Selective Dorsal Rhizotomy For Spastic Diplegia

Background

1. Procedure
Selective dorsal rhizotomy (SDR) is a surgical technique developed to reduce spasticity and improve mobility in patients with cerebral palsy (CP) and lower extremity spasticity. It involves the selective division of sensory rootlets in the lumbosacral spine, maintaining a balance between elimination of spasticity and preservation of function. SDR aims to reduce spasticity, improve function, and improve mobility, reducing dependence and possibly making dependent children independent.

2. Cerebral Diplegia
Cerebral palsy comprises several clinical syndromes resulting from injury to the immature brain. They are characterised by abnormalities of posture and movement. Although the injury to the central nervous system is static, the clinical expression of cerebral palsy evolves as children grow. Children suffer from a combination of spasticity, dystonia, ataxia, hypotonia and rigidity. Spasticity is the predominant problem in up to 60% of these children; this may take the form of diplegia or quadriplegia. Prenatal factors are primarily responsible in up to 80% of cases. Most of these children are born prematurely and have a very low birth weight (<1500 g). This predisposes them to periventricular leucomalacia and germinal matrix haemorrhage, with post-haemorrhagic ventricular dilatation. As the periventricular white matter is particularly susceptible to injury between 26 and 34 weeks of gestation, the leg fibres are predominantly affected, causing spastic diplegia. The increasing longevity of children with cerebral palsy, up to 95% 30-year survival in children with spastic diplegia, underlines the importance of appropriate early management of spasticity to optimise the quality of life for these children and their families.

Spasticity causes significant discomfort and stiffness, and associated spasms cause pain and interfere with function. It leads to muscle shortening and contracts in both tendon and soft tissues. In children, spasticity affects muscle growth resulting in torsion of long bones, and joint instability and degeneration. Spasticity interferes with the ability of carers to look after cerebral palsy children effectively.

3. History
Lumbosacral dorsal rhizotomy for spasticity was first described in 1898, by Sherrington, and then by Foerster in the early 1900’s. They reported promising early results with “congenital spastic paraplegia.” Their technique involved complete division of the posterior roots of L2, L3, L5 and S1, leading to marked improvement in spasticity. However, their early attempts at SDR were therefore abandoned due to complication rates, and numbness & proprioception loss in the legs. Without proprioception patients cannot tell where their legs are and this prevents them from walking.

Further interest in SDR was ignited with the advent of partial section of the nerve roots, instead of complete section. This was described by Gros in 1967, and then by Fasano in 1978, who described partial sectioning of the posterior nerve roots on the basis of intra-operative electrophysiological stimulation. Nerve rootlets producing sustained muscle activation with abnormal widespread involvement of unrelated circuits in the trunk and upper limbs on stimulation were assumed to be contributing to spasticity and were divided, leading to good long-term results. The technique was adopted and popularised by Peacock and Arens in the 1980’s.

4. Current status
SDR is now a standard neurosurgical procedure for the treatment of spasticity associated with CP. It is recognised and funded by all the major healthcare insurance providers in North America. Peacock described SDR performed either through a multilevel L1/2-S1 laminectomy or laminoplasty, but this has also been associated with later spinal
deformity in some centres. Dr Park has subsequently developed and reported SDR performed through a single level laminectomy at the position of the conus, as determined by intra-operative ultrasound\textsuperscript{28,31}. Between 50 and 70% of the nerve roots are divided; most surgeons minimise rhizotomy at L4 and S2 to avoid significant quadriceps weakness and bladder dysfunction respectively. Intra-operative neurophysiology is an integral part of the procedure and allows selective division of nerve rootlets.

5. Patient selection
The general selection criteria, defined by Peacock in 1987, still apply\textsuperscript{32}. These include predominantly spastic CP without significant ataxia or dystonia, good trunk control, a degree of ambulation with or without assistive devices and good lower-extremity antigravity strength. A brain magnetic resonance imaging (MRI) scan is now often considered necessary to exclude injury to the basal ganglia, brainstem or cerebellum. Significant femoral head dislocation (Reimer’s index beyond 40\%) should be excluded on pelvic radiographs. It is also ideal to wait at least three months from the last botulinum toxin injection, and at least one year from the last orthopaedic procedure.

