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CURRENT CONCEPT REVIEW

Surgical management of spasticity

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Abstract Intractable and severe spasticity in childhood has the ability to impact on the quality of life, function and care of the child. Where medical and physical measures have proved insufficient, a surgical approach may be pursued. Irrespective of the underlying pathology, intrathecal baclofen will reduce spasticity in a controllable and reversible fashion, whereas selective dorsal rhizotomy is reserved for the management of bilateral cerebral palsy due to early birth. Owing to the potential for complications of intrathecal baclofen and the permanence of selective dorsal rhizotomy, careful selection and preparation are required to produce satisfactory results.

Keywords Spasticity · Rhizotomy · Intrathecal baclofen · Cerebral palsy

Spasticity

Spasticity is a regular feature of upper motor neurone syndrome. However, our understanding of the phenomenon is incomplete. Various definitions of spasticity have been formulated, but Lance's broad definition emphasising the positive effect on muscle tone related to the velocity of muscle elongation remains the most commonly agreed definition [1]. The clinical assessment of spasticity lacks reliability [2] and quantitative measures either depend upon cumbersome equipment that addresses measurement at one joint [3] or is not able to measure the full scale of spasticity from mild to severe [4].

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The upper motor neurone syndrome has positive and negative effects in terms of clinical features that are enhanced (such as tone) and reduced (such as strength). Spasticity is, thus, one of the positive features of upper motor neurone syndrome in the sense of expression, but a different aspect is that of impairment [5]. In general, spasticity inhibits movement and causes discomfort either directly through excessive muscle tension, leading to cramp, or articular pain as a result of extreme joint position or subluxation. A small category of patients gain benefit from spasticity where the resistance to movement leads to easier control of posture either in terms of the ability to stand to transfer or to sit upright. Thus, where weakness or control impairment prevent function, spasticity needs to be considered as a possible helpful feature of upper motor neurone syndrome rather than automatically being seen as a target for abolition. The site of the lesion has an influence on the severity of the phenomenon and the quality of spasticity. For example, cerebral palsy resulting from early birth leads to the interruption of cortico-rubral tracts, removing positive drive to the tone suppressing the mechanism that drives the rubro-spinal tracts, accompanied by impairment of fine motor control [6], whilst spasticity arising from neuronal migration disorders leads to a more profound enhancement of tone, often with an element of spastic dystonia.

Spasticity often develops in relation to posture, with infants with cerebral palsy developing the phenomenon increasingly on assuming the upright posture. A suggestion that spasticity may peak in early childhood and then reduce with development needs to be considered, but methodological flaws in the assessment of spasticity may undermine the validity of the main existing report of this observation [7].

The location of the causative lesion(s) of upper motor neurone syndrome will determine whether there is a pure

form of motor disorder or whether there is a combination of different abnormalities of motor control. Lesions that include the basal ganglia are liable to produce dystonia or athetosis, whilst cerebellar involvement will lead to ataxia. More diffuse involvement of the brain resulting from metabolic or traumatic injuries often leads to a mixture of motor disorders.

Cerebral palsy

Resulting from an injury to the central nervous system in early life, cerebral palsy has a wide variety of presentations, with a mixture of positive and negative features of upper motor neurone syndrome. Thankfully, improvements in obstetric care have led to a reduction in the incidence of hypoxic ischaemic encephalopathy and kernicterus, but advances in neonatal care for the premature child has turned those who would not have survived into survivors with a neurological handicap. Infants who would have previously survived with a handicap are now frequently completely neurologically normal, but the overall burden of disability secondary to prematurity has not dramatically reduced with better care.

Mechanism of action: intrathecal baclofen

Unlike other destructive surgical treatments for spasticity, intrathecal baclofen acts at a receptor level by acting on metabotropic gamma amino butyric acid receptors ($GABA_BR$), which, in turn, activate G-protein K^+ channels. Benzodiazepines act on the ionotropic variety of GABA receptor ($GABA_AR$). By modulating the excitability of the reflex arc within the spinal cord, baclofen produces a reversible effect as opposed to the surgical interruption of the reflex arc.

