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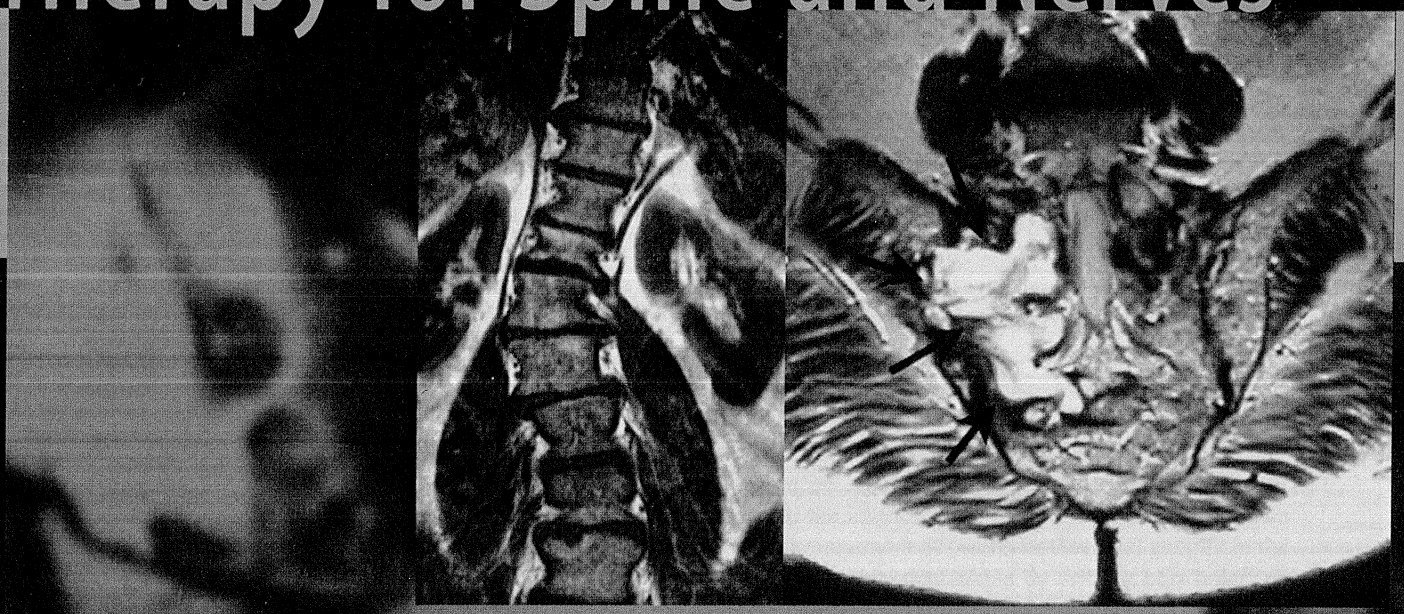
Advances in Minimally Invasive Surgery and Therapy for Spine and Nerves



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Application of Pulsed Radio Frequency to the Dorsal Horn and Dorsal Roots

Omar Omar-Pasha MD

Abstract In the world of neuromodulation for pain management, the new multifunctional electrode presented in this article, together with the associated procedure described, considerably extends the range of therapeutic options in the hands of pain physicians. Besides the definite therapeutic effect, the lower rate of complications and side effects, further factors also make this new procedure and device appear an attractive diagnostic and therapeutic modality.

Keywords Dorsal horn stimulation · Functional DREZectomy · Multifunctional electrode · PASHA-electrode® · PRF spinal cord modulation

Introduction

The treatment of chronic pain remains a challenge in modern medicine. Whenever pharmacologic and other conservative treatments of chronic pain fail, ablative and interventional methods are attempted on the assumption that interrupting nerve conduction prevents central pain cognition [21]. Chemical procedures such as injecting phenol or alcohol [8] have been almost completely replaced by cryosurgical and especially thermosurgical interventions because of their superior dosability and placement accuracy [17, 25]. High-end therapies such as spinal cord stimulation or intrathecal drug infusions are expensive and not free of complications [22]. There is still a large gap between the standard therapies and these high-end methods [2].

When using the thermosurgical approach, radiofrequency thermocoagulation (RFTC) is the method of choice. The temperatures applied usually reach 70–85°C [7, 15].

Since pulsed radiofrequency (PRF) technology has been shown to be effective in the management of chronic pain, it is an interesting option for the invasive treatment of chronic pain and has a much lower rate of side effects compared to other techniques [1, 10, 18]. The temperature in the treated tissue does never rise above 42–43°C and there is thus no tissue destruction (Fig. 1).

Histochemical investigations have shown enzyme-like protein induction in PRF-treated nerve cells which is not observed in cells treated with continuous RF [6]. Moreover, histological analyses have not revealed any significant tissue damage to the treated nerve cells [3]. Maintaining a safety distance from the treated nerves is no longer necessary, on the contrary, distance diminishes the outcome.

Since only rigid electrodes and the thin electrodes (SMK-electrode) developed in the 1980s were available interventions had to be restricted to stimulating the nerves in or peripheral to the intervertebral foramina. A closer approach to the roots or treatment of (sacral or thoracic) ganglia in the spinal canal was only achievable by drilling burr holes, an intervention eschewed by many pain specialists [19].

