·临床研究·

单纯马尾神经损伤后慢性神经病理性疼痛手术治疗分析

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【摘要】 **目的** 对比分析单纯马尾神经损伤后慢性神经病理性疼痛的手术策略及其有效性和长期安全性。**方法** 回顾分析2011年9月至2020年12月首都医科大学宣武医院收治的24例单纯马尾神经损伤后慢性神经病理性疼痛患者的临床资料，根据损伤部位、损伤程度、疼痛分布行脊髓背根入髓区（DREZ）毁损术或脊髓电刺激术，采用视觉模拟评分评价疼痛程度，疼痛缓解率≥50%判断为手术有效，并记录出院时及随访期间并发症发生率。**结果** 共24例患者，行脊髓电刺激术14例，9例疼痛缓解率60%～80%，植入永久脉冲发生器；2例疼痛缓解率为60%，但未达预期，拒绝植入永久脉冲发生器；3例疼痛缓解率<10%，改行DREZ毁损术，2例疼痛缓解、1例仍无效。行DREZ毁损术10例，7例疼痛消失；2例部分区域残留疼痛；1例无效，改行脊髓电刺激术，疼痛仍未缓解。行脊髓电刺激术植入永久脉冲发生器后，2例因植入部位反复积液取出脉冲发生器。行DREZ毁损术后，3例于疼痛区域上界出现新发疼痛，术后2周至1个月逐渐消失；1例术后2年疼痛复发，再次行DREZ毁损术后疼痛消失。两组手术有效率差异无统计学意义（9/13对11/15；Fisher确切概率法：$P=1.000$），但DREZ毁损术的疼痛缓解率高于脊髓电刺激术[100%（0，100%）对25%（0，75%）；$Z=0.441$，$P=0.030$]。**结论** 病因明确的单纯马尾神经损伤后慢性神经病理性疼痛行脊髓电刺激术或DREZ毁损术均可获得较满意的长期疗效。存在一定下肢运动和大小便功能的患者首选脊髓电刺激术；疼痛区域广泛、下肢运动和大小便功能丧失的患者则首选DREZ毁损术。DREZ毁损术的疼痛缓解率优于脊髓电刺激术。

【关键词】 神经痛； 马尾； 脊髓； 电刺激； 疼痛测定

Analysis of surgical treatment of chronic neuropathic pain after simple cauda equina injury

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【**Abstract**】 **Objective** To analyze the surgical strategy, efficacy and long-term safety of chronic neuropathic pain (NP) after simple cauda equina injury. **Methods** The clinical data of patients with chronic NP after cauda equina injury treated by dorsal root entry zone (DREZ) derogation and spinal cord stimulation (SCS) in Xuanwu Hospital, Capital Medical University from September 2011 to December 2020 were analyzed. The DREZ derogation or SCS was selected according to the lesion location, injury degree and pain distribution. The long-term effect was evaluated according to the preoperative and postoperative Visual Analog Scales (VAS) scores, pain relief rate ≥ 50% was considered as effective, and the complications related to the surgery were followed up. **Results** Among 24 cases, 14 cases were treated with SCS, 9 cases had pain relief rate 60%-80%, and permanent pulse generator (IPG) was implanted; the pain relief rate was more than 60% in 2 cases, but it did not meet expectation so that the IPG was not implanted; no pain relief in 3 cases, DREZ derogation was performed later, the pain was relieved in 2 cases, and one case was still ineffective. DREZ derogation was firstly performed in 10 cases, and the pain disappeared in 7 cases; 2 cases had residual pain in some areas; one case was ineffective, and the pain was