Advantages of intrathecal baclofen

The ability to adjust the level of spasticity reduction achieved and, to a degree, the anatomical extent of spasticity reduction proves useful where heavily handicapped individuals depend upon their spasticity to enable function. Postural control of the head and trunk is often impaired in heavily involved children. The observation that infants affected by significant degrees of cerebral palsy are initially hypotonic reflects the lack of postural control, as tone is not a feature of normal relaxed muscle. Loss of sitting balance resulting from intrathecal baclofen can be reversed, allowing value judgements in terms of what the patient and carers perceive as being the major gains from treatment. Further refinement can be achieved by setting the pump to vary the dose on a diurnal basis, allowing more profound control at some specified times during the day. Variation in the level of spasticity may occur as a result of pain, faecal impaction or generalised illness, and this can be reversibly accommodated by altering the pump's delivery rate.

A single intrathecal test dose or an indwelling intrathecal catheter can be used to give confirmation of efficacy. Where dystonia makes a significant contribution to the motor disorder, a catheter trial may be preferred over a few days, as dystonia does not generally respond to a single injection of baclofen [8]. An ability to diminish the intensity of dystonia makes intrathecal baclofen a safer option in children with GMFCS IV involvement, where the greater extent of the injury to the developing brain increases the chances that there will have been some injury to the basal ganglia. Refractory dystonia has been reported to respond to intrathecal baclofen treatment [9].

Disadvantages of intrathecal baclofen

Although modern implantable pumps are highly reliable, procedural errors or catheter problems do occasionally arise, producing potentially fatal crises of withdrawal or overdose [10]. Many case reports of acute withdrawal exist, often associated with the disconnection of the catheter from the pump [11, 12]. Prompt recognition of acute baclofen withdrawal allows early support with pump review and surgical catheter replacement or reconnection. Patients may hallucinate or exhibit behavioural changes, coupled with hypertension and hyperthermia. $GABA_A$ agonists such as propofol or benzodiazepines may be of use during the immediate period prior to re-establishment of baclofen delivery, but the numbers of cases is sufficiently small that a systematic therapeutic approach has not been established. There is no pharmacological agent available to manage baclofen overdose characterised by respiratory depression, reduced consciousness with fixed pupils and hypotension. Stopping the pump and allowing the baclofen to metabolise whilst providing intensive care support is necessary. Cerebrospinal fluid (CSF) aspiration has been advocated but is not regularly employed in the paediatric population. Frequently, the process of recovery from overdose is followed by withdrawal symptoms.

Reported rates of infection after intrathecal baclofen pump implantation vary from under 1 [13] to 9 % [14]. The treatment of pump-related infection often requires the administration of antibiotics through the pump, allowing the device to be retained [15]. Children with extensive involvement of cerebral palsy often have co-morbidities that increase the risk of infection, including malnutrition; skin breakdown or maceration secondary to deformity; stomas and gastrostomy sites; behavioural problems

leading to interference with wounds and urinary and faecal incontinence [16]. The organisms involved are varied and thorough sampling and bacteriological assessment is required prior to the commencement of antimicrobial therapy [15, 17].

Scoliosis is common in children with extensive neuromuscular disease. The effect of intrathecal baclofen on the progression of spinal curves is disputed, with some claiming exacerbation [18–20] and others suggesting no effect on scoliosis [21, 22]. Where posterior arthrodesis has already been performed in the lumbar region prior to the insertion of a pump, the catheter may be placed antegrade from the cervical spine [23]. Posterior arthrodesis of the spine in the presence of a pump requires care in prone positioning; avoidance of the catheter and vigilance in the immediate post-operative period for signs of baclofen withdrawal.

Uncommonly, the tip of the catheter can become occluded by the formation of a granuloma, leading to a reduction in efficacy of the treatment [24]. Catheter tip granuloma formation is more commonly seen in patients receiving intrathecal opiates than in intrathecal baclofen treatment.

Children with extensive spasticity are often underweight, even when fed by means of a gastrostomy. The removal of significant amounts of spasticity, particularly when the child does not have the functional capacity to exercise after pump implantation, and obesity can develop sometimes sufficiently to make refilling the pump difficult [25].

Intrathecal baclofen treatment imposes a significant cost to health services as a result of the initial cost of the pump, the initial implantation and the need for regular refills of the pump reservoir [26]. Any treatment system that carries a high rate of complications will be expensive, as the average cost of a major complication is approximately six times more expensive than the primary procedure. The requirement for regular trips to the baclofen pump clinic also imposes costs on patients and families, who often have multiple contacts with health services for other aspects of the child's condition.

