IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Selecting Dorsal Rhizotomy Part I:

Applying SDR to improve gait and ambulatory function in the child with cerebral palsy

Objectives

- Describe characteristics of patients that are consistent with a predictable positive result following SDR.
- Learn the benefits of a multidisciplinary collaborative evaluation in these patients.
- Explore the techniques of rhizotomy and the benefits of utilizing a selective approach in the procedure.
- Review the post SDR short and long term outcomes data.

Why SDR?

- SDR is safe
- SDR rarely worsens gait function when candidates are chosen following careful selection parameters
- SDR is effective at reducing spasticity of cerebral origin
- SDR is permanent
- SDR almost always improves efficiency of gait
- SDR helps reduce the number of orthopedic procedures that need to be performed in order to keep these patients walking

Definitions of abnormal tone

- Hypertonia
  - Abnormally increased resistance to externally imposed movement about a joint. It may be caused by spasticity, dystonia, rigidity, or a combination of features
  - By definition excludes resistance to movement imposed by joint, ligament, or skeletal properties
- Spasticity
  - A velocity dependent resistance to muscle stretch
- Dystonia
  - Involuntary alteration in the pattern of muscle activation during voluntary movement or maintenance of posture
  - With or without hypertonia
- Rigidity
  - Common in adults (parkinsonism), rare in children; resistance to passive movement is not dependent on velocity
  - Task Force on Childhood Motor Disorders 2003

Mechanisms of abnormal tone

Pyramidal or Extrapyramidal

Pyramidal
- Upper motor neurons
- Primary motor area of cerebral cortex
- Internal capsule
- Corpus striatum

Extrapyramidal
- Basal ganglia
- Thalamus
- Brainstem
- Cerebellum

Primarily Spasticity
- Dystonia, Rigidity, Athetosis, Chorea

Pyramidal
- Periventricular Leukomalacia

Extrapyramidal
- Global or watershed injuries
- Spasticity
- Dystonia, Rigidity, Athetosis, Chorea
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Multidisciplinary Approach

- Physical Therapy Evaluation including video
- Gait Lab Evaluation
- [Social Work Consult]
- [Psychology Consult]
- Spasticity Clinic Evaluation
  - Pediatric Neurosurgery
  - Pediatric Orthopedics
  - Pediatric Physiatry

“Checks and Balances”

Physical Therapy Evaluation

- GMFCS
- Equipment
- ROM
- Strength/Selectivity
- Contracture/Deformity
- Tone
  - Ashworth scores
  - Dystonia
  - Interference w/ function
- GMFM
- Subjective Behavior Evaluation

Physical Therapy Video

- Rolling
- Prone on Elbows
- Supine to Sit
- Crawling forward and backward
- Quadruped to side-sit – both sides
- Tall kneel and knee walking
- Kneel to stand
- Sit to stand
- Walking
- Running
- Stairs
- Other

Multidisciplinary Approach

- Physical Therapy Evaluation including video
  - Gait Lab Evaluation
- [Social Work Consult]
- [Psychology Consult]
- Spasticity Clinic Evaluation
  - Pediatric Neurosurgery
  - Pediatric Orthopedics
  - Pediatric Physiatry

Gait and Motion Analysis Laboratories
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Gait and Motion Analysis

- Helps quantify and localize areas of spasticity
- Helps identify non-spastic tone patterns (dystonia, athetosis, etc.)
  - Evaluates for evidence of primitive stepping patterns in gait that truly represent mass flexion-extension patterns
- Quantifies energy expenditure in gait
- Kinetics of typical gait patterns responsive to SDR can be seen – flat knee curves and plantar flexed ankles at IC

Gait Analysis Resources

- www.cmlainc.org/AccreditedLabs.html
- www.gcmas.org/

Multidisciplinary Approach

- Physical Therapy Evaluation including video
- Gait Lab Evaluation
- (Social Work Consult)
- (Psychology Consult)
- Spasticity Clinic Evaluation
  - Pediatric Neurosurgery
  - Pediatric Orthopedics
  - Pediatric Physiatry

"Checks and Balances"

