ORIGINAL RESEARCH

Intraoperative feasibility of bulbocavernosus reflex monitoring during untethering surgery in infants and children

Takeaki Shinjo[1] · Hironobu Hayashi[1] · Tsunenori Takatani[2] · Eishu Boku[3] · Hiroyuki Nakase[3] · Masahiko Kawaguchi[1]

Abstract

Bulbocavernosus reflex (BCR) monitoring is used to assess the integrity of urinary and bowel function. In this study, we evaluated the feasibility of BCR monitoring during untethering surgery in infants and children to predict postoperative urinary and bowel dysfunction. The records of 22 patients ranging from 4 days to 10 years old (mean 2.7 ± 3.3 years) were reviewed. Anesthesia was maintained by propofol or sevoflurane/opioid without neuromuscular blockade. BCR waveforms induced by electrical stimulation (20–40 mA, train-of-four pulses with 500 Hz) to the penis or clitoris were recorded from bilateral external anal sphincters. To assess the sensitivity and specificity of BCR monitoring, we investigated the association between a significant continuous decrease in BCR amplitude at the end of surgery and postoperative urinary and bowel dysfunction after surgery. Reproducible baseline BCR waveforms were successfully recorded in 20 of 22 patients (90.9%). A significant continuous decrease in BCR amplitude was observed in 8 patients. The results of intraoperative BCR monitoring included three true-positives, twelve true-negatives, five false-positives, and zero false-negatives. Therefore, the sensitivity and specificity of BCR monitoring used to predict postoperative urinary and bowel dysfunction were 100 and 70.6%, respectively. BCR monitoring during untethering surgery in infants and children under general anesthesia was found to be a feasible method to prevent postoperative urinary and bowel dysfunction.

Keywords Bulbocavernosus reflex · Monitoring · Untethering surgery · Urinary and bowel dysfunction · Infants · Children

1 Introduction

Tethered cord syndrome is a neurological dysfunction caused by the retraction of the caudal spinal cord in the vertebral canal resulting from adhesions either of congenital or acquired origin. Neurological manifestations may include urinary and bowel dysfunction, or sensorimotor disturbances in the lower extremities. A surgical procedure is performed to release the tethered cord so as to prevent further progression of neurological dysfunctions associated with a tethered cord syndrome. However, inappropriate surgical maneuvers during the untethering surgery may damage neural structures and cause new neurological dysfunctions or deterioration of pre-existing neurological symptoms. The incidence of exacerbation of pre-existing urinary and bowel dysfunction after untethering surgery in adult patients was reported to range from 0 to 7.7% [1–5]. In younger patients, Pierre-Kahn et al. reported that neurological complications occurring immediately after untethering surgery in 291 patients with congenital lumbrosacral lipoma were observed in 32 patients (11.0%) including 20 patients with urinary retention, 13 patients with incontinence and one patient with anal paralysis [6]. Therefore, it is essential to implement neurophysiological intraoperative monitoring for the assessment of urinary and bowel function during untethering surgery [7, 8]. The bulbocavernosus reflex (BCR) has been used in various clinical settings to assess the functional integrity of the sacral reflex through S2-4 that enables urinary and bowel function [9]. The afferent sensory pathway is composed of the dorsal penile or clitoral nerve, pudendal nerve, sacral plexus and sacral roots of S2-4 [10]. The efferent motor pathways involve both somatic and parasympathetic fibers simultaneously [10]. The efferent somatic motor pathway

✉ Hironobu Hayashi
   payashi77@hotmail.com

1 Department of Anesthesiology, Nara Medical University, 840 Shijo-cho, Kashihara, Nara 634-8522, Japan

2 The Central Clinical Laboratory, Nara Medical University Hospital, 840 Shijo-cho, Kashihara, Nara 634-8522, Japan

3 Department of Neurosurgery, Nara Medical University, 840 Shijo-cho, Kashihara, Nara 634-8522, Japan

is composed of onuf's nucleus located in the ventral horn of the sacral spinal cord, sacral roots of S2-4, the pudendal nerve and the external anal and urethral sphincters [10, 11]. The efferent parasympathetic motor pathway is composed of sacral roots of S2-4, the pelvic nerve and the bladder [10]. In 1997, Deletis et al. first reported the feasibility of intraoperative monitoring of BCR, which was elicited from the external anal sphincter by electrical stimulation to the dorsal penile or clitoral nerve under general anesthesia [12]. However, BCR may be greatly suppressed by general anesthetic agents, especially when inhalational anesthetic agents are used because it is an oligosynaptic reflex [13]. Furthermore, obtaining robust and monitorable BCR responses is considered challenging, especially in young children under general anesthesia [7, 14, 15]. Nevertheless, there is an increasing demand for BCR monitoring during untethering surgery in infants and children, since tethered cord syndrome is often a complication of congenital pediatric diseases such as myelomeningocele or spinal lipoma [16]. Modern anesthetic management and recent advances in neurophysiological monitoring devices such as artifact reduction may allow BCR monitoring to be used even for infants and children under general anesthesia where elicited BCR responses are likely to be low. In this study, we retrospectively reviewed our recent experience with BCR monitoring in infants and children during untethering surgery to evaluate the feasibility of intraoperative BCR monitoring in this patient population.

2 Materials and methods

The present research was a retrospective study based on secondary data analysis using existing anesthesia records and electronic charts. This study was approved by the clinical research ethics committee of Nara Medical University. The records of 22 infants and children who underwent untethering surgery under general anesthesia with BCR monitoring between August 2012 and September 2015 were analyzed. All untethering surgery procedures came with a risk of postoperative urinary and bowel dysfunction.

