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Review

Gait analysis to guide a selective dorsal rhizotomy program

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ABSTRACT

Selective dorsal rhizotomy is a valuable surgical option to manage spasticity in children with bilateral cerebral palsy with the objective of improving function. Choosing the correct patient for rhizotomy requires considerable effort and a comprehensive evaluation. Instrumented three-dimensional gait analysis provides supporting evidence in the selection of the ideal child for SDR as well as enabling quantitative monitoring of outcome and post-operative management up to skeletal maturity.

1. Introduction

Selective dorsal rhizotomy has been used for the past 40 years to manage spasticity secondary to bilateral cerebral palsy resulting from early birth. As such the procedure should be accurately understood in terms of outcome and effect but this is not the case. The most recent guidance by the United Kingdom's National Institute for Health and Care Excellence (NICE) suggests that whilst evidence on efficacy is adequate, research focused on long term outcomes is needed [30]. A clear understanding of the irreversible nature of selective dorsal rhizotomy is expressed in the NICE guidance and emphasis is placed on explaining this to the parents of prospective patients. In a recent evidence review, Novak et al. [29] placed selective dorsal rhizotomy amongst the interventions for cerebral palsy with evidence of efficacy. Whilst long-term studies exist of patients treated in South Africa in the 1960s and 70s by Warwick Peacock, programmes in North America are generally less comprehensively documented. The United Kingdom's medium term experience dates back 20 years and is systematically documented with gait analysis but involves small numbers of patients derived by very careful selection. By the very nature of long term analysis, the technology available at the start of a historical series of cases is likely to be less widely available than is currently the case.

2. Gait analysis

Whilst the primary effect of sectioning the dorsal root is a reduction in afferent drive to the reflex arc and thus a reduction in or abolition of spasticity, the procedure is typically performed for the secondary objective of maintaining or improving function. Manual measures of spasticity are prone to error but the magnitude of the change seen after rhizotomy is such that relatively insensitive tests are able to detect changes. Pain can also be measured as can quality-of-life with suitable instruments. Functional assessment varies from questionnaires to more rigorous objective measures such as the Gross Motor Function Measure [34]. Where the function to be measured is walking a well-established technology developed mainly around paediatric cerebral palsy is available in the form of gait analysis. Many papers evaluating selective dorsal rhizotomy record parameters such as speed and step length with a few using 2-D measures and a significant number employing 3-D measures. Relatively few studies examine energy consumption or the effects of rhizotomy on patterns of EMG activation.

3. Selective dorsal rhizotomy

3.1. Boundaries of SDR

Selective dorsal rhizotomy has evolved over the past 35 years and encompasses a variety of techniques. Originally, exposure of the cauda equina was performed through a long laminectomy from L1 to L5 generally with replacement of the laminae at the end of the procedure. The extensive nature of the laminectomy was blamed for a significant but variable incidence of post-operative scoliosis. In order to reduce the surgical trauma and risk of scoliosis a minimally invasive procedure at the conus was introduced guided by intra operative ultrasound. At the conus the nerve roots are much more organised and provided they are not disturbed the dorsal roots can be picked up sequentially. A direct comparison of

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the two techniques concluded that there was little difference between the two in terms of outcome [31]. A variety of strategies have been adopted with regards to the number of roots sectioned varying from lower lumbar and sacral roots to all lumbar and the first two sacral roots. Whilst it has been claimed that including the second sacral root improves the durability of the procedure [21] a significant proportion of pudendal sensation is carried by the second sacral root suggesting that difficulties with sphincter or sexual function might follow either immediately or as a result of the ageing process [19]. During the procedure different centres adhere to a maximum portion of each dorsal root for sectioning. Our practice was to limit root section to 50% as advised by Warwick Peacock but more recently 75% section has become popular leading to a profound loss of tone. Most centres continue to use intra-operative neurophysiology to identify those portions of each dorsal root that are most liable to produce disseminated motor activity when stimulated although one study comparing un-guided versus neurophysiological guided rhizotomy and failed to show a difference in outcome or complications [40].

3.2. *Objectives of SDR*

Success in any endeavour requires a defined objective against which to measure change. Few authors are explicit in their objectives when describing surgical case series.