In 2003, the flexible multifunctional electrode (PASHA-electrode®) was developed.

The multifunctional electrode is a flexible probe which allows us to apply PRF without restriction to almost any-target. This flexible electrode is a combination of a catheter with two electrodes located at the tip.

The rationale underlying this approach is that the dorsal horn plays a central role in modulating all nociceptive inputs on their way to the central nervous system.

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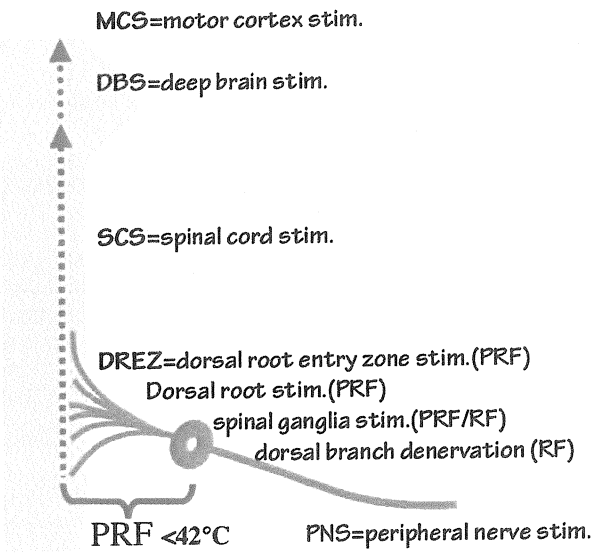

Fig. 1 Targets for neuromodulation. *PNS* peripher nerve stimulation; *PRF* pulsed radiofrequency stimulation of the DREZ region; *SCS* spinal cord stimulation; *DBS* deep brain stimulation

With this Device We Can Perform the Following Procedures

- Stimulate any nerve or spinal nerve root at any frequency, e.g. 80 Hz test stimulus for sensory stimulation, in order to determine the exact level
- Apply PRF at the dorsal root entry zone, the dorsal roots and conus medullaris peripheral nerves and any other structures
- Injection of medications and agents
- Online measurement of the temperature at the tip to avoid damage to surrounding tissues
- Accurate placement without the need for radiopaque contrast materials, due to the visibility of the device in radiography and test stimulations
- SCS trial stimulation
- The multifunction device can be left in place for repeated PRF or injections

This paper summarizes these results and presents technical conclusions. After the treatment of more than 2500 patients, new algorithms have been developed for the management of chronic pain patients.

The Multifunctional Electrode

The flexible multifunctional electrode is a combination of a catheter and two electrodes placed at its very soft distal end (each 3 mm long and 4 mm apart). The distal opening of the catheter is situated between the two electrodes. The catheter is 60 cm long and has a maximum outer diameter of 1.38 mm (4 F), the stylet diameter is 0.35 mm (Fig. 2).

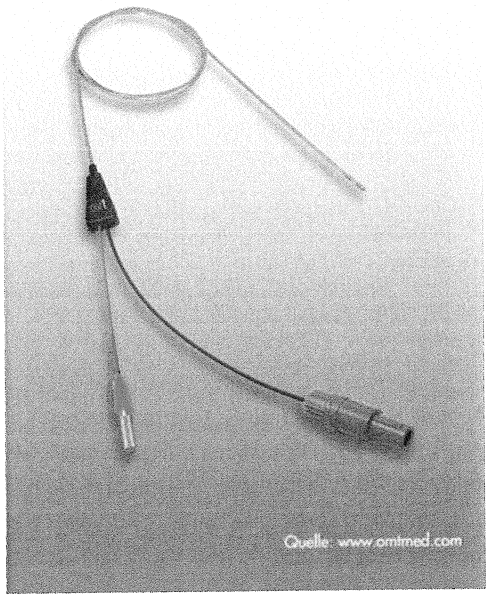

Fig. 2 Multifunctional electrode (PASHA-electrode)

Stimulation Parameters

The generator power output is in the 0,1–5 Watt range (in a few cases above 10 W). The conductivity of electrical current in epidural fat is very low ($0.04\ \Omega^{-1}\ m^{-1}$) compared to $1.4\ \Omega^{-1}\ m^{-1}$ in the CSF. The duration of the active phase is 20 ms and the pause between active phases lasts 480 ms, resulting in two active phases per second. The voltage usually is less than 45V (Fig. 3).

Practical Implementation

The epidural space is accessed using the loss-of-resistance technique. X-ray visualization is recommended. The narrowness of the epidural space should be considered and only small amounts of NaCl injected. In the cervico-thoracic region, the ligamentum flavum is thin and may even be non-existent, in which case the loss-of-resistance technique is inaccurate and even dangerous. For that reason, we prefer to penetrate the epidural space at the T3/4/5 level or even lower when treating the cervical spine (Fig. 4).

