M. Schaan
B. Boszczyk
H. Jaksche
G. Kramer
M. Günther
M. Stöhrer

Intraoperative urodynamics in spinal cord surgery: a study of feasibility

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M. Schaan (✉) · B. Boszczyk · H. Jaksche
Department of Neurosurgery,
Unfallklinik Murnau,
Prof. Küntscher Strasse 8,
82418 Murnau, Germany
Tel.: +49-8841-482851,
Fax: +49-8841-482854,
e-mail: mschaan@bgu-murnau.de

G. Kramer · M. Günther · M. Stöhrer
Department of Urology,
Unfallklinik Murnau,
Prof. Küntscher Strasse 8,
82418 Murnau, Germany

Abstract Intraoperative monitoring (IOM) of bladder function in spinal cord surgery is a challenging task due to vegetative influences, multi-level innervation and numerous supraspinal modulating factors. Despite routine use of urodynamics in neurosurgery for implantation of bladder stimulators or denervation of nerve fibres in spastic reflex bladders, application of IOM in patients with spinal cord tumours or tethered-cord syndrome is not widespread. Combining urodynamics with sphincter electromyography (EMG) in IOM enables identification of bladder efferents responsible for contraction and continence. We monitored four patients with ependymoma of the Cauda equina, one patient with tethered-cord syndrome and two patients with cervical intramedullary tumours. In all patients undergoing operations of the Cauda equina,

identification of bladder efferents responsible for detrusor contraction was possible. There was good correlation between preoperative bladder dysfunction, preoperative urodynamics and intraoperative pressure increase by bladder contraction or latency between stimulation and contraction. This method proved unsuitable for intramedullary tumours where no contraction of the bladder could be observed while stimulating the spinal cord. Intraoperative monitoring of urodynamics is an effective tool for identifying bladder efferents in the Cauda equina. Intraoperative conclusions on bladder dysfunction through registration of pressure increase and latency are possible.

Keywords Intraoperative monitoring · Neurogenic bowel · Urodynamics · Spinal cord surgery

Introduction

The use of urodynamics in spinal operations is an established method in neurosurgery, in particular for the denervation of spastic reflex bladders [6, 13, 14] or for the implantation of bladder stimulators to support bladder contraction in paraplegics [4, 5, 6, 13]. Despite these applications, the use of urodynamics in IOM is not practised routinely and only few publications on this subject are found [5, 12, 15]. Routine use of somatosensory evoked potentials (SEP) or continuous EMG recordings are a standard in most neurosurgical units [3, 8, 10, 11]. Our intention

was to evaluate the use of urodynamics in spinal cord surgery and to determine indications, possible applications and limitations of this method. Monitoring of bladder function focuses mainly on the preservation of continence and voiding. The control of urinary continence by continuous EMG recording of the external anal sphincter is a well-established method in neurosurgery [1, 7, 9]. According to James et al. [7] muscle action potentials of the external anal sphincter reflects the function of the external urethral sphincter as both are innervated by the pudendal nerve from the S2–S4 segments.

Monitoring of voiding ability is less straightforward than EMG recording due to bladder function being controlled

by a multineural complex of supraspinal and spinal cord pathways, local segmental reflex arcs and autonomic nerve structures with excitatory and inhibitory impulses. The parasympathetic system innervates the musculature of the bladder via the pelvic nerve which arises from the lateral horns of the spinal segments S2–S4 and synapses with postganglionic fibres near the bladder. The sympathetic system arises preganglionic from the spinal cord between Th11 and L2 with most of the fibres synapsing with the postganglionic fibres in the inferior mesenteric and sacral ganglia. These postganglionic fibres together with the preganglionic fibres from the spinal cord make up the hypogastric nerve. Besides many other functions, the sympathetic fibres enable relaxation of the detrusor vesicae, while the voiding contraction is mediated parasympathetically. Intraoperative stimulation of the parasympathetic nerve roots S2–S4 results in detrusor contractions of the bladder with consecutive pressure increase. These pressure changes can be measured urodynamically. Regarding the spinal cord above the conus medullaris, it may be expected that stimulation of the corticospinal or reticulospinal tracts would induce changes in bladder tension as the fibres travelling through these tracts modulate the micturition centre within the conus medullaris.