Anesthesia was induced by either inhalation or intravenous induction. We used sevoflurane 5–8% and nitrousoxide for inhalation induction and propofol 1.0–2.0 mg/kg for intravenous induction. After the patients lost consciousness, we additionally administered fentanyl 1.0–4.0 µg/kg and rocuronium 0.6–1.0 mg/kg. Anesthesia was maintained by propofol 33–167 µg/kg/min in 18 patients and sevoflurane 0.5–2.0% in the other 4 patients. The depth of anesthesia was adjusted to maintain a bispectral index (BIS) of 40–60. However, in infant patients, the depth of anesthesia was adjusted to keep motor evoked potential (MEP) from abductor pollicis brevis constant throughout surgery because the accuracy
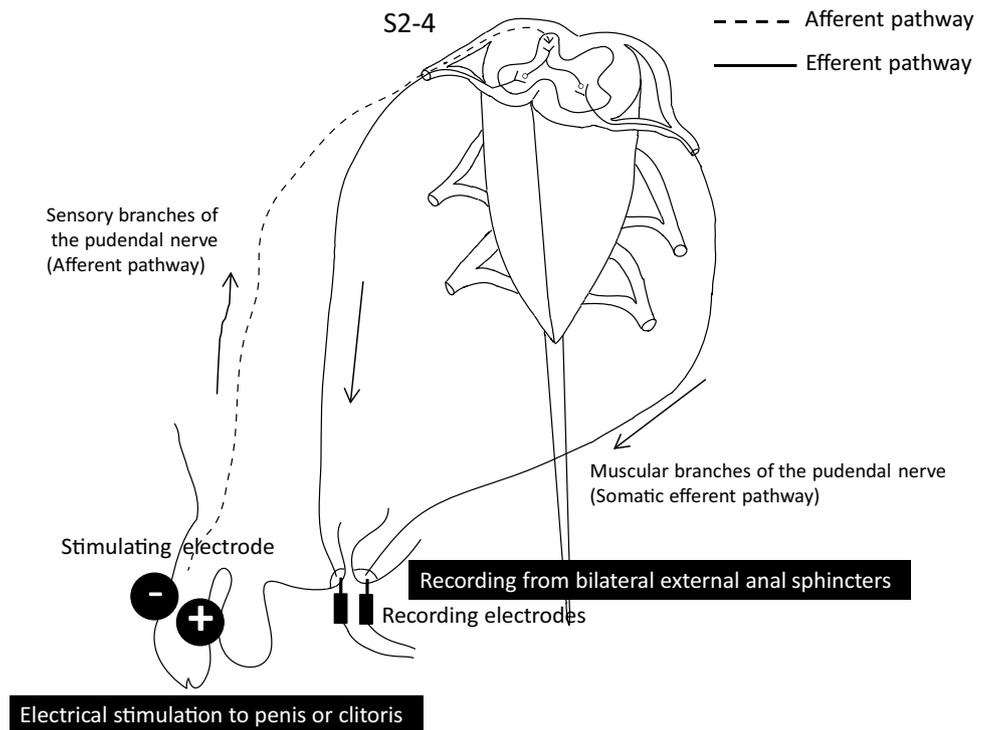
of BIS has been reported to be inferior in infants than in older children [13, 14]. In all patients, we administered remifentanil 0.2–1.0 µg/kg/min and fentanyl intermittently. No additional neuromuscular blockade was administered after tracheal intubation to avoid pharmacological reduction of BCR. Sugammadex was administered to reverse residual neuromuscular blockade induced by rocuronium prior to initiating BCR monitoring if the ratio of the fourth response to the first response in the train-of-four monitoring at the timing of commencing with BCR monitoring did not return to at least 0.80. The nasopharyngeal temperature was maintained at a target of 36–37 °C using a convective air-warming system.

At our institution, standardized modalities of neurophysiological intraoperative monitoring in untethering surgery included BCR, transcranial electrical MEP from lower extremity muscles and external anal sphincters, and lower extremity somatosensory evoked potentials. Additionally, neurophysiological mapping techniques to identify neural structures was also used with stimulated electromyography from lower extremity muscles and external anal sphincters.

2.1 Methods of recording BCR

The intraoperative neurophysiological monitoring technician set up the equipment for intraoperative BCR monitoring after induction of anesthesia. BCR monitoring was performed via the neurophysiological monitoring unit (Neuromaster MEE-1232; Nihon Kohden, Tokyo, Japan). In performing BCR monitoring, responses from the bilateral external anal sphincters were recorded after electrical stimulation was applied over the sensory branches of the pudendal nerve, the dorsal penile or clitoral nerve (Fig. 1). For BCR recording, four needle electrodes were inserted into the external anal sphincters on both left and right sides at the mucocutaneous junction. The two needle electrodes on the left (or right) were paired together for a bipolar recording to obtain a lateralized BCR response. For stimulation of the bilateral dorsal penile nerves, a single cathode was placed on the dorsal surface of the penis and a single anode on the ventral surface of the penis (Fig. 2). For stimulation of the bilateral dorsal clitoral nerves, a single cathode was placed on the clitoris and a single anode in the adjacent labia (Fig. 2). Surface electrodes were used to stimulate the dorsal penile or clitoral nerve. A single train consisting of four stimulation pulses with a duration of 0.2–0.5 ms was delivered with an interstimulus interval of 2 ms (500 Hz). The stimulus intensity was set to a suprathreshold value 20% above the minimum intensity required to generate a recordable BCR waveform (approximately 20–40 mA). We did not perform a summation or averaging. We set a 1-Hz low-cut filter and a 3000-Hz high-cut filter.