Clinic Appointment

60 – 120 minutes

- Nurse evaluation
  - review the medical record with family
  - review current medications
  - review interim history
- Review of MRIs, radiography, gait analysis results, PT eval and video
- Multidisciplinary Clinic Evaluation
  - Neurosurgery
  - Orthopedics
  - Physiatry

- History Review
  - identify family expectations of visit
- Focused Physical Exam
  - ROM
  - Spine exam
  - Torsional measurements/joint health
  - Spasticity (Other abnormal tone)
  - Selectivity
  - Strength

Multidisciplinary Discussion

- Team convenes outside of the patient’s clinic room to collaborate on findings and to develop an agreed upon plan

Selection
What crucial information does gait analysis provide regarding spasticity management decision-making?

Tom F Novacheck, MD
Director, Center for Gait and Motion Analysis
Gillette Children’s Specialty Healthcare
Associate Professor, Dept of Orthopaedics
University of Minnesota

Candidacy for SDR
- Prematurity with periventricular leukomalacia
- Hypertonia 2° spasticity
- Energy inefficiency
- Antigravity muscle strength
- “Adequate” motor control and selectivity
- Severe contractures not present (4-7 yo)
- Psychosocial factors -- adequate cognitive function and motivation

The Challenge with SDR
- Destructive/irreversible
- CP is not uniform.
- Bad results d/t
  - Poor patient selection
  - Excessive rhizotomy
  - Incorrect selection of nerve root levels
  - Unmanaged lever arm

Selection process
- Gait analysis
- Multidisciplinary spasticity clinic

Overall Factor Tree
- Birth History
- Tone
- Selectivity
- Strength
- Energy

Birth/Imaging History Factor Tree
- Born premature
- Periventricular Leukomalacia
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Tone Factor Tree (Average Ashworth score)
Pure spastic tone dictated in SPEV clinic notes and gait interpretation consistently

Plantarflexor
- < 2
- 2 ≤ < 5
- ≥ 5

Rectus/hamstring
- < 2
- 2 ≤ < 5
- ≥ 5

Hip flexor/adductor
- < 2
- 2 ≤ < 5
- ≥ 5

Average Selectivity Factor Tree

Average Strength Factor Tree

Energy Factor Tree

Physical examination

Hypertonia Assessment Tool (HAT)
- Increased involuntary movements or postures of the designated limb with tactile stimulus of a distant body part
- Increased involuntary movements or postures with purposeful movement of a distant body part
- Velocity dependent resistance to passive stretch
- Presence of a spastic catch
- Equal resistance to passive stretch during bi-directional movement of a joint
- Increased tone with movement of a distant body part
- Maintenance of limb position after passive movement

Selectivity Grade Key
0 - Only patterned movement observed
1 - Partially isolated movement observed
2 - Completely isolated movement observed

Selectivity, Strength

Flexion
- Hip 0: 2.3/5
- Hip 90: 2.3/5

Abduction
- 2.3/5

Adduction
- 1.5/5

Spasticity
Dystonia
Rigidity
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Physical examination

- Spasticity (Ashworth Scale)
  - Hip flexors Left: 2 Right: 2
  - Adductors Left: 3 Right: 4
  - Hamstrings Left: 3 Right: 3
  - Rectus femoris Left: 2 Right: 3
  - Plantarflexors Left: 3 Right: 3
  - Posterior tibials Left: 1 Right: 1
  - Ankle clonus Left: ++/U Right: ++/U

Poor selective motor control

- Kinematics
  - primitive movement pattern
  - "mass flexion/mass extension"

Good selective motor control

- Kinematics
  - Stiffness
  - Diminished ROM
  - typical spastic movement pattern
  - Could be contractures

Sagittal plane kinematics

Hamstring muscle lengths

EMG “patterned”

Not Ideal
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

**EMG cospasticity**
- **Rectus Femoris**
- **Medial Hamstrings**

**Energy Efficiency**
- Normalized O2 Consumption
- Typical Velocity
- 3.44X Normal

**GMFCS: 1**

**GMFCS: 2**
- 5+6 diplegic CP

**GMFCS: 3**
- 5+3 diplegic CP

**Pre/post video**

**Rhizotomy Procedure**
- Peter Kim, MD, FAANS
  - Pediatric Neurosurgeon
  - Gillette Children’s Specialty Healthcare

---

*September 2014  AACPDM 68th Annual Meeting, San Diego, CA*
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Selective Dorsal Rhizotomy Surgeons