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still unrelieved after SCS. After long-term implantation of IPG, 2 cases had been taken out of the stimulator due to fluid accumulation at the implantation site. After DREZ derogation, 3 cases had pain at the upper boundary of the preoperative pain area, which gradually disappeared within 2 weeks to one month. In one patient, the pain disappeared in early stage, which recurred after 2 years, and disappeared after the second DREZ derogation. There was no significant difference in the effective rate between 2 groups (9/13 vs. 11/15, Fisher′s exact probability: $P = 1.000$). However, DREZ derogation had high pain improvement rate than SCS [100% (0, 100%) vs. 25% (0, 75%); $Z = 0.441$, $P = 0.030$]. **Conclusions** For chronic neuropathic pain after simple cauda equina injury with clear etiology, both SCS and DREZ derogation may receive satisfactory long-term effect. SCS is the first choice for patients with lower limb movement, urinary and bowel function in pain area. DREZ derogation is the first choize for patients without lower limb movement, urinary and bowel. The pain improvement rate of DREZ derogation was better than that of SCS.

【Key words】 Neuralgia; Cauda equina; Spinal cord; Electric stimulation; Pain measurement
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马尾神经位于脊髓圆锥以下，由腰神经$L_2 \sim L_5$、骶神经$S_1 \sim S_5$及尾节共10对神经根组成，属于周围神经，有硬膜囊保护，悬浮于脑脊液中，对外力具有一定缓冲，故较重的外力方能损伤马尾神经。马尾神经损伤常见于低位腰椎、骨盆及骶骨骨折，椎管或骶管肿瘤，以及医原性损伤等[1-3]。25%～50%的马尾神经损伤患者可出现慢性神经病理性疼痛（NP），多发生于下肢或者肛周会阴区，严重影响日常生活[4-5]。与高位脊柱外伤造成的脊髓联合神经根损伤后神经病理性疼痛相比，单纯马尾神经损伤后慢性神经病理性疼痛不合并脊髓损伤，目前主要采用脊髓背根入髓区（DREZ）毁损术[6-9]和脊髓电刺激术（SCS）[10-14]，但国内针对这两种手术方法有效性和安全性的单中心临床研究较少见。首都医科大学宣武医院近年来分别采用DREZ毁损术或脊髓电刺激术治疗24例单纯马尾神经损伤后慢性神经病理性疼痛患者，整体疗效确切，现总结如下。

资料与方法

一、临床资料

1.纳入标准 （1）外伤、肿瘤或医原性损伤马尾神经致慢性神经病理性疼痛。（2）病程＞1年。（3）疼痛主要位于下肢或肛周会阴区。（4）视觉模拟评分（VAS）＞5分，疼痛严重影响日常生活。（5）既往药物治疗（普瑞巴林、加巴喷丁、曲马多、吗啡等）、神经阻滞、椎管内探查等治疗效果欠佳。

2.排除标准 （1）影像学检查提示合并胸髓、腰髓或圆锥损伤。（2）存在腰背部皮肤感染、破溃、肝肾功能障碍、凝血功能障碍等手术禁忌证。（3）无明确病因，疼痛部位呈游走性，无法准确描述。

3.一般资料 选择2011年9月至2020年12月在首都医科大学宣武医院功能神经外科住院治疗的马尾神经损伤后慢性神经病理性疼痛患者共计24例，男性16例，女性8例；年龄29～74岁，平均为51岁；致伤原因分别为外伤16例（包括低位腰椎骨折14例、骶骨骨折1例、骨盆骨折1例）、肿瘤3例（椎管内肿瘤2例、骶骨肿瘤1例）、医原性损伤3例（包括椎间盘突出症手术损伤1例、脊髓拴系综合征手术损伤1例、腰椎硬膜外麻醉穿刺损伤1例）；疼痛部位主要位于单侧或双侧下肢22例、肛周会阴区1例、下肢合并会阴区1例；疼痛区域感觉正常1例，感觉减退11例，感觉缺失12例；VAS评分6～10分，平均7.80分。