Fig. 1 The afferent and efferent pathway assessed by BCR monitoring. The electrical stimulation applied to the sensory branches of the pudendal nerve, the dorsal penile or clitoral nerve, generates an impulse (afferent pathways) and forms the reflex arc at lumbosacral S2-4. This produces contraction of the external anal sphincter muscles by excitation of the muscular branches of the pudendal nerves (efferent pathways). For BCR recording, four needle electrodes were inserted into both the left and right external anal sphincter muscles. The two needle electrodes on the left (or right) were paired together for a bipolar recording to obtain a lateralized BCR response

S2-4

- - - - Afferent pathway
——— Efferent pathway

Sensory branches of the pudendal nerve (Afferent pathway)

Muscular branches of the pudendal nerve (Somatic efferent pathway)

Stimulating electrode

Recording from bilateral external anal sphincters

Recording electrodes

Electrical stimulation to penis or clitoris

Fig. 2 Placement of electrodes for dorsal penile and clitoral nerve stimulation. For stimulation of the bilateral dorsal penile nerves, a single cathode was placed on the dorsal surface of the penis and a single anode on the ventral surface of the penis. For stimulation of the bilateral dorsal clitoral nerves, a single cathode was placed on the clitoris and a single anode in the adjacent labia. Surface electrodes were used to stimulate the dorsal penile or clitoral nerve
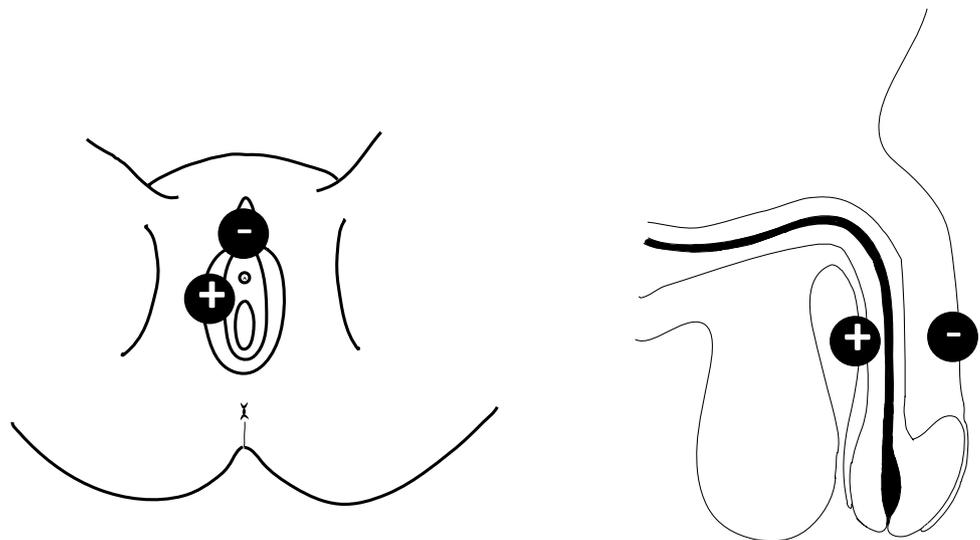
2.2 Definition of significant decrease in BCR and intervention

The baseline BCR waveforms were obtained after the dura mater was opened. BCR waveforms were recorded at least two or more times to confirm reproducibility. Subsequently, the intraoperative neurophysiological monitoring technician performed BCR recording at regular intervals during the surgery as delivery of a BCR stimulus does not provoke sudden movement or disrupt the surgery. In particular, BCR were consecutively recorded at intervals of 1-min or less during

the critical part of the untethering procedure or tumor resection from neural structures. BCR was evaluated by examining the peak-to-peak amplitude between the maximum negative and minimum positive peaks in the first early oligosynaptic response (R1) (onset latency 30–35 ms) because it is more constantly seen and remarkable for its lack of habituation under general anesthesia (Fig. 3) [9, 17]. On the other hand, the second late response (R2) is more susceptible to anesthetic agents because of its polysynaptic response originating in the central nervous system. We defined a BCR response to be present when its amplitude was of at least
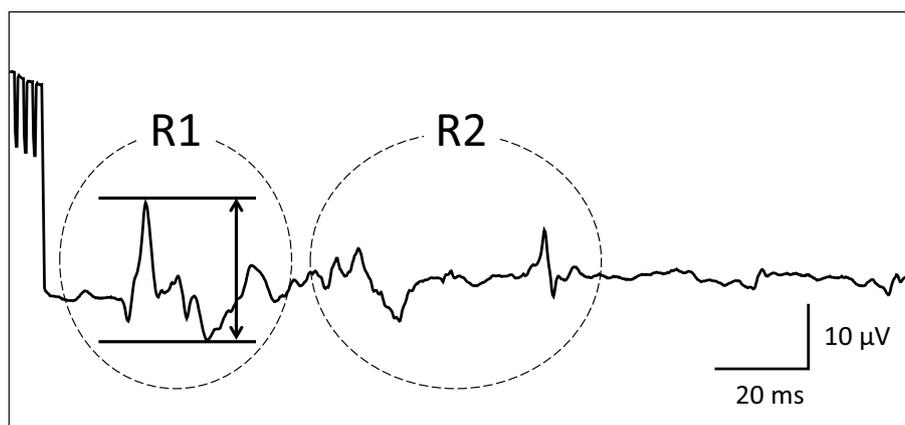
Fig. 3 Example of the bulbocavernosus reflex. In the bulbocavernosus reflex, the first early oligosynaptic response (R1) and the second late polysynaptic response (R2) can be observed after stimulation to the dorsal penile or clitoral nerve. BCR amplitude was defined as the distance between the maximum positive and negative peak in R1 response. A decrease in BCR amplitude was considered significant when it consisted of a persistent reduction in amplitude > 50% compared with the baseline