Materials and methods

We monitored four patients with ependymoma of the Cauda equina, one patient with tethered-cord-syndrome and two patients with cervical intramedullary tumours. Patient demographics are listed in Table 1. All patients referred for treatment of intradural tumors during a 12-month period were included in the investigation. The patients suffered from neurological complaints from 1 month to 2 years duration, four of them showed incomplete paraplegia (patients 1 and 4) or tetraplegia (patient 6 and 7); prior surgery had been done in 1 case (patient 1) resulting in incomplete tumor resection 1.5 years before by another neurosurgical unit.

Patients 1 and 4 had impaired preoperative bladder function: patient 1 suffered from urge incontinence and patient 4 from stress incontinence while coughing and sneezing. The bladder history showed elevated residual urine in both cases (130 and 200 ml). Patient 1 had pathological detrusor activity during bladder filling. Both patients showed an inadequate pressure elevation during bladder contraction.

Technique

Two hundred fifty milliliters of normal saline at 37°C is instilled into the bladder through a regular double-lumen transurethral catheter. The catheter is connected to a pressure device and the pressure changes are recorded by a transportable urodynamic unit. A rectal balloon catheter is used to record the abdominal pressure according to the International Continence Society's recommendations [1]. As the bladder lies entirely within the abdominal cavity, any abdominal pressure change is transmitted to the bladder, increasing the intravesical pressure (P_{ves}). The pressure built up by the detrusor contraction (P_{det}) can now be calculated as the difference between these simultaneously measured parameters:

$$P_{det} = P_{ves} - P_{abd} \quad (1)$$

All three pressure values are simultaneously displayed as trend curves and digital values.

In order to maintain a constant level of expertise during this investigation, the monitoring was exclusively performed by very experienced staff members of the Department of Urology. They continuously assessed the electronic feedback of the stimulation, immediately reporting pressure elevations by bladder contraction and consecutively enabling identification of the bladder fibres by the surgeon.

All of our patients were stimulated intraoperatively in the same manner using bipolar stimulation instruments with a frequency of 4.6 square pulse stimulations per second. Stimulation levels did not exceed 4–5 mA and the operative field was kept as dry as possible. These measures are necessary to limit the stimulation to the desired nerve root. All of our cases underwent a preoperative urological examination with urodynamic evaluation, regardless of whether preoperative bladder dysfunction was suspected or not. As all patients were surgically treated in the prone position, the intraoperative pressure level of the bladder recorded before stimulation was between 5 and 10 cm H₂O.

The other applied IOM parameters were continuous 6-channel EMG activity recordings of the quadriceps femoris, tibialis anterior and gastrocnemius muscles and the external anal sphincter along with SEP recordings following tibial nerve stimulation.

No specific anaesthesia protocol was used in this collective with the exception of limiting muscle relaxants to the intubation.

The monitoring setup can be done during the anaesthesiological preparations and does not take longer than 10 min. With the exception of the portable urodynamic unit (which is a routinely used device in the Department of Urology), the additional costs for this procedure are minimal (catheters and saline).