二、研究方法

1.手术方法 入院后综合评估疼痛部位、疼痛区域感觉情况、下肢运动和大小便功能，分别行脊髓电刺激术或DREZ毁损术，存在一定下肢运动和大小便功能的患者首选脊髓电刺激术；疼痛部位广泛、下肢及大小便功能丧失患者首选DREZ毁损术。（1）脊髓电刺激术：以足部疼痛患者为例，行脊髓电刺激术。手术分两期，一期手术采用神经安定麻醉（NLA），患者俯卧位，经椎板间隙入路，于T_{11}下缘至L_1上缘做竖切口，显露T_{12}棘突和T_{12}–L_1椎板间隙，标记中线位置，黄韧带两侧开窗约1 cm，自T_{11-12}椎板间隙硬膜外植入板状外科电极（39565，美国Medtronic公司），电极尾端连接延长线自切口旁另戳孔引出，延长线经多通道测试电缆连接临时刺激器，返回病房。临时刺激器约测试1周，测试期间疼

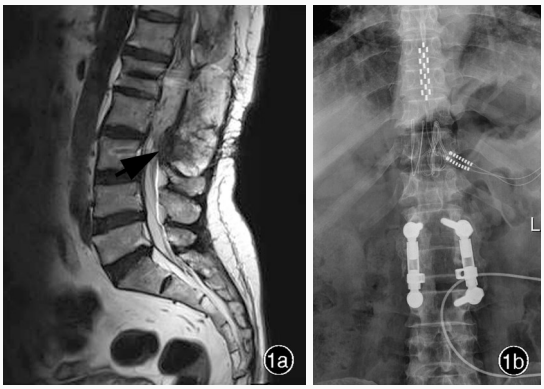

图1 男性患者，66岁，因$L_{1\sim3}$椎管内肿瘤切除术后双下肢疼痛1年入院，临床考虑医原性马尾神经损伤后慢性神经病理性疼痛。行走和大小便正常，先行脊髓电刺激术一期测试，测试期间下肢疼痛缓解良好，再行二期手术植入永久脉冲发生器 1a 脊髓电刺激术前矢状位T_2WI显示$L_{1\sim3}$椎管内马尾神经结构紊乱（箭头所示），未见肿瘤复发征象 1b 一期测试后正位X线显示，自T_{10-11}椎板间隙向头端植入电极，位于$T_{9\sim10}$椎体节段

Figure 1 A 66-year-old male was admitted to the hospital for pain in both lower limbs for one year after the resection of L_{1-3} intraspinal tumor. He was diagnosised as iatrogenic neuropathic pain after cauda equina injury. The movement, urinary and bowel function was normal. The patient underwent SCS screening test. During the test, the lower limb pain was relieved, and then IPG was implanted. Preoperative sagittal T_2WI showed nerve structural disorder in L_{1-3} spinal canal (arrow indicates) and no tumor recurrence (Panel 1a). The anterior-posterior X-ray imaging after the SCS screening test showed the electrode was placed rostrally from the T_{10-11} interlaminar space and be located at the level of T_{9-10} vertebra (Panel 1b).

痛缓解率≥50%且希望继续接受治疗的患者行二期手术。患者侧卧位，气管插管全身麻醉，打开原手术切口，松开电极尾部与延长线的连接，弃除延长线，于腹部皮下切开直至腹直肌，尾端游离呈囊袋，植入永久脉冲发生器（37702，美国Medtronic公司），经皮下隧道将电极尾部贯通至囊袋，连接脉冲发生器（图1）。（2）DREZ毁损术：以双下肢疼痛患者为例，行双侧$L_2\sim S_2$ DREZ毁损术。于T_9椎体下缘至L_1椎体下缘中线做竖切口，$T_{10}\sim L_1$椎板开窗后纵行切开硬脊膜，显露脊髓背侧直至圆锥。部分外力损伤严重患者可见神经根撕脱，脊髓背外侧沟萎缩。脊髓损伤时间较长的患者由于椎管内出血扩散至头端造成脊髓陈旧蛛网膜下腔出血，导致蛛网膜钙化。在L_{1-2}椎间孔探查L_1神经，沿神经向头端找到L_1入髓区，定位L_1，通常每个背根神经发出3～5个根丝进入脊髓背外侧沟，相邻根丝之间的自然间距为1～2 mm，根据这一间距向尾端逐个定位脊髓节段至S_2。于手术显微镜下自脊髓背根腹外侧纵行剪开软脊膜，与脊髓矢状面呈40°～50°以剥离子钝性分离脊髓背外侧沟深约3 mm直至背角，脊髓背角颜色变暗，有纤细纵行滋养穿支进入。分开脊髓背外侧沟后，双极电凝序贯，从头端至尾端连续低功率烧灼脊髓背角（图2，3）。