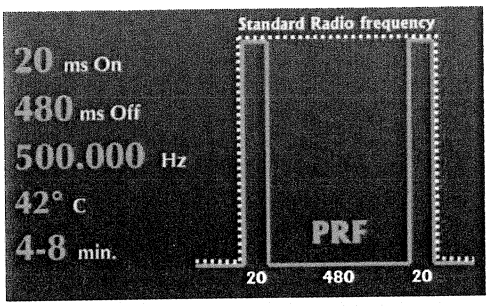

Fig. 3 PRF-stimulation parameters

Fig. 4 The paramedian access from the contra-lateral side

Our standard approach for lumbar, sacral and radicular pain in the legs is the paramedian access L3/4 from the contra-lateral side. We use introducing cannulae familiar to us from introducing spinal cord stimulation (SCS) electrodes [13, 14]. The introducer should not be less than 14 G to avoid difficulties in handling the electrode or prevent damage to the multifunctional electrode (Fig. 5).

Approximately 1.5 cm proximal to the tip, we bend the electrode slightly to make navigation easier (approximately 20–30°). This curvature must not be excessive as this would complicate the reinsertion of the mandrins (Figs. 5–8). We do not place the multifunctional electrode over the dorsal column as in SCS. When treating the lumbar and sacral area, our target is the dorso-lateral parts of the spinal cord (Fig. 9).

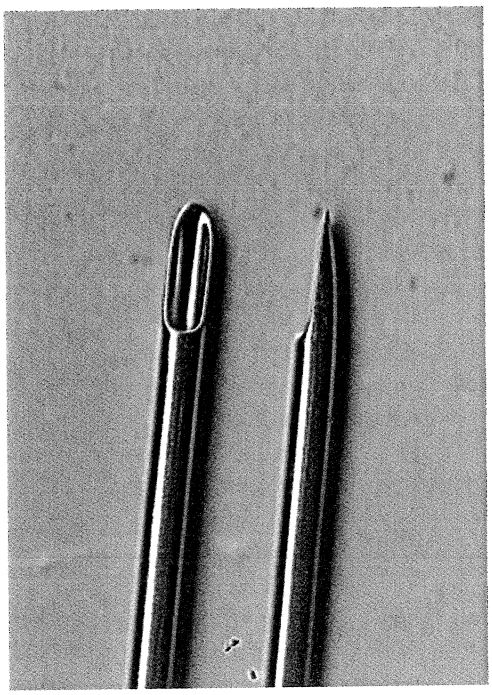

Fig. 5 14G Introducer

Targets When Treating the Spinal Cord and Its Nerve Roots

- By introducing the electrode using a paramedian approach and entering the epidural space between the third and fourth lumbar intervertebral space, we can treat all the lumbar roots and the upper sacral roots (Figs. 9–12).

Using this approach we are also able to treat the conus.
The electrode can be advanced, if required, to the thoracic and even cervical parts of the spinal cord. Usually, if our target is the thoracic region, we prefer to enter between the second and third vertebra. When treating the cervical spine, we usually introduce the electrode between the third and fourth thoracic vertebra.

- Treating the DREZ region at the conus medullaris or at the levels of the lower thoracic spine appears to have a similar outcome as treating the nerve roots directly. The specific indications for the different targets in the future will have to be determined by further research (Fig. 13).
- The electrode can be introduced via the sacral hiatussacral hiatus. This method was adapted from our experience in performing adhesiolysis. The primary indication for this method is treatment of the sacral nerves, which are difficult to approach in the lumbar spine because they are concealed ventral to the lumbar roots. For the management of mononeuropathy, e.g. affecting the pudendal or obturator nerves, we chose the sacral approach. Treating