3 µV, as lower amplitudes can be difficult to distinguish from background noise. A decrease in BCR amplitude was considered significant (i.e. an "alert") when it consisted of a persistent reduction in amplitude of more than 50% compared with the baseline. When a significant decrease in BCR amplitude was observed during surgery, this was reported to the surgeon after a false-positive BCR decrease had been excluded. The presence or absence of a false-positive BCR decrease was checked by first verifying the mechanical settings as a potential cause (e.g. dislodgement of stimulating and recording electrodes, lack of electrical stimulation and broken wire). If there were no problems with the mechanical settings, the anesthetic and physiological parameters were checked. Following which, the anesthesiologist was asked if a propofol bolus had been administered or a continuous dose of propofol and inhalation concentration of sevoflurane had been increased. Changes in body temperature and blood pressure, which have significant effects on BCR, were also checked. Once all of the above had been confirmed, a warning was issued to the surgeon. The surgeon would pause the surgical maneuver and temporarily stop traction of spinal cord and nerve roots. If the BCR amplitude remained significantly decreased after 10 min of pausing the operation, the surgeon would cautiously restart the operation and modified the surgical procedure on a case-by-case basis based on his or her expert opinion.

2.3 Data analysis

Data were described as mean ± standard deviation or number (%). The success rate of recording of reproducible baseline BCR waveforms was analyzed. Furthermore, to assess the sensitivity, specificity, positive predictive value and negative predictive value of intraoperative BCR monitoring, we investigated the association between a significant decrease in BCR amplitude that persisted at the end of surgery and postoperative urinary and bowel dysfunction after surgery. In all patients, postoperative urinary and bowel function were routinely reexamined on postoperative day 2–7 after removal of the urethral catheter. The evaluation of urinary and bowel function was performed by a pediatric neurosurgeon to assess for a newly diagnosed or worsened pre-existing symptoms with regard to involuntary control of urination or defecation (incontinence), or a loss of desire to urinate or defecate. In cases involving infants, only urinary function was evaluated by weighing of diapers and measuring voided volume. Patients with postoperative urinary dysfunction required intermittent urethral catheterization. Postoperative urinary dysfunction was defined as newly diagnosed or prolonged postoperative intermittent urethral catheterization. Postoperative bowel dysfunction was defined as newly diagnosed or worsened constipation or fecal incontinence.

3 Results

The age of our 22 patients ranged from 4 days to 10 years (mean 2.7 ± 3.3 years). These included 14 males and 8 females. Table 1 shows the background characteristics of the 22 patients included in the present study. Table 2 lists the diagnoses that caused the tethered cord syndrome. Nine patients (40.9%) needed intermittent self-catheterization preoperatively due to urinary dysfunction caused by a tethered cord syndrome. None of the patients had any preoperative bowel dysfunction. Seven patients (31.8%) had preoperative motor disturbances in the lower-extremity caused by the tethered cord syndrome.

Table 1 Patient characteristics (n = 22)

	Number of patients
Age	
≦ 1 month	2
> 1 month, ≦ 1 year	9
> 1 year, ≦ 6 years	6
> 6 years, ≦ 10 years	5
Sex (male/female)	14/8
Congenital heart disease	1
Neuromuscular disorder[a]	0
Urinary/bowel dysfunction	9
Motor disturbance in lower extremity	7

[a]Neuromuscular disorder other than that caused by tethered cord syndrome

Table 2 Diagnoses causing a tethered cord syndrome (n = 22)

Diagnosis	Number of patients (%)
Spinal lipoma	13 (59)
Myelomeningocele	3 (14)
Diastematomyelia	2 (9)
Dermal sinus tract	2 (9)
Spinal cystic tumor	1 (5)
Tight filum terminale	1 (5)

Reproducible baseline BCR waveforms were successfully recorded in 20 of the 22 patients (90.9%). In the 20 patients, the baseline BCR amplitudes from the left and right external anal sphincters were 59.3 ± 70.5 and 50.6 ± 48.4 µV, respectively. Reproducible baseline BCR waveforms could not be obtained in two patients (4-year-old female and 10-year-old male). The two patients had preoperative urinary dysfunction resulting from neurogenic causes and needed intermittent urethral catheterization. In these two patients, anesthesia was maintained by continuous infusion of propofol (67 and 87 µg/kg/min, respectively) and remifentanil (0.2 and 0.3 µg/kg/min, respectively).

A significant decrease in BCR amplitude was observed in 10 patients, including two patients with a temporary significant decrease and eight patients with significant decrease persisting even at the end of surgery (Table 3). We observed newly diagnosed postoperative urinary dysfunction in one patient (Case No. 6) and exacerbation of pre-existing urinary dysfunction in two patients (Case No. 4 and 22) (Table 3). Postoperative bowel dysfunction was not observed in any patient. When the association between a significant decrease in BCR amplitude persisting at the end of surgery and appearance of new or worsening urinary dysfunction after surgery was evaluated, the results of intraoperative BCR monitoring showed three true-positives, twelve true-negatives, five false-positives, and zero false-negatives (Table 4). Therefore, the sensitivity, specificity, positive predictive value and negative predictive value of the intraoperative BCR monitoring used to predict postoperative urinary and bowel dysfunction were 100, 70.6, 37.5 and 100%, respectively.