2.手术疗效及安全性评估 （1）手术疗效：采用VAS评分评估疼痛程度，嘱患者在10 cm的直尺上选择最能代表疼痛程度的刻度，0为无疼痛，10为难以忍受的剧烈疼痛，总评分为10分，评分越高、疼痛程度越严重。计算疼痛缓解率，疼痛缓解率（%）=（术前VAS评分－术后末次随访时VAS评分）/术前VAS评分×100%。疼痛缓解率≥50%判断为手术有效。（2）手术安全性：记录术后出院时及随访期间并发症发生率，主要包括术区感染（电极植入部位和脉冲发生器植入部位）、术区血肿、神经损伤，脊髓电刺激术硬件故障、植入部位积液，以及DREZ毁损术后感觉平面过度上移（术后新发感觉缺失部位超过原有疼痛区域上界2个以上皮节）、新发部位疼痛等。

3.统计分析方法 采用JASP 0.15统计软件进行数据处理与分析。计数资料以相对数构成比（%）或率（%）表示，采用Fisher确切概率法。本研究样本量较小，采用Shapiro-Wilk检验进行正态性检验，呈非正态分布的计量资料以中位数和四分位数间距[$M(P_{25},P_{75})$]表示，采用Mann-Whitney U检验。以$P\leq0.05$为差异具有统计学意义。

结 果

本组24例患者入院后行DREZ毁损术10例（单侧6例，双侧4例），7例疼痛消失；2例部分区域残留疼痛，拒绝再次手术；1例疼痛无改善，行脊髓电刺激术测试，疼痛仍未缓解。入院后行脊髓电刺激术14例，9例疼痛缓解率60%～80%，植入永久脉冲发生器；2例疼痛缓解率为60%，但未达预期，拒绝植入永久脉冲发生器；3例疼痛缓解率<10%，改行DREZ毁损术，2例疼痛完全缓解、1例疼痛仍无改善。本组共24例患者计28次手术，按照手术次数分为DREZ毁损术组（13例次）和脊髓电刺激术组（SCS组，15例次）。DREZ毁损术组9例次疼痛消失，4例次无效；SCS组11例次疼痛改善率60%～80%，4例次无效；两组手术有效率差异无统计学意义（Fisher确切概率法：$P=1.000$）。DREZ毁损术组