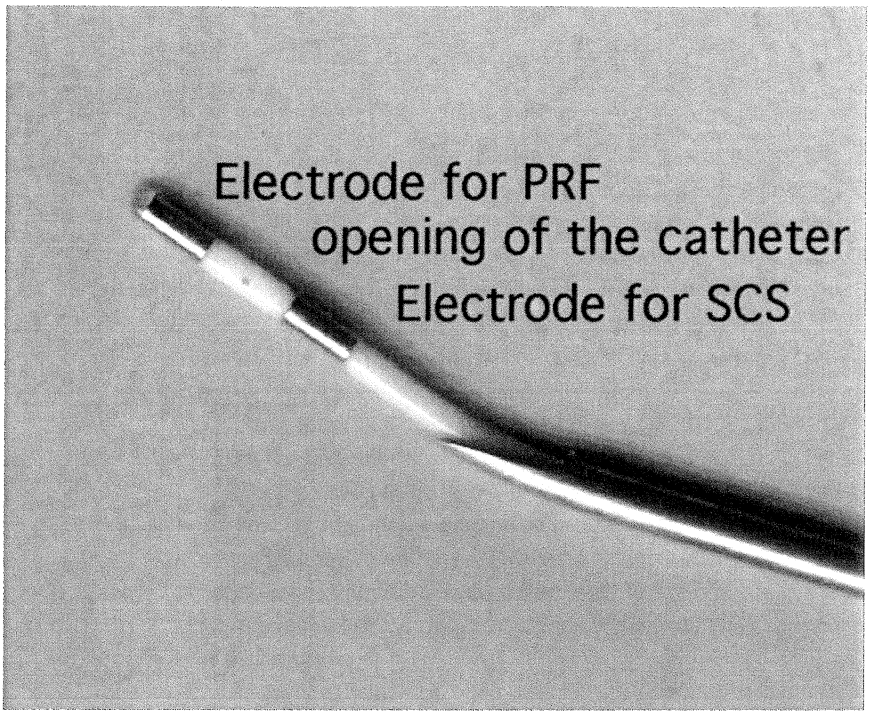

Fig. 6 Tip of the electrode. Notice the slight bending of the tip

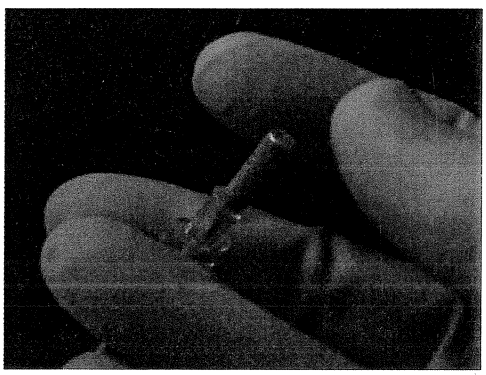

Fig. 7 Fixing the end of the electrode by the third and fourth digit

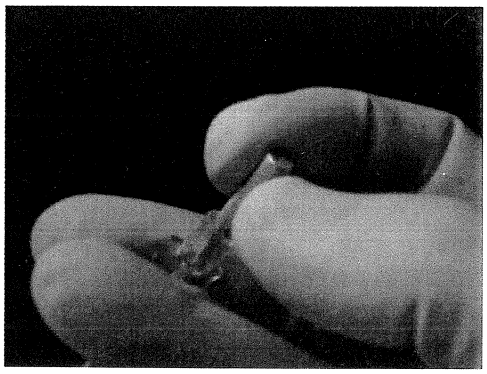

Fig. 8 Steering the mandrin by forefinger and thumb

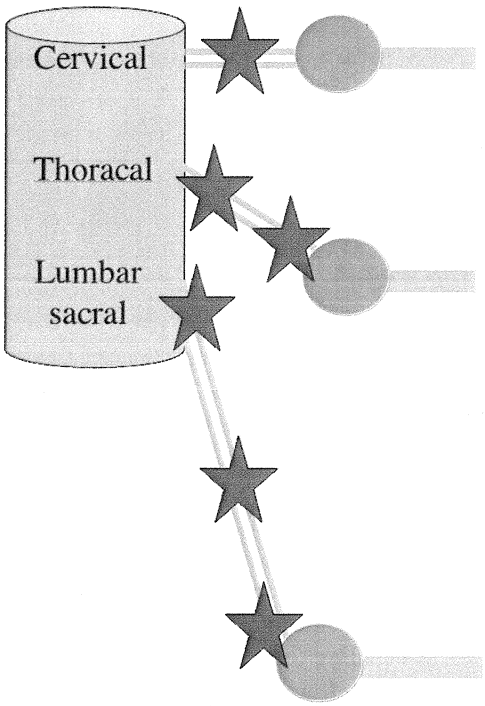

Fig. 9 Possible targets for PRF-stimulation at different spinal cord levels

the distal parts of the sacral roots therefore modulates the dorsal root entry zone (Fig. 14).

If the requirement is to treat an oligo or monoradiculopathy or use the technique for "educational" purposes, it is

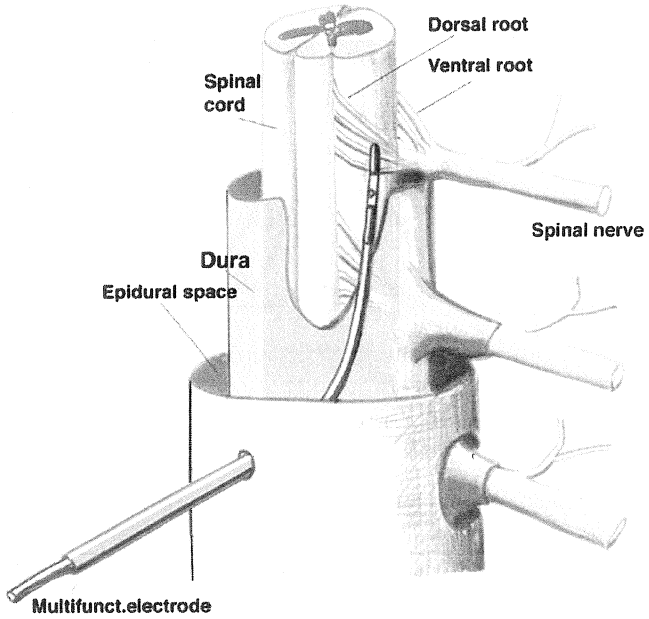

Fig. 10 View of the lumbar spine showing the position of the multifunctional electrode

preferable to stimulate the dorsal nerve roots directly. The technique can best be demonstrated in this region. Clearly, stimulating the roots one by one is the most time consuming of all techniques. For the patients, however, this technique is the most impressive because it allows them to identify each root exactly, thereby making it easier to distinguish the different painful areas. This can be psychologically significant.

The patient is placed in the prone position with a cushion under the abdomen to reduce the lordosis.

The return electrode (ground plate) is positioned cranially to the area we intend to modulate or ventrally over the abdomen.

Local anaesthesia is administered which already provides important information about the tissue to be passed. If the intervertebral space is too bony, the approach can be changed at this stage.

A small incision is made and the introducing cannula is advanced to the intervertebral ligaments.