*This list may be incomplete

Selective Dorsal Rhizotomy

Procedure

Conus method

Cauda Equina method

History:
Charles Scott Sherrington

DECKERHARTS RIGIDITY, AND REFLEX COORDINATION OF MOVEMENTS, BY C. C. DECKERHART, M.D. (University College, London). (These Figures are from:)

1. Ipsilateral rigidity.
2. Hypothenar hypesthesia.
3. Hypomotor rigidity.
4. Absent reflexes.
5. Absent tendon jerks.
6. Absent ankle clonus.
7. Absent plantar responses.
8. Absent abdominal reflexes.
9. Absent deep tendon reflexes.
10. Absent superficial reflexes.

1. Ipsilateral rigidity.
2. Hypothenar hypesthesia.
3. Hypomotor rigidity.
4. Absent reflexes.
5. Absent tendon jerks.
6. Absent ankle clonus.
7. Absent plantar responses.
8. Absent abdominal reflexes.
9. Absent deep tendon reflexes.
10. Absent superficial reflexes.

Fig. 1. a. Position of animal after section of median sternum. b. Position of animal after section of cerebral hemispheres when hemiataxia rigidity has developed. c. Position of animal after section of optic nerve when hemiataxia rigidity has developed. d. Effect of hemiataxia rigidity on severance of afferent spinal roots of both hemispheres.
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

History

- 1898 Sherrington showed relief of muscle spasticity in decerebrate cats by section of the dorsal root
- Won Noble prize in 1932 in medicine and physiology for “discoveries involving the function of neurons”
- Inhibition of function as an important state
- Coined the term synapse

History

- 1913 Otfrid Foerster 150 cases of dorsal rhizotomy from L2-S2 (Foerster operation)
- Emphasized rehabilitation and orthopedic procedures in the post–op period.
- Was Lenin’s personal physician and performed his autopsy

History

- 1967 Gros in Montpelier France modified the operation to cut 4/5 of dorsal roots from L1-S1.
- Gros reported 62 cases with 18 year follow up. (25 cases of CP)
- Noted improved speech and upper limb function in the CP sub-category

History

- 1978 Fasano et al in Italy reported using intra-operative EMG to select which dorsal rootlets should be cut.
- 109 cases done starting in 1971 (CP population)

History

- Peacock 1982

Science

- Pub Med search- Selective dorsal rhizotomy 273 results
- Pub Med search- Selective dorsal rhizotomy and controlled trial 16
  • 5 are anesthesia and analgesia papers and one is a meta-analysis
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

That was the science

- The rest of this talk is art

Technique

- Cauda Equina
  - Larger opening
  - Anatomic Localization
  - Most used
  - Long term spinal instability?
  - Longer operative time?
  - More blood loss?
  - Longer recover time?

- Conus
  - Smaller opening
  - Venous drainage
  - Less Bone Removal
  - Localization less precise
  - More urologic complications?
  - Less blood loss?
  - Less painful?

Cauda Equina

Technique: Cauda Equina

- Prone under general anesthesia
- EMG
- L1-L5 Laminotomy

Technique: Cauda Equina

- Anatomic and EMG identification of each rootlet L1-S1 (S2 included if < 50% of S1 sectioned)
- Dura closed

Technique: Cauda Equina

- Lamina replaced
- Flat for 48-72 hours
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

**Technique: Cauda Equina**
- Prone under general anesthesia
- EMG
- Laminectomy/Laminotomy guided by pre-op MRI and intra-operative ultrasound
- Laminectomy one or two segments (L1, L2)
- L2 root can be anatomically identified
- L3-S2 are isolated based on appearance and EMG recordings

**Technique: Conus method**
- Lamina may or may not be replaced

**Spinal deformity**
- Clear as mud
- Several studies have been done to answer this question in this population
- Still clear as mud