3.2.1. *Improved mobility*

The presence of spasticity renders mobility difficult as a result of abnormal stiffness affecting several key points in the gait cycle. Expressed in terms of the prerequisites of normal gait, spasticity does not primarily produce abnormal *pre-positioning at initial contact* as this is generally the result of impaired activity in the ankle dorsiflexors in bilateral cerebral palsy. Coronal deformity resulting from overactivity of tibialis posterior is more commonly seen in hemiplegia. *Instability during stance* is produced typically when, in response to loading of an equinus forefoot, spasticity in the calf leads to the generation and absorption of excessive amounts of power at the ankle in the first half of stance. Frequently, little power is produced in pre-swing at the ankle in the presence of spasticity because the ankle is already in full equinus at the point when a combination of muscular and elastic shortening of the calf should be propelling the leg forwards and upwards into swing. A lack of power developed in pre-swing in the calf combines with spasticity in the thigh principally affecting rectus femoris to produce stiff knee gait.

Two effects result from a limb that is functionally over long in swing phase secondary to spasticity. Firstly, a restriction of *clearance in swing* is produced by the knee being excessively straight in early swing and the ankle failing to dorsiflex as a result of residual tone in the calf and failure of active dorsiflexion. Secondly, failure of knee flexion produces an abnormally large moment of inertia in the lower limb rendering advance difficult. The lack of angular acceleration means that the limb lacks the velocity to reach full extension at the knee in time for initial contact even if spasticity was not evident in the hamstrings. When spasticity in the hamstrings is significant, a further constraint is placed upon terminal swing phase knee extension leading to initial contact with an excessively flexed knee producing high flexing moments during the loading response which encourage crouch as well as an *inadequate step length*. Spasticity in psoas also contributes to a short step length by preventing the thigh from becoming reclined in terminal stance. Removing spasticity from the lower limbs has the potential to improve walking at several points in the gait cycle but the key deficit identified by our group that can be helped by rhizotomy is a lack of pre-swing knee flexion. Sagittal knee kinematics represent the most valuable clinical decision-making data item within a 3-D kinematic study in the context of patient selection for selective dorsal rhizotomy.

3.2.2. *Quality of life*

Some authors justify the use of selective dorsal rhizotomy in cerebral palsy on the grounds of improvement in quality-of-life. In a large survey of children aged between eight and 12 years of age growing up with cerebral palsy across the European Union (SPARCLE I), quality-of-life was compared with that experienced by typically developing children [12]. The survey used an extensively validated questionnaire to measure quality-of-life as reported by children [33]. An unexpected outcome of the study was that in the absence of pain, children affected by cerebral palsy had very similar quality-of-life measures when compared with typically developing children. Pain is a frequent problem during childhood complicated by cerebral palsy as a result of spasticity and its secondary effects. Hip subluxation, foot deformity, pressure within orthotics and muscle cramps can all produce pain which is often not reported by the child unless specifically sought. Approximately 10% of children have pain daily or frequently as a result of cerebral palsy [32]. Where pain results from muscle cramps or spasticity leading to excessive pressure within orthotics, treatment may well focus primarily on the spasticity.

The ability to take part in activities at school, at home and in the community constitutes participation as described in the ICF-CY [47]. Participation is generally significantly restricted as a result of cerebral palsy but this varies according to environmental factors as well as the severity of the condition [27]. Improvement in mobility resulting from effective treatment should lead to an improvement in participation. Whether the level of the improvement is from wheelchair ambulation to walking or from walking with a posture walker to walking with sticks, the ability of the child to engage more normally should be improved. In the context of selective dorsal rhizotomy the treatment benefits are thus likely to be seen in connection with participation but not with quality-of-life in the absence of pre-operative pain.

3.2.3. *Ease of care*

Spasticity can lead to difficulties for parents in caring for a child typically with GMFCS grade 4 or 5 involvement. In the lower limb adductor spasticity makes hygiene and dressing difficult and in the presence of hip subluxation leads to discomfort. Sagittal plane contractures makes sitting difficult and often lead to wind sweeping when the child lies supine. Generally these children have involvement of the trunk and upper limb which are not directly amenable to the effects of a selective dorsal rhizotomy. A high underlying incidence of scoliosis which is related to the severity of involvement is also likely to be increased following the laminectomy associated with a rhizotomy. In children where intrathecal baclofen management has been tried but not been found to be suitable, rhizotomy might be considered as a fallback option, recognising the limitations of rhizotomy when compared with a reversible and more comprehensive therapeutic modality. Rhizotomy has the advantage of being significantly less expensive than intrathecal baclofen management but it is permanent and intolerant of dystonia which is seen increasingly in higher grades of the GMFCS involvement.

3.3. *What does SDR do?*

3.3.1. *Spasticity*

Firstly, by reducing afferent drive to the reflex arc, selective dorsal rhizotomy reduces spasticity. Unfortunately, even with neurophysiological testing, it is not possible to isolate the afferents associated directly with the tonic stretch reflex. Even if it