any dimension on a spherical surface, which represents the anatomical relationship between the nerve roots and sacral cyst from different angles. On the basis of the 3D thin-layer axial T2 scan, repeated spherical reconstruction of various dimensions clearly illustrated the number, direction, and branches...
Table 4 Presentation of cysts without nerve root

|                | Filamentous cysts | simple fistulas | arachnoid diverticula | Maximum diameter (cm) | Location |
|----------------|-------------------|----------------|-----------------------|-----------------------|----------|
| Single         | 9                 | 10             | 8                     | 5 ± 2.1               | 2        |
| Multiple       | 0                 | 0              | 1                     | 3.2                   | 1        |
| Mixed          | 2                 | 1              | 0                     | 3 ± 1.6               | 1        |

Fig. 11  A. Preoperative MRI scanning showed huge cyst accompanied by presacral pelvic cyst. B (Sagittal T2), C (Coronal T2). Reconstructive MRI image showed the relationship between sacral cyst (red box) and the junction point of pelvic cyst (red arrow). D. The isthmus which connected the sacral and presacral cyst was observed during surgery with obvious flowing of CSF (black arrow). E. Cyst neck received firm transfixion. F. Postoperative MRI image

Table 5 Follow up information (Meningeal diverticula cysts, 24 cases)

| Clinical features                                      | Numbers of cases |
|--------------------------------------------------------|------------------|
| Initiation presenting symptoms                         |                  |
| Lower extremity weakness                               | 2 (8.3%)         |
| Lower extremity numbness                               | 6 (25%)          |
| Perineum and external genitalia numbness               | 5 (20.8%)        |
| Bowel/bladder and sexual dysfunction                    | 4 (16.7%)        |
| Pain                                                    | 7 (29.2%)        |
| More than one symptom                                  | 8 (33.3%)        |
| Found by chance                                        | 5 (20.8%)        |
| Follow-up symptoms                                     |                  |
| Lower extremity weakness                               | 0                |
| Lower extremity numbness                               | 0                |
| Perineum and external genitalia numbness               | 1 (4.2%)         |
| Bowel/bladder and sexual dysfunction                    | 1 (4.2%)         |
| Pain                                                    | 2 (8.3%)         |
| More than one symptom                                  | 2 (8.3%)         |
| Complete resection rate                                | 100%             |
| Long-term recurrence                                   | 0                |

Table 6 Sacral cysts accompanied by presacral pelvic cysts

| Gender          | Maximum diameter of cysts | Part of sacral canal | Part of presacral canal |
|-----------------|---------------------------|----------------------|-------------------------|
| Male            | 1                         | 4.4 ± 5.5            | 6.2 ± 8.6               |
| Female          | 1                         | 4.0 ± 3.6            | 8.0 ± 14.0              |

of nerve roots, as well as the leakage source (cyst neck). The design of the skin incision and bone window relied on the preoperative MRI evaluation. If cysts were found in the nerve roots, the bone window was designed to cover the entire length of the nerve roots and branches. If cysts were found without nerve roots, the bone window was designed to precisely cover the leakage source. An ultrasonic knife was used to open the bone window and expose the cysts. After the treatment, the posterior wall of the sacrum was resettled.
Table 7  Follow up information (Presacral pelvic cysts, 4 cases)

| Clinical features                                      | Numbers of cases |
|--------------------------------------------------------|------------------|
| Initiation presenting symptoms                          |                  |
| Abdominal symptoms                                     | 2 (50%)          |
| Perineum and external genitalia numbness                | 1 (25%)          |
| Bowel/bladder and sexual dysfunction                    | 1 (25%)          |
| Follow-up symptoms                                     |                  |
| Abdominal symptoms                                     | 1 (25%)          |
| Perineum and external genitalia numbness                | 0                |
| Bowel/bladder and sexual dysfunction                    | 1 (25%)          |
| Complete resection rate                                 | 100%             |
| Long-term recurrence                                   | 0                |

Table 8  Analysis of cases receive secondary operation

| Types                              | Gender | Age (years) | Numbers of previous operations | Causes of failure                                      | Type of the operation                                      | Post-operation situation       |
|------------------------------------|--------|-------------|--------------------------------|--------------------------------------------------------|------------------------------------------------------------|-------------------------------|
| Case 1                             | F      | 31          | 1                              | Received internal fixation of the sacral vertebra without reinforce of cyst | Nerve root sheath reconstruction                          | Well                           |
| Case 2                             | F      | 21          | 1                              | Recurrent                                              | Nerve root sheath reconstruction                          | Well                           |
| Case 3                             | F      | 75          | 1                              | Cyst was opened without reinforce                      | Nerve root sheath reconstruction                          | Good, preoperative urinary retention was not improved       |
| Case 4                             | M      | 21          | 2                              | Received bypass operation without reinforce            | Shunt take out and nerve root sheath reconstruction       | Excellent, improvement of sexual dysfunction                 |
| Case 5                             | M      | 40          | 1                              | Glue injection and fat flap transplantation           | Release the nerve adhesions and nerve root sheath reconstrucion | Excellent, post-operative pain was significantly improved |
| Case 6                             | M      | 36          | 1                              | Mixed type of cysts                                   | Terminal filament resection, cyst neck transfixion and nerve root sheath reconstruction | Excellent                      |
| Case 7                             | F      | 36          | 1                              | Percutaneous puncture                                 | Cyst neck transfixion                                     | Excellent                      |
| Case 8                             | F      | 55          | 4                              | Repeated percutaneous puncture and glue injection     | Cyst neck transfixion and free myocutaneous flap transplantation | Systemic spread, died                          |
| Case 9                             | F      | 31          | 2                              | Percutaneous puncture                                 | Nerve root sheath reconstruction                          | Excellent                      |

Conclusion

The 3D-FIESTA-C sequence-guided MRI reconstruction enables an accurate preoperative determination of the nerve root condition of the SCs. Combined with intraoperative electrophysiological monitoring, the affected nerve roots can be properly protected to avoid severe nerve defects, and cysts were completely resected without complications after surgery. MRI reconstruction provides valuable information that is critical for the optimal surgical management of SCs.
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Declarations

Conflict of interest No conflict of interest was declared.

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