3.1 Representative case

A 3-month-old boy (Case No. 6) with tethered cord syndrome caused by a spinal lipoma underwent resection of the spinal lipoma and an untethering surgery (Table 3). Urinary and bowel function before the surgery was normal. General anesthesia was maintained by propofol 50–83 µg/kg/min, remifentanil 0.8–1.0 µg/kg/min and intermittent

Table 3 The details of ten patients with significant intraoperative temporary and continual decrease in BCR amplitude

Case No.	Age	Sex	Preope bladder dysfunction	Anesthetic maintenance	Baseline BCR amplitude (L/R) (µV)	Final BCR amplitude (L/R) (µV)	Significant decrease in BCR	Postope urinary dysfunction	Result of BCR monitoring
3	7 y	M	+	Propofol	30/48	5.6/8.8	Continual		FP
4	5 y	M	+	Propofol	254/87	54/29	Continual	Exacerbation	TP
6	3 m	M		Propofol	78/65	0/0	Continual	New	TP
9	6 y	M	+	Propofol	12/22	0/0	Continual		FP
14	1 m	F		Sevoflurane	30/29	30/15	Temporary		TN
16	6 y	M	+	Propofol	9.8/5.7	0/0	Continual		FP
18	1 y 8 m	M	+	Propofol	0/15	0/0	Continual		FP
19	1 y 5 m	M		Propofol	56/87	40/40	Continual		FP
20	2 y	F		Propofol	30/116	29/111	Temporary		TN
22	4 y	M	+	Propofol	32/33	17/7.9	Continual	Exacerbation	TP

BCR bulbocavernosus reflex, *Preope* preoparetive, *Postope* postoperative, *M* male, *F* female, *FP* false positive, *TP* true positive, *TN* true negative

Table 4 The association between significant intraoperative decrease of BCR amplitude and postoperative urinary/bowel dysfunction

Significant decrease in BCR amplitude	Postoperative urinary/bowel dysfunction	
	+	−
+	3	5
−	0	12

Significant decrease in BCR amplitude was defined as ≤50% of the baseline BCR amplitude

administration of fentanyl. The baseline BCRs were successfully recorded bilaterally. The adhesion of the spinal lipoma to the right S2 nerve root was severe. The bilateral BCRs were completely abolished during detachment of the spinal lipoma at 13:29 (Fig. 4). At the same time, MEPs from bilateral external anal sphincters were decreased by more than 50% in amplitude compared with baseline, but not completely disappeared (left/right at baseline and the end of surgery: 155/143 and 49/28 µV, respectively) Since MEPs from bilateral upper and lower extremities were unchanged, anesthetic depth could be excluded as the cause of the loss of BCR. The surgeon was informed about the disappearance of BCRs and significant reduction of MEPs, and temporarily paused the surgical maneuver to wait for the recovery of BCRs. However, significant improvement in the amplitude of BCRs and MEPs were not observed even after the surgery was completed. Postoperatively, we recognized the presence of a new urinary dysfunction (impairment of voluntary voiding) and therefore categorized this case as a true-positive result of intraoperative BCR monitoring. The patient needed postoperative urethral catheterization for 9 days after surgery. The voluntary control of voiding progressively improved from postoperative day 14 and ultimately recovered to baseline over a period of 2 months after surgery. In this case, the surgeon was immediately alerted when the loss of BCRs occurred so that further and permanent nerve injury could be prevented.

4 Discussion

The present research was a retrospective study with the primary goal of evaluating the feasibility of BCR monitoring during untethering surgery in infants and children. At the baseline, the success rate of recording reproducible BCR waveforms was 90.9% (20 out of 22 patients). The sensitivity, specificity, positive predictive value and negative predictive value of intraoperative BCR monitoring to detect new and worsening urinary and bowel dysfunction after untethering surgery were found to be 100, 70.6, 37.5 and 100%, respectively.