The decision as to whether SDR is the optimal procedure for a particular child at a particular time is not easy and needs to be taken within a multidisciplinary context. It is based on a formal, defined physical examination and evaluation. In our unit this is carried out in a multidisciplinary spasticity treatment clinic – where a paediatric neurosurgeon, a paediatric neurologist, and a paediatric physiotherapist see the patient. Where necessary, further assessments are also undertaken by a paediatric orthopaedic surgeon prior to any decision to proceed with SDR. The clinic is set-up to review patients for suitability for intrathecal baclofen (ITB) or SDR. Separate clinics exist in Leeds to provide joint paediatric neurology/orthopaedic review and also for Botulinum Toxin injection. Only a small number of children with spastic diplegia are suitable for SDR. Other options, such as repeated injections of botulinum toxin, ITB therapy and multilevel orthopaedic surgery may be better for some children. Agreement by all involved carers on the goals of treatment for the individual child is crucial. The principal goals of SDR include improved motor function, increased mobility, increased independence and improvement in ease of care\textsuperscript{6}.

Evidence of effectiveness

1. Randomised clinical trials
Three randomised controlled trials have evaluated the effectiveness of SDR for spasticity in children\textsuperscript{30,21,40,46}. In the Toronto study, 24 children with mild to moderate CP and spastic diplegia were randomly assigned to SDR + PT or PT alone\textsuperscript{46}. In the former group, evaluation at 12 months showed significant improvements in GMFM scores, knee and ankle tone, passive ankle range of motion, soleus EMG reflex activity on forced dorsiflexion and foot – floor contact pattern. In the Vancouver trial, 15 patients were randomly assigned to SDR + PT or PT alone\textsuperscript{40}. Significant improvements in GMFM, spasticity and range of movement were demonstrated in the group undergoing SDR + PT. In the Seattle trial, 43 children with spastic diplegia were randomly assigned to SDR with physical therapy (PT) or SDR alone\textsuperscript{21}. Spasticity was quantified with an electromechanical torque-measuring device (spasticity measurement system, SMS); the gross motor function measure (GMFM) score documented changes in functional mobility. At 24-months the SDR, PT group showed a significant reduction in spasticity compared with the PT only group. Improvements in the GMFM were not significant; this study was however different in that only a mean of 25\% of dorsal roots were divided. This is in contrast to the currently accepted SDR technique, in which between 50 and 70\% of the sensory nerve roots are divided.

A subsequent meta-analysis of these three trials pooled the baseline and 9 to 12 month outcome data\textsuperscript{30}. Pooled data for 90 patients revealed an increase in GMFM of 4 points in patients undergoing SDR and PT at 12 months post-operatively. Ashworth scores were reduced by a mean of 1.2 points. None of the studies reported any adverse events. A direct linear relation between the extent of dorsal roots transected and magnitude of gain in function was observed, explaining the reduced changes in GMFM in the Seattle study.

2. Prospective non-randomised patient series
A large number of prospective non-randomised patient series have been reported. Steinbok reviewed outcomes of large published patient series in 2001\textsuperscript{37}. Quantitative assessment of spasticity, most commonly using the Ashworth scale, were reported in 10 studies, in addition to the randomised controlled trials referred to above; these represent over 350 patients, and consistently show a significant reduction in spasticity. Eight prospective case series (352 patients) document improvement in the range of movement in the lower limbs. Nine prospective case series (approximately 100
patients) reported improvement on formal instrumented gait analysis. Eight studies (213 patients) showed improvement in qualitative assessment of sitting ability in over 70% of patients. Eight studies (346 patients) documented improvement in qualitative assessment of ambulation in 50 to 78% of patients. Two prospective studies (45 patients) evaluated the Paediatric Evaluation of Disability Inventory (PEDI) and identified improvements post-SDR in self-care and mobility domains. The Functional Independence Measure for Children was used in two further studies (122 patients); this showed improved motor scores, sphincter function and cognitive scores after SDR.