Mechanism of action of selective dorsal rhizotomy

Selective dorsal rhizotomy works by reducing the afferent input to the reflex arc but in an unselective way, which produces a reduction of cutaneous and proprioceptive awareness. Fortunately, there is a degree of redundancy to cutaneous sensation in the lower limb in the child. Whether the loss of neurones related to the ageing process leads to a post-selective dorsal rhizotomy syndrome in a fashion analogous to the post-polio syndrome remains to be seen.

Advantages of selective dorsal rhizotomy

Spasticity is generally perceived as being a long-term feature of cerebral palsy, varying in severity according to the patient's condition, but returning to a baseline level of abnormal resistance to muscle elongation once exacerbating factors such as pain are removed. In contrast to cerebral palsy, which is a fixed neurological injury, conditions such as hereditary spastic paraparesis or neuro-metabolic abnormalities show progression of involvement and, thus, the severity and, occasionally, the type of motor disorder. The longest systematic follow up of selective dorsal rhizotomy examined Warwick Peacock's South African patients at least 20 years following the procedure and demonstrates the permanent nature of the spasticity reduction [27].

Because of the permanent nature of the treatment, the health economics of selective dorsal rhizotomy demonstrate an increasing benefit in terms of cost per quality adjusted life year over time. The absence of repeat visits for pump refill and the cost of replacing the pump makes selective dorsal rhizotomy significantly less expensive than intrathecal baclofen treatment, but this author feels that the two procedures are suited to separate populations of children with cerebral palsy, so the comparison is somewhat artificial.

Our experience has been that selective dorsal rhizotomy leads to a significant reduction in soft tissue orthopaedic surgery, with less impact on the need for bony surgery [28]. Earlier treatment leads to a slightly greater reduction in the need for soft tissue surgery, but this imperative must be balanced against the need to select the correct child for rhizotomy.

Disadvantages of selective dorsal rhizotomy

The permanent nature of rhizotomy is its main advantage in the ideal patient, but represents a disadvantage in less suitable patients. GMFCS IV patients with some walking ability may demonstrate a deterioration in their ability to walk following selective dorsal rhizotomy [29]. Insufficient extensor strength and control may be revealed by spasticity removal, leading to a failure of the patient to be able to stand to transfer at skeletal maturity, leading to higher levels of dependency in the long term.

Scoliosis has been a regularly reported consequence of selective dorsal rhizotomy, along with kyphosis and spondylolisthesis. The long-term review of patients revealed a high incidence of minor scoliotic curves at a minimum of 17 years post-rhizotomy [30]. Generally, there is a relationship between the severity of involvement and the incidence of scoliosis [31, 32]. Apart from rotational and coronal deformity, sagittal plane deformities occur

frequently in the form of spondylolisthesis, kyphosis and lordosis. Excessive lumbar lordosis may be a precursor to spondylolysis and spondylolisthesis. Persistent contracture and spasticity in the hip flexors or hamstrings or excessive weakness in the hip extensors may lead to a sacrum up posture in the walking child, resulting in hyperlordosis in the lumbar spine.

Where impaired control of the spine is masked by spasticity, a release of the psoas by sectioning of the L1 root may lead to the need for the spine to settle at the end range to give a new stable configuration. Poor pre-existing spinal control should be seen as a risk factor for future sagittal plane deformity after a rhizotomy.

Obesity following intrathecal baclofen is also seen in children who undergo selective dorsal rhizotomy. Our observation was that those children who walked slowly (<0.4 M s) before rhizotomy were the most liable to gain unwanted extra weight post-operatively, perhaps because they did not have sufficient strength or control to burn off the calories "freed up" by not being consumed by spastic muscle [33]. Hip subluxation has been reported after selective dorsal rhizotomy in up to 25 % of cases [34]. Higher levels of pre-operative disability were noted in those patients who required femoral or pelvic surgery to correct subluxation. Tellingly, the group of patients reported showed no change in their ambulatory status, suggesting that the selection of the patients had been imperfect. A careful radiological review suggested that selective dorsal rhizotomy could produce an improvement of hip coverage and had, overall, a positive effect on hip stability [35].

Sensory impairment after rhizotomy has been reported as a temporary phenomenon, but long-term cutaneous sensory deficits are not reported, owing to the redundancy of sensation. The extent of the denervation varies between 40 and 75 % according to the protocols employed in individual centres. The long-term effect of removing a substantial proportion of sensory input is unknown, given that the loss of neurones is a regular feature of the ageing process. Particularly where perineal roots are extensively sectioned, there might be a long-term consequence in terms of sexual function in later life, but there is insufficient long-term experience of selective dorsal rhizotomy to identify the risk of a late adverse effect.