**Spinal deformity: the work of JC Peter**
- 2007 "Incidence of spinal abnormalities in patients with spastic diplegia 17 to 26 years after selective dorsal rhizotomy."
- 1990 "Incidence of spinal deformity in children after multiple level laminectomy for selective posterior rhizotomy."
- "Except for spondylolisthesis, spinal deformities did appear to progress with time. However, this increase was not marked, and the development of relatively mild scoliosis was the only statistically significant increase." 2009
- "Spondylolysis/spondylolisthesis is the only abnormality that appeared to be more common in this group than in children with CP" (9%) 1990
- Spondylolisthesis rates for general population is 4-6%
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Conclusion

- Both methods are acceptable
- No good evidence exists at this time to suggest one should be done over the other

Rehabilitation following SDR

- Some centers do no inpatient work
- Some centers do six weeks of inpatient therapy or more
- Many centers do somewhere in between

Goals of Rehabilitation

- ROM
- Strengthening
- Sitting
- Mobility/weight shifting
- Reciprocal Movement
- Balance
- Motor control
- Ankle/Feet preparation for stance phase of gait
- Pre-ambulation
- AFO selection
- Transition work
- Endurance
- Speed

ROM

- Hip extension
  - Prone lying time
  - Prone stander/mobile stander
- Knee extension
  - Prone lying time
  - Prone stander/mobile stander
  - K't's
- Dorsiflexion
  - Prone stander/mobile stander
  - AFO’s

Strengthening

- Certainly leg strengthening
- Don’t forget the arms!
  - OT daily
- Core muscle strengthening

Sitting

- Side sitting
- Long sitting
- Tailor sitting
- Transitions
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Mobility and Weight shifting

Pre-ambulation

AFO Selection

- Solid AFO to rigid PLS
  - Support the patient in stance
  - Maintain ROM
  - Reduce crouch

Endurance

Outpatient Therapy

- At discharge, outpatient therapy remains imperative:
  - 5 days/week X ~1 month – accomplished typically between the school team and the outpatient therapy team
  - Decreased dosing of PT is approved as the child demonstrates solid and retained improvement in ambulation goals
  - Many children continue with 2-3 days/week at 6 months
- The child returns for PT evaluations at Gillette approximately 6 and 12 months postoperatively

Outcomes of Spasticity Reduction for Children with Cerebral Palsy

Maximizing Efficacy
Minimizing Risk
Tom F Novacheck, MD
Gillette Children's Specialty Healthcare
Director, Center for Gait and Motion Analysis
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

**Outcome**


**Study Design**

- Retrospective Analysis
- Subjects
  - Gait analysis 0-18 months prior to SDR
  - Gait analysis 8-36 months subsequent to SDR
  - SDR performed at 1994 - 2003
    - Gillette Children’s Specialty Healthcare, or
    - Shriners Hospital for Children – Twin Cities Unit

**Outcome Measures**

- Gillette Gait Index
  - Overall measure of gait pathology
- Gillette Functional Assessment Questionnaire
  - 10 level walking scale
- Oxygen Cost
  - Net nondimensional cost
- Ashworth Score
  - Sum of specific muscles

**Subjects**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number</th>
<th>Age</th>
<th>Follow-Up Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>55</td>
<td>76</td>
<td>21</td>
</tr>
<tr>
<td>Male</td>
<td>81</td>
<td>69</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>136</td>
<td>72</td>
<td>21</td>
</tr>
</tbody>
</table>

**Outcome Categories**

- Poor
  - Lost
    - Pre: within typical range, Post: outside typical range
  - Worsened
    - Pre: outside typical range, Post: further outside typical range
- Neutral
  - Unchanged
    - Pre: outside typical range, Post: outside typical range, no further/closer to typical (within exp. Error)
  - Maintained
    - Pre: within typical range, Post: within typical range
- Good
  - Improved
    - Pre: outside typical range, Post: outside typical range, but closer to typical
  - Corrected
    - Pre: outside typical range, Post: within typical range

**Table 2 . Patient Characteristics**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number</th>
<th>Age</th>
<th>Follow-Up Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>55</td>
<td>76</td>
<td>21</td>
</tr>
<tr>
<td>Male</td>
<td>81</td>
<td>69</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>136</td>
<td>72</td>
<td>21</td>
</tr>
</tbody>
</table>

Age and Follow-Up Time in Years
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

What do we know about gait outcome?