Kan et al compared two groups of 71 children, all with severe spasticity; one group underwent SDR before 1997 and the other underwent ITB therapy after 1997. The SDR group showed significantly better improvements in Ashworth scale, lower extremity passive range of motion and GMFM scores.

Buckon et al reported differences within 25 children with spastic diplegia, of whom 18 underwent SDR and 7 underwent appropriate orthopaedic procedures, as decided by informed parents. Children undergoing SDR demonstrated higher improvements on the Gross Motor Function Measure (GMFM), as well as significantly better gains in self-care skills, and a decrease in care-giver assistance throughout the two year follow up period. A review of 158 children with spastic diplegia undergoing SDR also demonstrated that early SDR, between two and three years of age, was associated with a reduced long-term need for orthopaedic procedures. The same group, in their overall study of 178 children and young adults with CP, demonstrated a significant reduction in the need for orthopaedic surgery after SDR undertaken prior to four years of age, with 10-years’ follow-up. They found that, if children become independent ambulators following SDR, about 20% required subsequent orthopaedic procedures. However, if they ambulated with assistance following SDR, about 50% required subsequent orthopaedic procedures. Finally, in a non-randomised study, children undergoing SDR had a significantly reduced need for orthopaedic surgery when compared to age and GMFCS-score-matched children undergoing ITB therapy.

Suprasegmental effects have also been reported after SDR. Six studies (256 patients) noted suprasegmental improvements, mostly involving the upper limbs, in up to 80% of patients. Quantitative assessments were used in 5 studies (148 cases); these demonstrated improved block stacking, improved upper limb tone and better manipulation patterns. Improved cognitive function was also noted at six months post-SDR in one prospective non-randomised study.

3. Long-term results

Nordmark et al studied a group of 35 children with spastic diplegia over a five-year post-operative period. SDR resulted in immediate reduction of tone in adductors, hamstrings and dorsiflexors, with no recurrence of spasticity over five years. Similarly, there was significant improvement in passive range of movement in hip, knee and ankle joints, as well as significant improvements in GMFM and PEDI scores. Improvements on the PEDI score, particularly on the self-care and mobility domains were also evident in another series of 30 patients. Subramanian et al performed gait analysis in a cohort of 11 children ten years after SDR. He found that, unlike pre-operative values, ranges of motion for the hips and knees were within normal limits at ten years, and were maintained at a normal midrange point, confirming long-term gait improvements. Improvement in spasticity, range of movement and gait pattern was also maintained over ten years in a cohort of 208 children with spastic diplegia. Locomotor function was also shown to be improved 20 years post-operatively in a cohort of 13 children who underwent SDR for spastic diplegia in 1985. These children also demonstrated sustained improvements in their functional status, as measured on the International Classification of Functioning, Disability and Health model, at 20 years.

A recent 10-year follow-up study of 29 patients has been published by Josenby et al from Sweden. They concluded that, 10 years after undergoing SDR, muscle tone was normalised and mean passive range of motion was unchanged. The mean capacity of gross motor function (GMFM-66) was found to increase steadily over the study period. The long-term changes in gross motor function were associated with preoperative GMFCS levels.

4. Complications and safety

Permanent complications are rare after SDR. Transient dyseaesthesia has been reported in 2.5 to 40% of patients, and lasts up to a few weeks from surgery. The incidence of permanent hypoesthesia is rare. Transient urinary retention is more frequent, occurring in between 1.25 and 24%. Permanent urinary incontinence is rare. Most centres now advocate pudendal monitoring and limitation of the division of the S2 nerve root in order to limit adverse effects related to detrusor function. Hip subluxation tends to stabilise in up to 80% of patients post-SDR; up to 40% of patients show improvement in the degree of hip subluxation post-operatively. Back pain, occurring weeks to months after surgery, has been reported in 4-7% of patients. SDR performed through multilevel laminoplasties or...
laminectomies may increase the incidence of spinal deformity, (thoraco-lumbar scoliosis, kyphosis, hyperlordosis or spondylolisthesis), particularly in children with severe quadriplegic spasticity\textsuperscript{28}. These children, however, are often treated with ITB, and a large patient series has shown that limited laminectomies limited to the level of the conus are not associated with significant long-term spinal deformity\textsuperscript{29}.