Results

The intraoperative identification of nerve fibres from S2 to S4, inducing detrusor vesicae contraction after stimula-

Table 1 Patient demographics

Patient no.	Age (years)	Gender	Diagnosis	Local pain	Radicular pain	Motor deficit	Sensory deficit	History
1	43	M	Ependymoma Cauda equina L3	Yes	Yes	Yes	Paraplegic incomplete	2 years
2	57	M	Ependymoma Cauda equina L5	Yes	Yes	Yes	Radicular	13 months
3	52	F	Ependymoma Cauda equina L3	Yes	Yes	Yes	Radicular	6 months
4	38	F	Ependymoma Cauda equina L5/S1	Yes	Yes	Yes	Paraplegic incomplete	2 months
5	31	M	Tethered-cord syndrome	Yes	No	No	Pseudoradicular	19 months
6	48	F	Intramedullary astrocytoma C4	No	No	Yes	Tetraplegic incomplete	1 month
7	62	M	Intramedullary astrocytoma C7	Yes	No	Yes	Tetraplegic incomplete	2 months

Fig. 1 Patient 4. Ependymoma Cauda equina L5/S1, bladder function impaired, residual urine

Fig. 2 Patient 1. Ependymoma Cauda equina L3, bladder function impaired, residual urine. Stimulation intensity 5 mAmp, pdet 35 cm H₂O, Latency 10 s

tion, was possible in all cases of spinal tumours of the Cauda equina and tethered-cord syndrome. The pressure increase after stimulation was between 35 and 70 cm H₂O, and the latency between stimulation and contraction was between 2 and 10 s. The stimulus had to be applied continuously to achieve contraction. The pressure decreased in all cases with an average latency of 2 s after termination of stimulation. Patients with bladder dysfunction had longer latencies and lower pressure levels than those with normal bladder function (Figs. 1, 2, 3; Table 2).

Fig. 3 Patient 2. Ependymoma Cauda equina L5, bladder function not impaired. Stimulation intensity 3.1 mAmp, pdet 68 cm H₂O

The intraoperative recordings of EMG and SEP showed a good agreement of SEP and bladder function impairment: patient 1 had a preoperative right tibial p40 of 44.3 and 46.3 ms on the left with pathological bilateral reduction in amplitude (2.2 and 1.9 μ V); patient 4 showed a latency of 48.0 ms on the right with amplitude reduction (1.5 μ V) and no left-sided potential; patient 5 had latencies of 41.1 ms on the left and 40.7 ms on the right. Intraoperative increases in latency were only found temporarily in case 4, perhaps due to inadvertent use of retractors. There was a normalisation in latency after correction of retractor position and the patient suffered from a temporary left-sided hypo-aesthesia for 5 days after the operation.

The EMG recordings showed occasional contact activity comparable to routine IOM settings except for case 3 (ependymoma Cauda equina L3), where a prolonged series of pathological spontaneous activity at L3 correlated with a postoperative temporary paresis grade 4. Pathological anal sphincter EMG contact activity without simultaneous bladder contraction was registered in 4 patients. In the anal sphincter EMG, an electrically silent condition in the micturition period, could always be observed, corresponding to the physiological relaxation of the external anal sphincter during bladder contraction.

The two patients with cervical intramedullary astrocytomas showed only physiological pressure changes caused by ventilation while stimulating the region of the expected pathways in the descending spinoreticular and corticospinal tracts of the spinal cord. Here, effects of stimulation could only be recorded in the EMG of the neighbouring nerve roots.

No complications related to the monitoring procedure occurred.

Table 2 Intraoperative neurophysiological findings

Patient no.	Diagnosis	Preoperative bladder function	Stimulation possible	Stimulation intense (mAmp)	Latency (s)	Pves (cm H ₂ O)	Pdet (cm H ₂ O)	Pabd (cm H ₂ O)	Pressure decrease (s)
1	Ependymoma Cauda equina L3	Impaired, residual urine	Yes	5	10	45	35	10	1
2	Ependymoma Cauda equina L5	Balanced	Yes	3.1	2	78	68	8	4
3	Ependymoma Cauda equina L3	Balanced	Yes	3.5	3	74	48	26	3
4	Ependymoma Cauda equina L5/S1	Impaired, residual urine	Yes	5	3	52	41	11	3
5	Tethered-cord syndrome	Balanced	Yes	4.3	3	73	63	10	2
6	Intramedullary astrocytoma C4	Balanced	No	—	—	—	—	—	—
7	Intramedullary astrocytoma C7	Balanced	No	—	—	—	—	—	—

Discussion

In the conventionally practised method of intraoperative monitoring of bladder function it is only possible to indirectly assess the function of the external urethral sphincter through EMG monitoring of the external anal sphincter. It is, however, not possible to identify and protect the parasympathetic fibres of the Cauda equina responsible for regular voiding function.