The epidural space is accessed using the loss-of-resistance technique. Since many patients suffering from chronic pain have already undergone several operations, the procedure is sometimes not easy. If the dura is uninten-

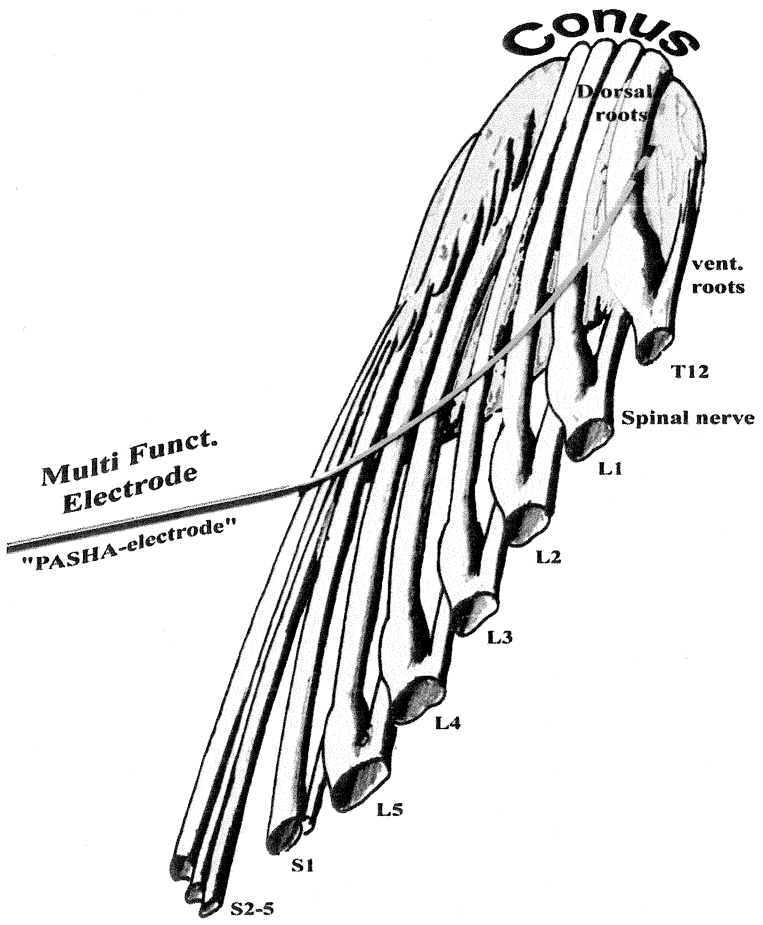

Fig. 11 PRF stimulation of the conus medullaris and dorsal roots

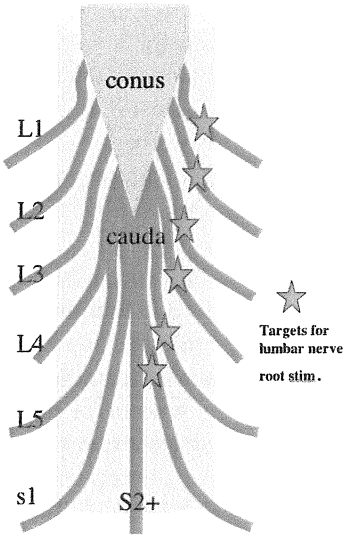

Fig. 12 PRF stimulation of the lumbar spinal roots

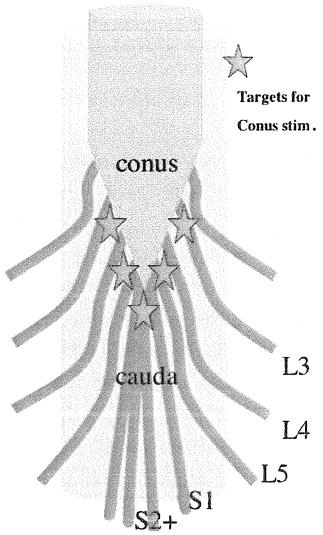

Fig. 13 PRF stimulation of the conus medullaris

tionally punctured, the introducer is not retracted, and the procedure is continued. The following steps are even easier if performed intrathecally and PRF appears to be even more effective. The intrathecal approach is not the preferred method because of the likelihood of dural headache and other possible – if rare – complications.

The electrode is introduced through the cannula and advanced smoothly towards craniolateral. The soft curved tip acts as a guiding mechanism facilitating advancement to the levels above the area to be treated.

It should be attempted to produce perceptible stimulation in the patient with voltages <0.8 V to ensure that the tip of the electrode is close enough to the nerve roots, which considerably enhances the effect of the PRF. If the electrode

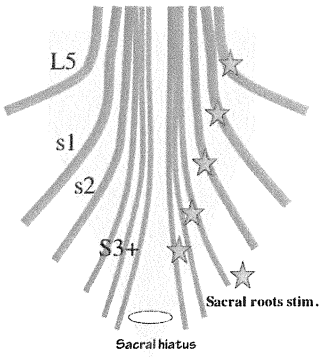

Fig. 14 PRF stimulation of the sacral and lumbar roots via hiatus sacralis

is accidentally or intentionally positioned intraspinally, the stimulation is perceived at considerably lower currents – sometimes as low as 0.1 V. However, the currents required vary depending on where the electrode is positioned in the spinal canal. If the dura is thick or calcified, higher currents may be required. If there is severe nerve root damage and deafferentation, the patient often has no sensation. In this case, it is necessary to rely on the fluoroscopic position of the electrode.