Fig. 4 Representative case of a true positive result from BCR monitoring. A 3-month-old boy with tethered cord syndrome had normal urological function before the surgery. Bilateral baseline BCRs were successfully recorded. Subsequently, bilateral BCRs were elicited until 13:19, but precipitously disappeared at 13:29 during surgical manipulation. Finally, significant improvement in the amplitude of BCRs and MEPs were not observed even after the surgery was completed. The patient presented with impairment of voluntary voiding control after surgery. As a result, BCR monitoring in this case was categorized as a true positive
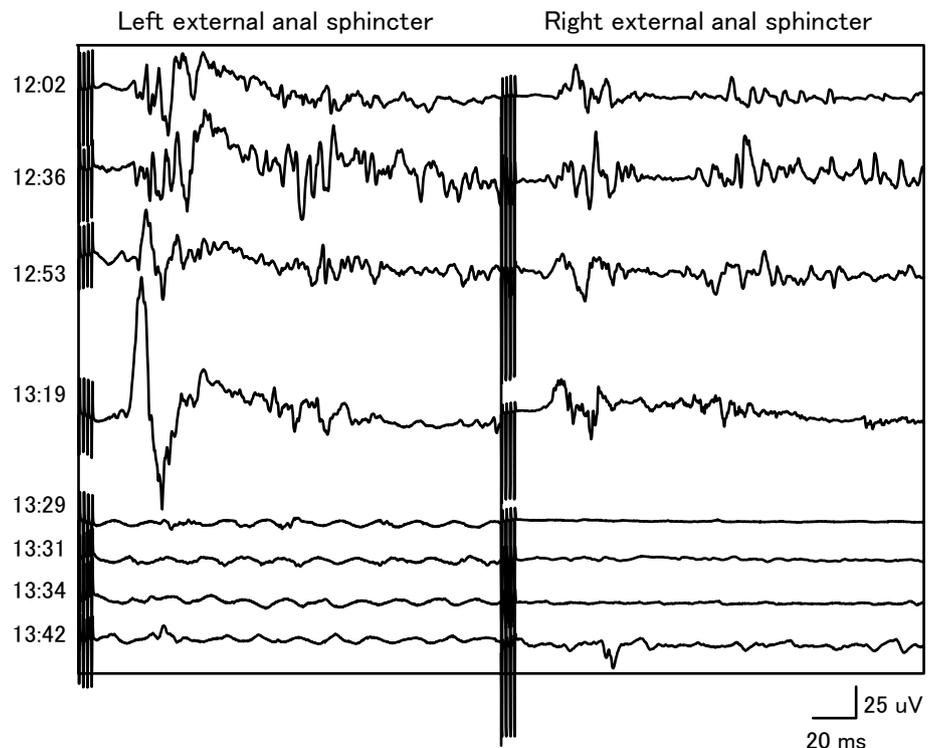
Untethering surgery is associated with a risk of damage to neural structures during the separation of adhering structures surrounding the filum terminale and conus medullaris. Therefore, proper identification of neural structures and the use of careful surgical maneuvers for neural separation are critical. Possible neurological complications resulting from the untethering surgery include urinary retention, urinary and fecal incontinence, and lower-extremity sensorimotor disturbances. Intraoperative sensorimotor functions of the lower extremities can be monitored in real time by somatosensory evoked potentials and by transcranial electrical MEP [7, 8]. Urinary and bowel function also can be assessed intraoperatively by several methods. One method is via direct electrical stimulation in the operative field to record the external anal sphincter muscle potentials, which allows for identification of the pudendal nerves (S2-4) that control the external anal and urethral sphincter muscles [1, 2, 7, 8, 11]. Another method is MEP induction by transcranial electrical stimulation to record the response from the external anal sphincters [7, 8]. However, these methods cannot evaluate the afferent pathways and the spinal reflex centers related to urinary and bowel function. In contrast, BCR monitoring can be used for intraoperative assessment of the integrity of urinary and bowel function including the afferent pathways, the spinal reflex centers and the efferent pathways (Fig. 1). Stimulation to the dorsal penile or clitoral nerve, which is the sensory branch of the pudendal nerve, forms the reflex arc at the sacral level of S2-4 through the dorsal root of the pudendal nerve (the afferent pathways) [9, 10]. The efferent pathways exiting from S2-4 represent motor fibers to the external anal and urethral sphincters (somatic efferent pathway) and the bladder (parasympathetic efferent pathway) [9–11]. In performing BCR monitoring, responses from the external anal sphincter are recorded after stimulation to the penis or clitoris. A distinct group of motor neurons in the gray matter of the sacral spinal cord, called Onuf's nucleus, is seen in the ventrolateral part of the ventral horn [10]. Onuf's nucleus innervates the striated muscle of the external anal and urethral sphincters (somatic efferent pathway) [10, 11, 18]. Somatic efferent nerves travel within the pudendal nerve to the external anal and urethral sphincters, where they modulate voluntary sphincter contraction [10]. On the other hand, parasympathetic efferent nerves travel within the pelvic nerve to the bladder, where they modulate bladder contractions [10]. In the sacral spinal cord, somatic ventral horn cells forming Onuf's nucleus and the parasympathetic intermediolateral cell column organize urinary and bowel function [10]. Originally, BCR measurement in awake patients have been widely used in clinical practice by manually exerting pressure on the glans or clitoris then visually or digitally examining the contraction of the external anal sphincters to evaluate urinary and bowel function [19]. In 1997, BCR monitoring under general anesthesia was first reported by Deletis et al., who described a method to record muscle potentials from the external anal sphincter muscles after electrical stimulation of the dorsal penile or clitoral nerve in anesthetized patients [12]. They also evaluated the effects of intravenous anesthesia with propofol, inhalation anesthesia with nitrous-oxide and isoflurane, and use of muscle relaxant on BCR waveforms. They found that a higher concentration of nitrous-oxide (60% inspired concentration) or isoflurane 1.25% significantly suppressed BCR waveforms and that muscle relaxants completely abolished BCR waveforms. Although inhalational anesthetic agents should not be used because of marked suppression on the BCR, sevoflurane was sometimes used in infants where the use of propofol remains debatable. In the present study, 18 out of 22 patients were managed by total intravenous anesthesia using propofol, whereas sevoflurane was used in the other four patients (4 days, 1 month, 4 months and 4 months of age) to maintain anesthesia. When the patients were managed by sevoflurane, the inhaled concentration of sevoflurane was adjusted to a level where the baseline BCR waveform could be reliably measured. As a result, reproducible baseline BCR waveforms were successfully obtained in the four patients maintained by sevoflurane. In infants, the depth of anesthesia was adjusted to keep MEP from the abductor pollicis brevis constant throughout the surgery. BIS monitoring was used in infants to monitor the depth of anesthesia depth. As toddlers tend to have higher BIS values compared with older children, it might be difficult to maintain an appropriate level of anesthesia for younger children using BIS monitoring [20–22]. Furthermore, it is reported that the reliability of BIS monitoring is diminished in infants less than 1 year of age [20]. Conversely, some authors reported the successful use of intraoperative BIS monitoring in younger children when BIS was used for an intraoperative wake-up test in a neonate undergoing surgical repair of myelomeningocele [23] and reducing the recovery time in 3–18 years old patients undergoing tonsillectomy and adenoidectomy [24].

Sala et al. reported that the success rate of recording was 59% when BCR monitoring was performed in 33 patients with a tethered cord [7]. They concluded that the use of BCR might require a higher degree of neuromonitoring expertise although BCR can impact the neurological outcome. In the present study, the success rate of BCR recording was 90.9% (20 out of 22 patients). The two patients without a successful recording of BCR waveforms were a 4-year-old female and 10-year-old male. Notably, these two patients were maintained by propofol, which is known to be less suppressive on BCR. One potential reason for failure to obtain reproducible baseline BCR waveforms was that they had pre-existing urinary dysfunction before surgery from the myelomeningocele. Hayashi et al. reported that neurophysiological monitoring such as MEP was difficult to apply in

patients who suffered from motor weakness preoperatively [25]. Additionally, the young age might have affected the recording of baseline BCR. Neurophysiological monitoring to assess motor pathways is also known to be difficult to apply in young children because of the immaturity of axonal fibers [26, 27]. Although preoperative neurological states of urinary/bowel and range of age in their report were similar to that in the present study, Sala et al. reported a lower success rate of BCR recording than that in the present study (59 vs. 90.9%) [7]. The discrepancy might be explained by the difference in anesthetic regimen. Unlike our study, their anesthetic regimen involved nitrous oxide. Additionally, they did not state the method used to adjust the depth of anesthesia. In contrast, we routinely adjusted the depth of anesthesia to avoid pharmacological suppression of BCR by keeping the MEP from the upper extremity constant through the surgery. With regard to the sex-specific reliability of BCR monitoring, Rodi et al. examined 65 patients who underwent surgery for lower thoracic and lumbar spinal trauma and found that the success rate of baseline BCR recording in women (13%) was much lower than in men (81%) [28]. However, we were able to record the baseline BCR in 13 of 14 male patients and in seven of eight female patients. As such, we did not recognize any sex differences in this study.