The use of urodynamic pressure monitoring of the bladder is a simple method which allows the identification of these fibres. There were no complications in the small case number, and although statistical analysis therefore cannot be forwarded, the nature of the method is very unlikely to produce any significant compromise of the patients' health. An investigation on the morbidity of ambulatory urodynamics showed a 1.1% chance of developing a positive urinary culture [2].

The advantages of this method therefore lie in the quick and easy installation, a low complication rate, reproducible results and, most importantly, the possibility to directly monitor the responses of the bladder which is not possible with conventional EMG recordings. Furthermore, this method allows the actual assessment of voiding function.

Its use in monitoring surgical procedures in the region of the lumbosacral plexus is conceivable, but it is important to keep in mind that this method only allows identification of nerve fibres innervating the detrusor vesicae. Online monitoring, such as continuous EMG activity registration, is not possible due to the long stimulation time and latency between stimulation and contraction. As Shinomiya et al. [12] suggested, direct cystoscopic needle application into the detrusor vesicae with direct recording of muscle action potentials might be an alternative, but besides possible complications in perforating abdominal structures, high technical expenditure is necessary.

We found one positive bladder pressure response while stimulating the filum terminale in a patient with tethered-cord syndrome. Through more Caudal exposure of the filum and repetitive stimulation it was possible to locate the point of disappearance of pressure response with the consequence of a more Caudal sectioning of the filum with preservation of bladder function. Pang and Kenneth [9] described similar observations in several cases of long-standing tethered-cord syndrome interpreting them as cases with an extremely elongated conus. If we accept this anatomical theory, the presented case offers a promising conclusion that stimulation of the conus may be possible. In our patient population no surgical exploration of the conus medullaris was necessary; thus, no attempts to stimulate this region could be made.

In all cases of surgery of the Cauda equina, we recorded a significant bladder contraction on stimulation of S2–S4.

The above-discussed case of tethered-cord syndrome reveals the first advantage of this method, as it allowed electrophysiological identification and mapping of the filum with respect to detrusor function and finally sectioning in a safe region. In cases of neoplasms of the Cauda equina, the fibres innervating the detrusor may be recognised in addition to those responsible for EMG activity of the external sphincters and nerve roots of the lower extremities, which is an advantage when seeking to identify the location of these fibres beneath dense tumorous growth, as in case no. 4 where the normal anatomy was severely distorted.

Nevertheless, a detrusor contraction could not be recorded when stimulating the spinal cord in the cervical region, as we saw in two cases. The reason is obviously the character of the stimulated fibres, which possess mainly modulating influences on the thoracic and sacral micturition centres.

It is clear that with this small number of patients statistical significance of the correlation between preoperative

bladder dysfunction and the intraoperative latency or detrusor pressure will not be reached. It is evident, however, that preoperatively recognised neurogenic bladder dysfunction will cause an increase in latency and decrease of detrusor contraction during intraoperative nerve stimulation. The most promising constellation with the current level of experience for the identification and therefore preservation of detrusor innervating fibres is given when preoperative urodynamics are unimpaired.

Conclusion

Intraoperative urodynamic monitoring during surgery of the Cauda equina is fast and easy to install, and no major or minor complications are to be expected.

This method is useful in identifying bladder nerve fibres; however, on-line monitoring, such as continuous EMG recording, is not possible.

While identification of bladder fibres is possible at the Cauda equina, a direct stimulation of descending pathways in the spinal cord is not promising.

A correlation between preoperative bladder deficiency and an increase in intraoperative latency and decrease in detrusor contraction during stimulation is expected, but further detailed studies are necessary.

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