In this way the roots can be located and treated in succession.

The duration of the active phase is 20 ms and the pause between active phases lasts 480 ms, resulting in two active phases per second.

Each nerve root is stimulated for 240 s. The temperature at the electrode tip measured online does not exceed 42°C.

The goal is to achieve the closest possible proximity to nervous structures.

The dorsal roots are stimulated with 70 Hz and the electrode tip is moved until the stimulation is sensed by the patient at its lowest voltage threshold.

The identified nerve roots are then treated with PRF. The electrode is gently withdrawn applying continuous stimulation until the following caudal root is localized, which is identified in the same manner by test stimulation and treated with PRF.

Results

Pain Reduction

95 of the first 101 treated patients, post-treatment pain ratings were obtained after 3 months
Mean age 59.7 years (maximum 94, minimum 32).
Females 71, males 27
88 patients lumbar pain – 1 patient thoracic pain – 11 patients cervical pain.
75 patients had back pain – 55 patients leg pain – 15-patients had neuropathic pain.

The mean VAS score before treatment was 8.5±1.3 U with a minimum 5 U and a maximum 10 U, indicating severe pain.

The mean post treatment pain score was 4.3±2.8 U, with a minimum 0 U and a maximum 10 U, indicating that some patients did not benefit from the treatment. Nevertheless, the pain reduction in the pre-post comparison is highly significant ($p<0.0001$). Mean pain reduction was 48.3%.

Dividing the group according to the duration of PRF stimulation (60, 120, and 240 s), the pre-post comparison for pain reduction in each subgroup is still highly significant (60 s, $N=21$, $p=0.0002$; 120 s, $N=28$, $p<0.0001$; 240 s, $N=46$, $p<0.0001$). Pain reduction in the subgroup with a 240-s stimulation period was mean 54.7±33.0%.

Besides the mean pain reduction, it was to be ascertained how many patients benefited substantially (more than 70% pain reduction) from the treatment. With a stimulation period of 60 s, 3 of 21 patients (14.3%) had a pain reduction of more than 70%. With a stimulation period of 120 s, 9 of 28 patients (32.1%) experienced this degree of pain reduction and with a stimulation period of 240 s, 22 of 46 patients (47.8%) experienced 70% pain reduction. These differences in frequency distribution were statistically significant (chi-square=7.29, $p=0.0262$) (Fig. 15).

PRF treatment of 101 patients was found to provide definite pain reducing effects without evidence of neuronal lesions. The only side effects were headache in four patients due to accidental intrathecal puncture.

With a stimulation period of 60 s, which is also used in RFTC, 3 of 21 patients (14.3%) had a pain reduction of more than 70%, and when the stimulation period was increased to 240 s, 22 of 46 patients (47.8%) responded with a pain reduction of more than 70% (Figs. 16–18).

The analysis showed a highly significant treatment effect. Using a 240 s stimulation period, 47.8% of the patients experienced a pain reduction of 70%.

The main parameter influencing the pain reducing effect was the stimulation period.

Long-Term Follow-Up

Post-treatment pain ratings were obtained of the first 101 treated patients after 3 years. Sixty-four patients answered the questionnaire:
The mean VAS score before treatment was 8.85. The mean VAS score after >3 years was 3.12.
The comparison for pain reduction: Post-operative pain reduction after 4 weeks was 80.71%. After >3 years the pain reduction was still 64.79%.
The team of V.Vadokas in Heilbronn had the following results $N=44$. The mean VAS score before treatment was 9.55.

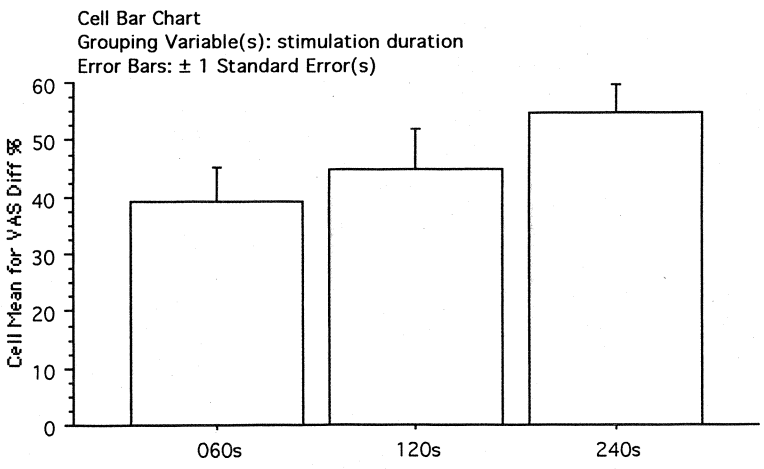

Fig. 15 Percent of pain reduction depending on stimulation period (60, 120, and 240 s). The longest stimulation period shows the best effect. Differences between 60, 120, and 240 s were statistically significant ($p=0.0462$)