In the present study, we observed two patients with temporary but significant decrease in BCR amplitude during surgery. In one of the two patients, the cause of the transient significant decrease in BCR amplitude could possibly be explained by a relatively high inhalation concentration of sevoflurane (2.0%). In this patient, BCR amplitude returned to baseline levels after reduction of the inhalation concentration of sevoflurane to 1.0%. In the other patient, the temporary but significant decrease in BCR amplitude is presumably attributed to the surgical maneuver because we observed a recovery of BCR amplitude after about ten minutes of pausing the operation. In eight of the 20 patients in which reproducible baseline BCR waveforms were successfully recorded, significant decrease in BCR amplitude persisted the end of surgery. Of these eight patients, three patients had postoperative urinary dysfunction. As a result, the positive predictive value of intraoperative BCR monitoring used to predict postoperative urinary and bowel dysfunction was 37.5%. The false-positive rate calculated as false-positive/ (false-positive + true-negative) was 29.4%, which was high for a test. This low positive predictive value and high false-positive rate might be attributed to our definition of a significant decrease in BCR amplitude (more than 50% reduction in BCR amplitude compared with baseline). Although the use of such a liberal criterion may increase the rate of false-positive results, we believe that such criteria used in this study would allow for the surgeon to be warned early so as to avoid postoperative urinary and bowel dysfunction. However, false-positives could interfere with surgical treatment

and undermine surgeons' confidence in BCR alerts. Therefore, the result of both low positive predictive value and high false-positive rate indicates that the methods to record BCR used in this study still need to be improved in order to be more effectively used in the operation room. In this study, three patients (13.6%) had new or worsening urinary and bowel dysfunction after the untethering surgery. All the three patients had a continuous significant decrease in BCR amplitude and resulted in true-positive results. The absence of false-negative results in this study supports the usefulness of intraoperative BCR monitoring.

The present study has some limitations that should be addressed in future research. First, there are no established warning criteria for intraoperative BCR monitoring to predict urinary and bowel dysfunction. Whereas in the previous study where a significant decrease in BCR amplitude was defined as the disappearance of BCR waveforms [9], we adopted a liberal warning criterion that defined a significant decrease in BCR amplitude to be a reduction of more than 50% compared with baseline in order to provide an opportunity for the surgeon to be warned early. However, further study involving a larger number of patients is required to identify the optimal cut-off value to perform reliable BCR monitoring based on a receiver operating characteristic curve to predict postoperative urinary and bowel dysfunction. Secondly, an optimal anesthetic regimen to perform reliable BCR monitoring in infants and children has not been established. Although normal or higher doses of inhalational anesthesia (more than 1 MAC) is generally known to have a marked suppressive effect on BCR waveforms, the use of lower doses of inhalational anesthesia (less than 0.5 MAC) might be applicable to obtain reproducible BCR waveforms. The previous study demonstrated that 0.5 MAC sevoflurane with remifentanil could be used when MEP was required for brainstem surgery [29]. Further study would be required to evaluate the applicability of lower doses of inhalational anesthesia with remifentanil for BCR monitoring in infants and young children. Additionally, the other study showed that MEP was favorably recorded when the propofol dosage was reduced by concomitantly administering dexmedetomidine [30]. Future studies investigating the use of dexmedetomidine during BCR monitoring are thus needed. Finally, there is no consensus on the optimal settings for intraoperative BCR monitoring. Skinner et al. demonstrated that BCR amplitude was successfully augmented by double train stimulation [31]. In their pilot study, they tested double train stimulation in a small number of patients (five patients) and did not perform statistical analysis. Further studies involving a larger number of patients are required to evaluate the validity of double train stimulation to improve BCR monitoring. In this study, we did not apply the double train stimulation to our patients. In addition, intraoperative BCR recording in women is known to be difficult due to

difficulties in attaching the stimulating surface electrodes. Further research to determine the optimal positioning and choice of surface and needle electrodes is needed for intraoperative reliable BCR monitoring.

5 Conclusion

Intraoperative BCR monitoring can be implemented even in infants and children to assess the integrity of urinary and bowel function including the afferent pathways, the spinal reflex centers and the efferent pathways during untethering surgery. Nevertheless, we recognize the need to explore the optimal techniques to reduce the rate of false-positive results.