**Cost-effectiveness**

There are no economic evaluations of SDR alone found on a Pubmed search. To ask for evidence of economic evaluation is therefore not appropriate at present. The evidence is not there. Absence of evidence is not of course the same as lack of proof of economic benefit. Indeed there are many interventions in childhood disability which are accepted a standard practice in which there has been no economic evaluation – eg many physiotherapy interventions. There are an increasing number of good quality studies showing long-term clinical benefit of SDR and using appropriate outcome measures. Recent studies use the WHO framework International Classification of functioning, activity and participation (ICF) for outcome assessment. This conceptual approach is internationally accepted as the gold-standard. As evaluation of this procedure has developed there are an increasing number of methodologically sound studies using the ICF domains and yielding results of positive benefits for SDR.

A number of studies have evaluated cost effectiveness of ITB therapy for severe spasticity\textsuperscript{3,9,13,27,33,35,36}. In a study from the UK on the cost – benefit ratio of ITB in severe spasticity, the authors concluded that the cost per QALY lies in the range of £6900 to £12800; they consider this to be acceptable in the context of other interventions funded by the National Health Service\textsuperscript{34}. De Lissovov et al reviewed cost effectiveness for ITB in a paediatric population with severe spasticity in the US, concluding that the cost per QALY for ITB is $42000; this figure lies well within the $50000 to $100000 range that is widely accepted as offering good value for money\textsuperscript{9}. A similar study from the Netherlands evaluated 15 children with intractable spastic CP and compared the effectiveness and cost of ITB against standard medical treatment over one year\textsuperscript{13}. This concluded that ITB is significantly more effective and costs €32737 per QALY. A study from France using Monte Carlo simulations also demonstrated that ITB is associated with a more favourable cost-effectiveness ratio compared to conventional medical management\textsuperscript{3}.

Only one study has evaluated cost-effectiveness of SDR compared to ITB\textsuperscript{9}. Ten children with spastic quadriplegia on ITB were matched with ten other children who had undergone SDR. Clinical care flow charts were created for each patient, identifying and costing each point of contact with the health care system. The cost-per-patient up to one year after treatment was CDN$63000 for patients treated with ITB and CDN$16913 for patients treated with SDR. The higher cost per patient on Baclofen was related to the cost of screening patients who did not go on to have implanation, and to additional hospitalisation for complications in the baclofen group\textsuperscript{9}.

To our knowledge, there are no studies evaluating cost-effectiveness for SDR in children with spastic diplegia. Based on our local experience with cerebral palsy in the context of a regional paediatric centre, most children at GMFCS 2-4, who would be potentially suitable for SDR, undergo multiple botulinum toxin injections and at least one episode of multi-level orthopaedic surgery. Young children with significant diplegia require botulinum toxin injections on a regular basis, from around four years of age onwards. Injections are administered under general anaesthetic and cost approximately £1400 each time. They are followed by a long period of intensive physiotherapy, often associated with several weeks of casting. Their effect typically lasts for three to six months; repeated injections are often associated with progressive reduction in clinical efficacy. Unlike SDR, they do not reduce the requirement for orthoses, which in growing children need to be changed frequently and cost approximately £400 every time. A matched comparison of SDR and four-monthly botulinum toxin injections in 40 diplegic children showed that improvements in spasticity and gait became insignificant 12-months after commencement of injections; in contrast, those undergoing SDR improved continuously during the 20-month follow up period\textsuperscript{45}.

Children at GMFCS 3 and 4 accumulate progressive lower limb skeletal, muscular and joint deorformities before reaching skeletal maturity. This frequently necessitates multi-level orthopaedic surgery, which often includes soft tissue release surgery in combination with femoral osteotomies and hip reconstruction. Watt et al prospectively studied 74 children with spastic CP and found that 61% had already undergone orthopaedic operations by 8 years-of-age\textsuperscript{44}. Excluding gait lab analysis and post-operative rehabilitation, the hospital NHS tariff for femoral osteotomy and internal fixation is up to £9061; that for femoral head relocation and derotation osteotomy is up to £16825. Although these procedures improve the cosmesis of gait, they do not address spasticity, the primary cause of deformity and contracture. A study comparing
SDR with multilevel orthopaedic surgery in 25 young children with spastic diplegia showed significant improvement in the GMFM score in the standing, walking, running and jumping domains in the SDR group, but only in the standing dimension in the orthopaedic group. Self-care skills, mobility, social function and independence gains were seen earlier and with greater frequency in the SDR group.