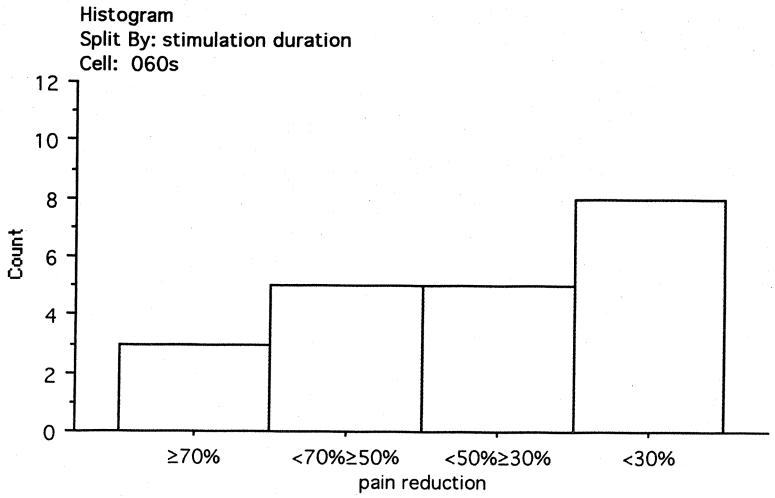

Fig. 16 Stimulation duration 60 s. Number of patients with a pain reduction of 70, <70 to 50, <50 to 30 and <30% respectively. The differences in frequency distribution are statistically significant (chi-square=7.29, p=0.0262)

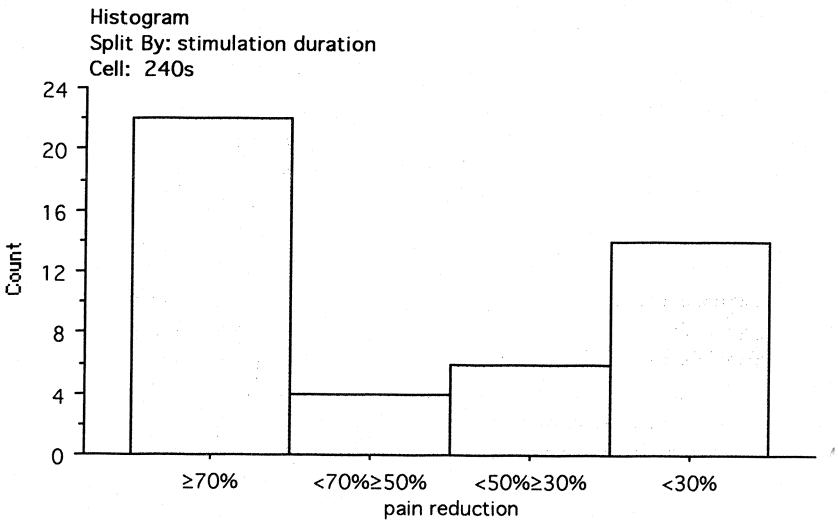

Fig. 17 Stimulation duration 120 s

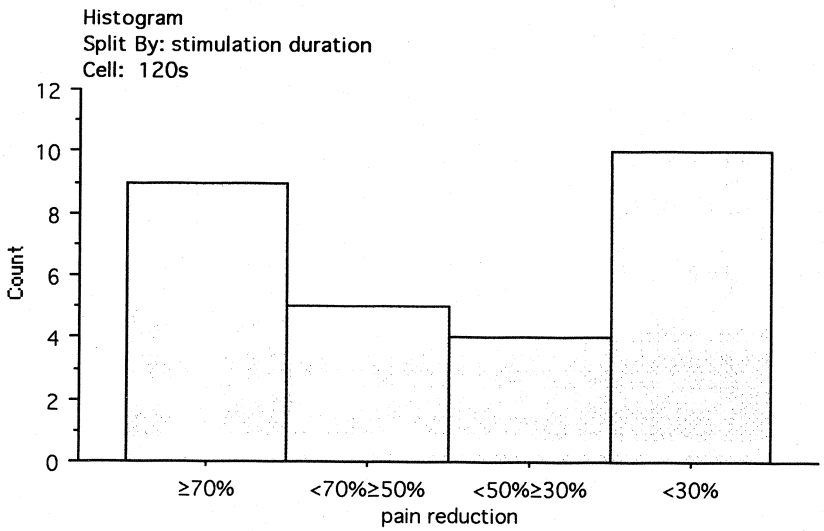

Fig. 18 Stimulation duration 240 s

Post-operative pain reduction after 4 weeks was 77.95%. After 12 months the pain reduction was 70.30% (personal information 2007).

Indications

The indications established to date for pulse radiofrequency (PRF) treatment and/or infiltration by means of the multifunction electrode are:

- Neuropathic pain
- CRPS 1 and CRPS 2
- "Failed back surgery syndrome"
- Cervical and thoracic spinal pain syndromes. Here this approach is safer and avoids the complications of the conventional needle puncture techniques
- Mixed pain: back and radicular pain
- All indications suitable for facet joint denervation (specifically thoracic and cervical)
- Multi-level spinal stenosis
- Restless leg syndrome
- Cervicogenic headache
- Visceral pain?

The varying origin of chronic pain sometimes makes it necessary to combine different procedures and apply them successively. The multifunction electrode allows multiple procedures to be completed in a single step, minimizing possible complications, treatment time and costs.