References

1. Pang D, Wilberger JE Jr. Tethered cord syndrome in adults. J Neurosurg. 1982;57:32–47.
2. Lee GY, Paradiso G, Tator CH, Gentili F, Massicotte EM, Fehlings MG. Surgical management of tethered cord syndrome in adults: indications, techniques, and long-term outcomes in 60 patients. J Neurosurg Spine. 2006;4:123–31.
3. Hüttmann S, Krauss J, Collmann H, Sörensen N, Roosen K. Surgical management of tethered spinal cord in adults: report of 54 cases. J Neurosurg. 2001;95(2 Suppl):173–8.
4. Iskandar BJ, Fulmer BB, Hadley MN, Oakes WJ. Congenital tethered spinal cord syndrome in adults. J Neurosurg. 1998;88:958–61.
5. van Leeuwen R, Notermans NC, Vandertop WP. Surgery in adults with tethered cord syndrome: outcome study with independent clinical review. J Neurosurg. 2001;94(2 Suppl):205–9.
6. Pierre-Kahn A, Zerah M, Renier D, Cinalli G, Sainte-Rose C, Lellouch-Tubiana A, Brunelle F, Le Merrer M, Giudicelli Y, Pichon J, Kleinknecht B, Nataf F. Congenital lumbosacral lipomas. Childs Nerv Syst. 1997;13:298–334.
7. Sala F, Squintani G, Tramontano V, Arcaro C, Faccioli F, Mazza C. Intraoperative neurophysiology in tethered cord surgery: techniques and results. Childs Nerv Syst. 2013;29:1611–24.
8. Kothbauer KF, Novak K. Intraoperative monitoring for tethered cord surgery: an update. Neurosurg Focus. 2004;16:E8.
9. Skinner SA, Vodušek DB. Intraoperative recording of the bulbocavernosus reflex. J Clin Neurophysiol. 2014;31:313–22.
10. Clemens JQ. Basic bladder neurophysiology. Urol Clin North Am. 2010;37:487–94.
11. Hauck EF, Schwefer M, Wittkowski W, Bothe HW. Measurements and mapping of 282,420 nerve fibers in the S1-5 nerve roots. J Neurosurg Spine. 2009;11:255–63.
12. Deletis V, Vodusek DB. Intraoperative recording of the bulbocavernosus reflex. Neurosurgery 1997;40:88–92.
13. Sala F, Krzan MJ, Deletis V. Intraoperative neurophysiological monitoring in pediatric neurosurgery: why, when, how? Childs Nerv Syst. 2002;18:264–87.
14. Sala F, Manganotti P, Grossauer S, Tramontano V, Mazza C, Gerosa M. Intraoperative neurophysiology of the motor system in children: a tailored approach. Childs Nerv Syst. 2010;26:473–90.
15. Husain AM, Watkins LR, Muh CR. Tetherd cord surgery. In: Husain AM, editor. A practical approach to neurophysiologic intraoperative monitoring. 2nd ed. New York: Demos Medical Publishing; 2015. pp. 142–55.
16. Tu A, Steinbok P. Occult tethered cord syndrome: a review. Childs Nerv Syst. 2013;29:1635–40.
17. Vodusek DB, Janko M. The bulbocavernosus reflex. A single motor neuron study. Brain 1990;113:813–20.
18. Geser F, Wenning GK. Primary autonomic failure. In: Schapira AHV, editor. Neurology and clinical neuroscience. Philadelphia: Mosby Elsevier; 2007. pp. 372–93.
19. Bors E, Blinn KA. Bulbocavernosus reflex. J Urol. 1959;82:128–30.
20. Jeleazcov C, Schmidt J, Schmitz B, Becke K, Albrecht S. EEG variables as measures of arousal during propofol anaesthesia for general surgery in children: rational selection and age dependence. Br J Anaesth. 2007;99:845–54.
21. Tirel O, Wodey E, Harris R, Bansard JY, Ecoffey C, Senhadji L. The impact of age on bispectral index values and EEG bispectrum during anaesthesia with desflurane and halothane in children. Br J Anaesth. 2006;96:480–5.
22. Davis PJ, Cladis FP, Motoyama K. Smith's anesthesia for infants and children. 8th ed. Philadelphia: Elsevier Mosby; 2011.
23. Govindarajan R, Babalola O, Gad-El-Kareem M, Kodali NS, Aronson J, Abadir A. Intraoperative wake-up test in neonatal neurosurgery. Paediatr Anaesth. 2006;16:451–3.
24. Bannister CF, Brosius KK, Sigl JC, Meyer BJ, Sebel PS. The effect of bispectral index monitoring on anesthetic use and recovery in children anesthetized with sevoflurane in nitrous oxide. Anesth Analg. 2001;92:877–81.
25. Hayashi H, Kawaguchi M, Yamamoto Y, Inoue S, Koizumi M, Ueda Y, Takakura Y, Furuya H. Evaluation of reliability of post-tetanic motor-evoked potential monitoring during spinal surgery under general anesthesia. Spine (Phila Pa 1976) 2008;33:E994–1000.
26. Lieberman JA, Lyon R, Feiner J, Diab M, Gregory GA. The effect of age on motor evoked potentials in children under propofol/isoflurane anesthesia. Anesth Analg. 2006;103:316–21.
27. Fulkerson DH, Satyan KB, Wilder LM, Riviello JJ, Stayer SA, Whitehead WE, Curry DJ, Dauser RC, Luerssen TG, Jea A. Intraoperative monitoring of motor evoked potentials in very young children. J Neurosurg Pediatr. 2011;7:331–7.
28. Rodi Z, Vodusek DB. Intraoperative monitoring of the bulbocavernosus reflex: the method and its problems. Clin Neurophysiol. 2001;112:879–83.
29. Hernández-Palazón J, Izura V, Fuentes-García D, Piqueras-Pérez C, Doménech-Asensi P, Falcón-Araña L. Comparison of the effects of propofol and sevoflurane combined with remifentanil on transcranial electric motor-evoked and somatosensory-evoked potential monitoring during brainstem surgery. J Neurosurg Anesthesiol. 2015;27:282–8.
30. Li Y, Meng L, Peng Y, Qiao H, Guo L, Han R, Gelb AW. Effects of dexmedetomidine on motor- and somatosensory-evoked potentials in patients with thoracic spinal cord tumor: a randomized controlled trial. BMC Anesthesiol. 2016;16:51.
31. Skinner S, Chiri CA, Wroblewski J, Transfeldt EE. Enhancement of the bulbocavernosus reflex during intraoperative neurophysiological monitoring through the use of double train stimulation: a pilot study. J Clin Monit Comput. 2007;21:31–40.