A series of studies evaluating the rate of orthopaedic surgery after SDR showed that in all age groups, 25% of independent walkers and 44% of assisted walkers required orthopaedic surgery over a nine-year follow up period. This is significantly lower than the rate of orthopaedic requirements in Watt’s series. It is probable that all patients who had SDR would have needed at least one orthopaedic procedure before skeletal maturity had SDR not been done. Those undergoing SDR at a young age demonstrated the lowest requirement for orthopaedic surgery after SDR. Given our local experience and this evidence, it would appear that undertaking early SDR would improve the cost effectiveness of spasticity management. It has been argued that SDR is analogous to surgery for intractable epilepsy, where early treatment of the pathological process then allows the child’s development to proceed as normally as possible.

For the last 25 years Dr Park has been performing SDR surgery in America. He currently advocates early surgery at age of 2-4 years. As of February 2012, he had done SDR on 1,161 children aged 2-4 years (232 children at 2 years, 480 children at 3 years and 449 at 4 years). In total, he has operated on 2,314 patients – therefore 50% of his SDR cohort of patients was aged 2-4 years at the time of SDR. In personal communication of these latest results, he concludes:

1) Early surgery prevents or reduces deformities and decreases the requirements for subsequent orthopaedic surgery. He reports that children receiving SDR at 2-4 years had significantly lower rates of orthopaedic surgery than children receiving SDR at later age.

2) There is no known benefit to spasticity in CP. In contrast, numerous adverse effects of spasticity in children are well known.

3) Children with spastic CP do not depend on spasticity for their movements – therefore the risk of causing harm to the child by removing the spasticity is minimal.

4) Early SDR frees children from spasticity and facilitate their motor developments. The young children often become independent walkers shortly after SDR.

5) There is no scientific rationale for delaying SDR until 4 or 6 years of age.

NICE

The National Institute for Health and Clinical Excellence has recently reviewed its guidance for SDR and issued a new document on the 15th December 2010 (http://www.nice.org.uk/guidance/IPG373). In this guidance, NICE acknowledged the increased evidence on efficacy and safety of the procedure, published since its last guidance in 2006. The guidance states that evidence on its efficacy is now adequate, and stated that ‘healthcare professionals across the NHS can offer the procedure under their hospital’s normal arrangements for consent, clinical governance and audit.

Conclusions

1. SDR is safe, and has been approved by NICE for delivery in the UK.
2. Published evidence confirms that SDR provides long-term benefits to the patient.
3. SDR is the only currently available treatment that can permanently reduce or remove spasticity in the legs of suitable children with spastic diplegic CP.
4. Published evidence confirms that SDR can reduce the need for subsequent orthopaedic surgery (and hence both improve the quality of life for the patient and save money for the NHS).
5. SDR appears cost-effective when compared with ITB.
Patient information and consent

This is an elective procedure and parents and families have ample opportunity to discuss surgery with team members at the spasticity clinic and at other pre-operative meetings. There are several websites that contain information on SDR and document patient and family experiences, and these are discussed with parents. The expected benefits and outcome from the procedure, as well as issues related to post-operative pain and discomfort, rehabilitation and the need for regular intensive physiotherapy are also discussed.

Information sheets for both patients and healthcare professionals are available on the Leeds Neurosurgery website – www.leedsneurosurgery.com/sdr. Families are encouraged to download and read the available information and are encouraged to contact the team through the secretarial team or through the spasticity specialist nurse if they have further questions.

The standard consent form used for paediatric neurosurgical procedures is used for SDR. The aim of SDR is to reduce spasticity. The complications, as detailed above, include infection, spinal haemorrhage, cerebrospinal fluid leak, incomplete reduction of spasticity, lower extremity weakness, sensory disturbance (almost always transient), transient bladder disturbance and low back pain. The risks of long-term spinal deformity, reduction in ambulatory potential, new permanent and disabling neurological disability, as well as the risk to life, are considered to be very small. As can occur with all intradural spinal procedures, children who also have a shunt may develop post-operative shunt malfunction. The post-operative need for commitment to a long-term physiotherapy programme is also discussed.