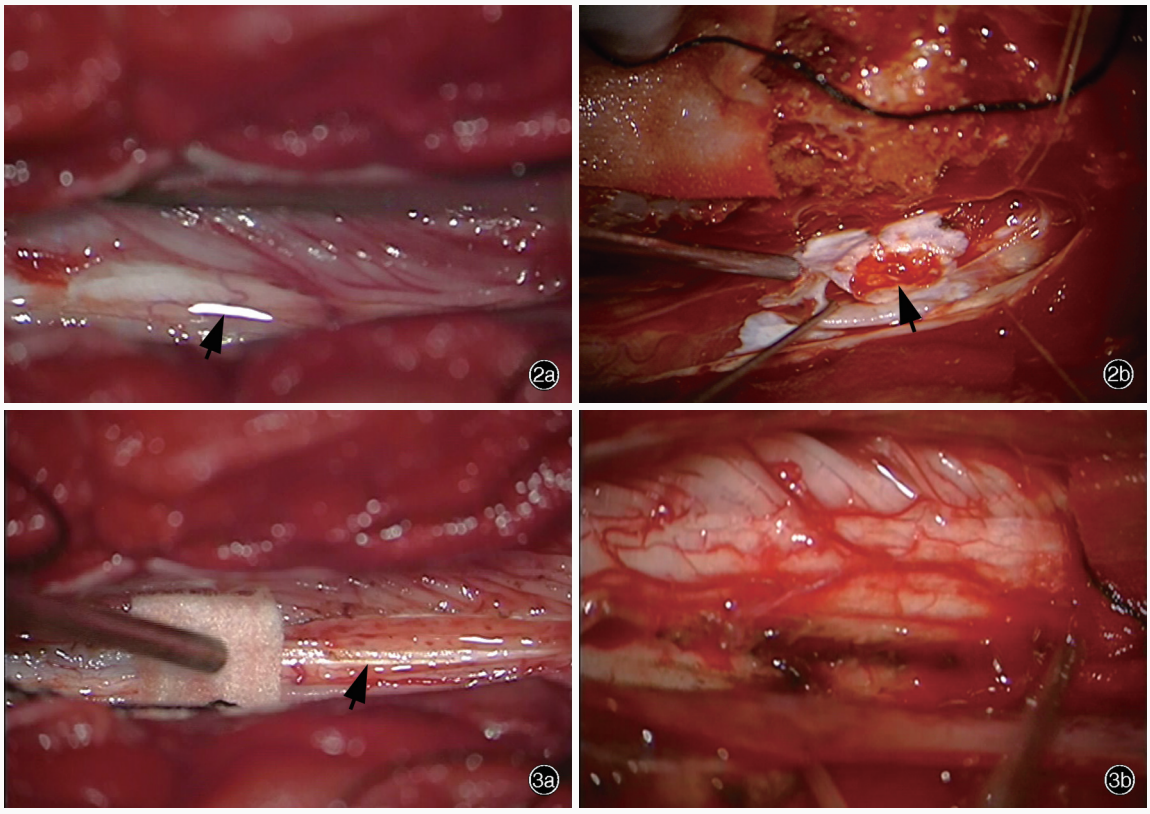

图2 男性患者，39岁，车祸伤致L_3椎体错位骨折，伤后即出现双侧下肢疼痛，行椎管减压内固定术，术后疼痛未减轻，临床诊断为马尾神经损伤后慢性神经病理性疼痛，行双侧$L_1\sim S_2$ DREZ毁损术 2a 术中打开L_1椎板，剪开硬脊膜后清晰显露圆锥（箭头所示），证实患者为单纯马尾神经损伤，圆锥结构完整 2b 术中剪开右侧$L_3\sim S_1$背外侧沟软脊膜，可见脊髓背角内有纤细穿支进入，颜色较脊髓表面发暗（箭头所示） **图3** 男性患者，64岁，背部砸伤致L_2椎体爆裂骨折后下肢疼痛20余年，临床诊断为马尾神经损伤后慢性神经病理性疼痛，行$L_2\sim S_1$ DREZ毁损术 3a 术中打开$T_{10\sim12}$椎板，剪开硬脊膜后可见椎管内大面积蛛网膜钙化（箭头所示） 3b 清理钙化的蛛网膜，显露神经根和脊髓后可见$L_{3\sim5}$按顺序排列，神经根入髓区之间有1～2 mm的间隔

Figure 2 A 39-year-old male suffered from L_3 vertebral dislocation fracture due to a car accident. After the injury, he had bilateral lower limb pain, and underwent spinal canal decompression and internal fixation. The postoperative pain was not alleviated. He was clinically diagnosed as chronic neuropathic pain after cauda equina injury and underwent bilateral L_1–S_2 DREZ lesion. During the surgery, the L_1 vertebral plate was opened, and the conus medullaris was clearly exposed after cutting the dura mater (arrow indicates). It was confirmed that the patient was simple cauda equina injury, and the structure of the conus medullaris was intact (Panel 2a). After incision of the pial of the right L_3–S_1 dorsolateral sulcus, there were fine perforating arteries in the dorsal horn of the spinal cord, and the color was darker than the surface of the spinal cord (arrow indicates, Panel 2b). **Figure 3** A 64-year-old male was injured in the back by a coal mine accident. After L_2 vertebral burst fracture, he had pain in the lower limbs for more than 20 years. He was clinically diagnosed as chronic neuropathic pain in the lower limbs due to cauda equina injury, and underwent L_2–S_1 DREZ derogation. During the surgery, $T_{10–12}$ lamina was opened, after cutting off the dura mater and tracted, a large area of calcification of the arachnoid membrane in the spinal canal could be seen (arrow indicates, Panel 3a). After cleaning up the calcified arachnoid membrane, the nerve roots and spinal cord were exposed, it was clear that the $L_{3–5}$ nerves were arranged in order. There was an obvious interval of 1–2 mm between the nerve root entry zone (Panel 3b).