Gait Pathology: GGI

Gait Changes: Pelvis

Gait Changes: Hip

Gait Changes: Knee

Gait Changes: Ankle

We know what is currently working.
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Gait Pathology: GGI

- Mean pre = 243
- Mean pst = 172
- Decrease of 29%

Spasticity: Ashworth

- Mean pre = 343% control
- Mean pst = 291% control
- Increased efficiency of 0.9 levels
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

**Function: Gillette FAQ**

| Walks outside the home for community distances, is able to get around on curbs and uneven terrain in addition to level surfaces, but usually requires minimal assistance or supervision for safety | Walks outside the home for community distances, able to get around on curbs and uneven terrain in addition to level surfaces, but usually uses wheelchair or stroller for community distances or in congested areas |
| Walks outside the home for community distances but only on level surfaces (cannot perform curbs, uneven terrain, or stairs without assistance of another person) |

**Purpose**

Test whether assistive device use (GMFCS level) was predictive of SDR outcome

- Motor control
- Stand alone indicator of risk

**Gross Motor Function Classification System (GMFCS)**

<table>
<thead>
<tr>
<th>Pre-op score</th>
<th>assistive device</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 or 2</td>
<td>independent</td>
</tr>
<tr>
<td>3 or 4</td>
<td>dependent</td>
</tr>
</tbody>
</table>

**Results**

- **GMFCS: 2**
  - 5+6 diplegic CP

- **GMFCS: 3**
  - 5+3 diplegic CP

- **GMFCS 1/2** independent N = 70
- **GMFCS 3/4** dependent N = 66

- The groups closely matched
  - age
  - % of rootlets cut
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

**Gillette Gait Index**

No difference

**FAQ - 10**

No difference

**Oxygen Cost**

Dependent greater chance of poor outcome (significant)

**Walking Speed**

Dependent more likely to improve (significant)

<table>
<thead>
<tr>
<th>5 + 6 yo diplegic CP</th>
<th>5+3 yo diplegic CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMFCS :</td>
<td>neutral</td>
</tr>
<tr>
<td>FAQ:</td>
<td>neutral</td>
</tr>
<tr>
<td>Speed:</td>
<td>neutral</td>
</tr>
<tr>
<td>O2:</td>
<td>good</td>
</tr>
<tr>
<td>GGI:</td>
<td>345</td>
</tr>
</tbody>
</table>
IC 4 - APPLYING SELECTIVE DORSAL RHIZOTOMY (SDR) TO IMPROVE GAIT AND AMBULATORY FUNCTION IN THE CHILD WITH CEREBRAL PALSY

Discussion

- Energy cost (O2) was more likely to be poor for dependent ambulators.
- That same group of children was more likely to walk faster.
- Ceiling effect -- independent ambulators walked at typical speed pre-operatively.
- No relationship between GGI or FAQ and O2.

Take Home

- Following SDR, children who use assistive devices have:
  - equal likelihood of a good outcome
  - gait (GGI, speed)
  - ambulatory function (FAQ)
  - 32% no longer use devices post-operatively
  - more likely to have poor energy outcome

Complications

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowel and bladder</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Skin related</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Wound healing</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Headache</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Parthenosis</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Weakness</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Miscellaneous related</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Miscellaneous not related</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

All resolved by time of discharge

We know that the current methods provide us with a high rate of good outcomes & a low risk of bad outcomes.

Conclusions

- SDR outcomes are good & complication rates are low
  - strict patient selection criteria
  - strict rootlet sectioning criteria
- Risk associated with deviation from the protocol described has not been assessed
  - High adherence to defined criteria
  - Other criteria or operative techniques may work as well, better, or worse

Remember...

SDR only addresses part of the problem (tone)

Orthopaedic problems typically need to be assessed and corrected at a later time