Patient pathway in Leeds

1. Pre-operative evaluation. Patients are initially seen in the paediatric multidisciplinary spasticity clinic – by a team of experts including paediatric neurosurgery, paediatric neurology and paediatric physiotherapy. This assessment aims to define the child’s baseline status, suitability for SDR against a set of defined criteria, his/her physiotherapy requirements and the expectations of the family. The referral criteria for consideration for SDR in Leeds are:
   a) Spastic Diplegic Cerebral Palsy
   b) Preterm birth or full term with typical signs of spastic diplegia
   c) Age 2+ years
   d) MRI shows typical cerebral palsy changes with no evidence of damage to key areas of brain controlling posture and coordination (cerebellum)
   e) GMFCS levels: aged 2-4 yrs = II-III / aged 4-12yrs = II-III (but children on either side of these may be considered)
   f) Definite dynamic spasticity in lower limbs affecting function and mobility
   g) No dystonia
   h) No evidence of genetic or progressive neurological illness
   i) Mild to moderate lower limb weakness with ability to maintain antigravity postures.
   j) No significant scoliosis or hip dislocation

A multi-disciplinary decision is reached during this clinic review and discussed with the parents. If the consensus decision is for SDR to proceed, a formal application for funding is made to the PCT.

2. Admission. If PCT funding is approved, arrangements are made for admission and surgery. The patient is admitted the day prior to surgery. A final pre-operative physiotherapy evaluation is performed (using standardised assessment tools such as GMFM) and a video recording is taken during this assessment; this provides the basis of subsequent evaluation of post-operative versus pre-operative outcomes.

2. Surgery. A typical SDR procedure takes four hours. Intra-operative neurophysiology is used.

3. Physiotherapy. We commence in-patient physiotherapy immediately post-operatively and then continue for a further three weeks. Children are then discharged to the care of community physiotherapists.

4. Audit. Prospective audit is carried out on all patients undergoing SDR. These children undergo regular physiotherapy post-operatively in the long term and will be formally reviewed at six, 12, 18 and 24 months. Longer-term review is also available through our paediatric spasticity clinic. A record of post-operative complications is prospectively maintained. Scores of spasticity, including the Ashworth Score and the GMFM are recorded, together with paediatric quality of life scores. Gait lab analysis is repeated at 24 months.
The Outpatient Pathway for Children being assessed in Leeds

Referral received
Triaged by consultant

Letter sent to family inviting to attend outpatient assessment

Information gathering form sent to physiotherapist

**Outpatient Assessment**
- Physiotherapy assessment: Functional Assessment, Muscle Tone, Joint Ranges, Muscle Power.
- Specialist nurse assessment: support spasticity treatment screening form completion.
- Consultant assessment: review of findings and discussion of decision-making process.

**1-2 hour appointment**

- Assessment identifies as SDR candidate
  - Individual Funding Request made to PCT
  - Placed on waiting list for inpatient procedure. (See in patient pathway)
  - POST SDR
    - 4, 12 and 24 month outpatient assessment as above

- Significant weakness identified
  - Decision postponed and request for strengthening programme forwarded to local physiotherapy team.

- Excessive weakness identified
  - Discharged

(See in patient pathway)
The Inpatient Pathway for Children treated in Leeds

Admitted to ward

Physiotherapy assessment (video’d):
GMFM 66/88, Tone, ROM, Power,
Fit for surgery assessment

SDR Operation performed

Admitted to PICU / HDU for 24-48h. Bed rest, analgesia & sedation

Day 3 rehabilitation started with physiotherapist

Remain as inpatient for 3 weeks with daily rehabilitation from physiotherapy team.

Week 2 discharge planning meeting.
Local team invited to attend where possible.

Week 3 discharged home to care of local team.
Home exercise programme provided to family and local physiotherapy team.

The Spasticity Treatment Team in Leeds

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