疼痛缓解率为10%～100%，中位值100%（0，100%）；SCS组疼痛缓解率为10%～80%，中位值60%（0，75%），组间差异具有统计学意义（$Z=0.441$，$P=0.030$），表明DREZ毁损术对疼痛改善效果较为明显。

本组患者随访至术后1～4年，平均2年。出院时均未发生术区感染、血肿、新发神经损伤。DREZ毁损术组有6例术后1周内出现不同程度全身瘙痒、疼痛发作，均为术前口服阿片类及类阿片类药物患者，考虑为术中脑脊液阿片类药物浓度骤降造成的短期戒断症状，出院时均基本缓解；3例疼痛区域上界既往感觉正常区域出现新发疼痛，术后2周至1个月逐渐消失；1例术后1年内疼痛消失，此后原区域疼痛复发，术后2年逐渐加重至术前水平，再次行DREZ毁损术后疼痛消失。SCS组9例植入永久脉冲发生器患者中2例因植入部位反复积液取出

脉冲发生器，余7例长期疼痛缓解效果稳定。

讨 论

病因明确的马尾神经损伤后慢性神经病理性疼痛方考虑手术治疗，故准确判断疼痛病因，有助于制定针对性治疗策略[2,5]。例如，背部手术后出现马尾神经支配区慢性神经病理性疼痛，首先需通过回顾术前症状及影像学检查，核实术前诊断；然后通过分析背部手术前后症状及体征、影像学检查、肌电图等变化以判断疼痛病因：是否术前诊断有误？相关的神经压迫有无解除？是否术中损伤脊髓、马尾神经或神经根？是否椎旁肌过度剥离造成肌肉疼痛？是否术中操作或金属植入物刺激脊髓背根或者内侧支？患者是否存在椎间盘源性腰痛等[4]？本研究有1例66岁女性患者入院前误诊为腰椎术后疼痛综合征（FBSS）[15]，经笔者团队进行病因分析发现，该例患者左下肢L_5支配区出现疼痛合并感觉减退，L_{1-2}椎间盘突出症手术摘除单侧椎弓根内固定后切口有脑脊液渗出，考虑术中硬脊膜破损，加之L_5在L_{1-2}椎间盘水平位于硬膜囊内，考虑手术损伤硬膜囊内L_5神经根所致，最终明确诊断为典型单纯马尾神经损伤后慢性神经病理性疼痛。

单纯马尾神经损伤后慢性神经病理性疼痛的外科治疗需多因素综合分析。根据前驱病史确定损伤部位和病因是首要因素，然后再定位疼痛皮节所对应的神经和脊髓节段、疼痛区域感觉减退程度、下肢运动和大小便功能，并结合影像学检查明确椎管内结构，尤其是圆锥位置[16]。本组24例患者手术方式的选择即参考上述因素：于圆锥水平行DREZ毁损术可破坏L_2以下马尾神经的传入功能，造成术后大小便障碍，故对于疼痛区域感觉正常或略减退、下肢运动和大小便功能正常的患者首选脊髓电刺激术[17-19]；而对于疼痛区域感觉缺失、下肢运动和大小便障碍的患者，首选DREZ毁损术[20-21]。此外，还可能存在疼痛区域感觉缺失或减退，但仍有一定下肢运动和大小便功能的患者，此类患者治疗较为棘手，需根据个体情况：若疼痛区域为单侧且范围较小，可考虑谨慎行单侧DREZ毁损术，术后对下肢运动和大小便功能影响较小；若双侧疼痛，则双侧DREZ毁损术造成下肢功能和大小便障碍的可能性极大，应视为禁忌证，可先行脊髓电刺激术测试，若测试无效，再考虑鞘内持续注射吗啡、可乐定等镇痛药。