The new approach is not intended to replace SCS, but is merely a step in the therapeutic algorithm, and may help patients without implanting expensive devices or attempting other invasive techniques.

In addition to the benefits described above, there is no longer any need for all the test infiltrations usually performed to identify pain pathways. The levels can be mapped more accurately with the electrode – and with fewer complications.

In fact, there are no complications except those also observed with any other catheter or electrode.

Since we are treating the transmission and translation of pain and are modulating the dorsal horn entry zone, the origin of the nociceptive input is not a primary consideration.

Causal treatment should self-evidently be the goal of every treatment, but where it fails, multifunctional electrode PRF can be used to modulate the input of the spinal cord at the dorsal root entry zone before considering the use of destructive techniques, SCS, intrathecal drugs or even initiating the use of morphine.

Topics of Interest for Future Research

- The optimal stimulation parameters have to be determined. It is not known whether a stimulation period longer than 240 s might provide even more effective pain relief.
- The long-term effect of the procedure also has to be evaluated. Good results have been reported in 2-year follow-up studies for radiofrequency thermocoagulation [9, 12, 15], but not yet for the relatively novel pulsed radiofrequency technology.
- In addition to stimulation of the spinal nerves, blockades of sympathetic ganglions are a common approach to treatment of chronic pain. Koenig et al [7] reported the effect of radiofrequency thermoçoagulation on the superior cervical sympathetic ganglion in non-traumatic neck pain. Applying PRF to sympathetic structures can yield comparable results [11].
- We used PRF stimulation of the dorsal roots in patients with neuropathic bladder dysfunction with extremely promising results. However, it is still too early to draw statistically significant conclusions.

It is not yet possible to predict the treatment outcome. There still is a lack of knowledge as to how the pain processing system functions and what physical and psychological parameters may alter the effect of the treatment. But is there an understanding of how spinal cord stimulation works, even though this procedure has been performed for decades?

Discussion and Outlook

An important factor in the pathogenesis of chronic pain appears to be the conditioning of central nervous structures by persisting sensory input of A-delta- and c-fibres of the peripheral nerve [14, 23]. The use of radiofrequency currents to interrupt this sensory input (radiofrequency thermocoagulation, RFTC) is effective in treating patients with chronic back pain syndrome [5, 25], although the idea that noxious heat is the main effect is doubted [16, 20]. Especially when using the radiofrequency current in pulsed mode (pulsed radiofrequency, PRF) the temperature in the tissue surrounding the electrode tip does not exceed 42°C, so that the electric field itself is thought to be effective in modulating

the sensory input to the spinal cord [10, 11, 16, 18, 20]. The main advantage of the PRF technology is thus the low risk of damaging the neuronal structures and causing sensory or motor impairment [2, 10].

In the treatment of 101 patients with PRF reported above, clear-cut pain reducing effects were observed without evidence of neuronal lesions. The only side effect was headache in four patients due to accidental intrathecal puncture. The main parameter influencing the pain reducing effect was the stimulation period. With a stimulation period of 60 s, which is often used in RFTC [15], 3 of 21 patients (14.3%) had a pain reduction of more than 70%, and when the stimulation period was increased to 240 s, 22 of 46 patients (47.8%) responded with a pain reduction of more than 70%. These results are very promising compared to those of RFTC technology [4, 12, 24].

Although PRF treatment shows good efficacy and is very safe, its use continues to present technical challenges. As mentioned above, PRF treatment produces the best results when the patient feels the sensation in the same area as the pain during diagnostic low frequency stimulation. This requires a search procedure to find the optimal stimulation position in the area of the dorsal root entry zone (DREZ).

With relatively rigid equipment like SMK-electrodes, this search procedure often requires multiple punctures at different sites. This can damage blood vessels or spinal nerve roots and can be very unpleasant for the patient. Especially in the cervical region, there is the risk of injuring the vertebral artery. In the thoracic region, the conventional needle approach can result in pleural puncture. The thoracic and sacral ganglia cannot even be treated without drilling holes.

The multifunctional electrode solves many of the technical problems associated with the use of PRF. The technique is comparable to that of an SCS electrode or an epidural catheter. The electrode can replace periradicular and paravertebral injections as well as facet joint denervations, since these interventions can be completed in a single-step procedure.

Conclusions

The new multifunctional electrode presented in this article, together with the associated procedure described above, considerably extends the range of therapeutic options for the management of chronic pain. In addition to the definite therapeutic effect, the lower rate of complications and side effects also make this new procedure and device appear an attractive diagnostic and therapeutic modality.

The 2,500 patients we have treated so far had undergone several other treatments that failed, meaning that a selection effect for "untreatable cases" may have been present. Very promising results were achieved in this sample and the outcome may be even better in "standard" chronic pain patients.

It is planned to modify the technique, optimize the parameters and define the indications and outcomes with greater accuracy in the future. PRF application to the dorsal horn entry zone and the dorsal roots could play a major role in the management of pain.

Conflicts of Interest Statement We declare that we have no conflict of interest.

Since this procedure has only minimal side effects (if any), its use can be considered where conservative treatments have failed and before performing ablative procedures or surgery, or even before considering long term opiate medication.

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