The development of motor control depends on the integration of sensory inputs and motor outputs from cerebellar, cortical and spinal centres. It is reasonable to assume that significantly reduced sensory return from muscles, ligaments, tendons and joints will impair the refinement of motor engrams necessary for the proper control of complex movements. Where control has been gained prior to rhizotomy, the patterns and skills already established are likely to be retained in the long term. Unfortunately, there is no possibility of identifying fibres within the dorsal root that are associated with muscle spindles to allow the preservation of cutaneous and articular sensory afferents.

Patient selection

Objective of management

The selection of treatment for spasticity depends crucially on being able to agree on an achievable objective for the child at skeletal maturity. Functional abilities such as walking, participation in sport and the ability to stand to transfer are possible goals. Excessive spasticity may lead to difficulty in providing care for the child by way of making perineal hygiene impossible or rendering seating uncomfortable. Symptoms, notably pain, may also be indications for treatment.

Severity of involvement

Mild degrees of spasticity may be manageable with oral medication or physiotherapy management. Localised treatment with injections of botulinum toxin or neural blockade are appropriate for localised spasticity that produces functional impairment or symptoms, but a significant degree of generalised involvement suggests the need to consider surgical treatment.

Motor disorder

Defining the precise mixture of motor syndromes (spasticity/dystonia etc.) is important when deciding on the appropriate treatment modality. Intrathecal baclofen treatment is quite effective in the management of dystonia, whereas selective dorsal rhizotomy in the presence of dystonia allows dystonic posturing to occur without the moderating restraint of spasticity. The spasticity of hereditary spastic paraparesis is generally acknowledged to be resistant to the effects of selective dorsal rhizotomy and the progressive nature of the condition suggests the need for a titratable treatment.

A careful evaluation of the diagnosis by a paediatric neurologist coupled with neuro-imaging will aid in the selection of the appropriate treatment and will preclude selective dorsal rhizotomy in cases where lesions other than isolated periventricular flare are found on magnetic resonance imaging (MRI) scanning.

Functional measures

Where improved mobility is the agreed goal, a pre- and post-operative measure of walking with instrumented gait

analysis is invaluable. Selective dorsal rhizotomy has its greatest effect on pre-swing knee stiffness, and a child with good elongation of the quadriceps at the end of stance is unlikely to gain much from a rhizotomy procedure. Restriction of knee extension at initial contact and excessive equinus are secondary areas where spasticity can be seen on gait analysis as targets for improvement. The permanent nature of rhizotomy suggests the need for quantitative measures to define the extent of impairment prior to treatment if only to give a baseline against which the results can be judged. Careful selection leads to measurable gains in functional 3D gait analysis measures [36].

Strength and control

An accurate assessment of voluntary muscle strength and control is a crucial determinant of the appropriate treatment strategy for a child with spasticity. Without volitional control, manual muscle testing will not give a true representation of the ability of the muscles to generate force. An example of this is the confusion test, where a mass withdrawal response can reveal active function in ankle dorsiflexors where volitional dorsiflexion is absent [37]. 3D gait analysis can occasionally show power in muscle groups that are not strong on manual muscle testing. The evaluation of control can be undertaken in the trunk as well as in the lower limb [38–40]. Spasticity surgery with a functional objective depends on having sufficient anti-gravity strength to allow improved function when spasticity is removed. A child who is unable to rise from sitting without the use of their arms or aids is unlikely to benefit from rhizotomy surgery, and extensive spasticity is better dealt with by means of intrathecal baclofen.

Conclusion

Where spasticity is severe and extensive, surgical management with intrathecal baclofen or selective dorsal rhizotomy should be considered. For the diplegic child with adequate selective motor control and strength and high levels of spasticity, a rhizotomy can produce dramatic and lasting improvement. More severely affected children where symptoms rather than function are the main problem can be helped with an intrathecal baclofen pump, which can transform the child's comfort and ease their care. In general, GMFCS IV and V children with severe spasticity are candidates for intrathecal baclofen and GMFCS grade II children with high levels of spasticity should be considered for selective dorsal rhizotomy. GMFCS grade III children present the greatest challenge in terms of identifying the correct modality of surgical treatment.

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