单纯马尾神经损伤患者在DREZ毁损术中打开硬脊膜后，大部分可见马尾神经萎缩变细、颜色发红发暗发黄，若外力较严重造成马尾神经牵拉，术中还可见神经根丝撕脱、脊髓背外侧沟萎缩、蛛网膜增生甚至钙化，而圆锥结构通常正常[5]。也有部分低位腰椎损伤致马尾神经损伤患者，打开硬脊膜后发现椎管内蛛网膜增生十分严重，脊髓与硬脊膜粘连明显，可能与外伤时椎管内出血有关。DREZ毁损术中应准确定位神经根节段，把握分离脊髓背外侧沟的角度及深度，是手术成功的重要因素。

慢性疼痛体验对患者而言属于“全”或“无”，仅改善部分区域疼痛，患者往往满意度较低。若疼痛区域较广泛，所有区域疼痛减轻的手术优于仅部分区域疼痛消失的手术。因此术前应根据疼痛区域确定脊髓电刺激术中电极植入位置或DREZ毁损术中需打开的椎体节段及其对应的脊髓节段。本研究有2例$L_{2\sim4}$椎体损伤致腹股沟以下疼痛患者，均行脊髓电刺激术，其中1例电极置于$T_{9\sim10}$椎体节段，余1例置于$T_{10\sim11}$椎体节段，前者腹股沟区域疼痛缓解，而后者未缓解，提示植入电极时应考虑疼痛区域上界，电极植入位置过低易造成疼痛上界无法覆盖，从而影响手术效果。本研究结果显示，DREZ毁损术与脊髓电刺激术的整体有效率无明显差异，但DREZ毁损术对疼痛缓解率优于脊髓电刺激术，主要原因为DREZ毁损术彻底破坏脊髓背角神经元的二级感觉传导通路，而脊髓电刺激术仅为电刺激，对脊髓结构并无破坏。

综上所述，单纯马尾神经损伤后慢性神经病理性疼痛采用DREZ毁损术或脊髓电刺激术均有较好疗效，手术方式和手术节段的选择取决于损伤部位、损伤程度、下肢运动和大小便功能等因素。DREZ毁损术的疼痛改善率较高，但属于不可逆操作，临床医师应谨慎选择。

利益冲突 无

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《中国现代神经疾病杂志》编辑部关于稿件统计分析方法的要求

《中国现代神经疾病杂志》编辑部对来稿中的统计分析方法一律要求明确研究设计方法,以及详细描述资料性质和结果,具体要求如下:

1.研究设计方法 要求交代研究设计的名称和主要方法。如调查设计应写明是前瞻性、回顾性还是横断面调查研究;实验设计应写明具体设计类型,如自身配对设计、成组设计、交叉设计、析因设计或正交叉设计等;临床试验设计应写明属于第几期临床试验,采用何种盲法措施等。应围绕"重复、随机、对照、均衡"四项基本原则进行概要说明,尤其要说明如何控制重要的非试验因素的干扰和影响。

2.资料及结果的表达与描述 采用均数±标准差($\bar{x}\pm s$)表示近似服从正态分布的定量资料,采用中位数和四分位数间距[$M(P_{25},P_{75})$]表示呈偏态分布的定量资料;采用相对数构成比(%)或率(%)表示计数资料,用相对数构成比时分母不能小于20。应写明所用统计分析方法的具体名称、统计量具体值,应尽可能给出确切的P值;当涉及总体参数时,在给出显著性检验结果的同时,给出95%CI。