Selective dorsal rhizotomy: meta-analysis of three randomized controlled trials

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This study is a comparative analysis and meta-analysis of three randomized clinical trials. Children with spastic diplegia received either 'selective' dorsal rhizotomy (SDR) plus physiotherapy (SDR+PT) or PT without SDR (PT-only). Common outcome measures were used for spasticity (Ashworth scale) and function (Gross Motor Function Measure [GMFM]). Baseline and 9- to 12-month outcome data were pooled (n=90). At baseline, 82 children were under 8 years old and 65 had Gross Motor Function Classification System level II or III disability. Pooled Ashworth data analysis confirmed a reduction of spasticity with SDR+PT (mean change score difference –1.2; Wilcoxon p<0.001). Pooled GMFM data revealed greater functional improvement with SDR+PT (difference in change score +4.0, p=0.008). Multivariate analysis in the SDR+PT group revealed a direct relationship between percentage of dorsal root tissue transected and functional improvement. SDR+PT is efficacious in reducing spasticity in children with spastic diplegia and has a small positive effect on gross motor function.

Cerebral palsy (CP) has an incidence and prevalence rate of about two per 1000 in children (Grether et al. 1992, Yeargin-Allsopp et al. 1992). Spasticity is a major clinical feature of over 75% of cases of CP and is conventionally considered to be a major cause of discomfort, gait abnormalities, and functional limitations for persons with CP. Many resources have been directed at the treatment of spasticity and the current treatment choices include oral medications, orthotics, orthopaedic surgical procedures, electrical stimulation, intramuscular injections, physiotherapy, 'selective' dorsal rhizotomy, continuous intrathecal baclofen infusion, and a host of alternative treatment methods.

Many of the treatments introduced for spasticity and other aspects of CP were inadequately evaluated when first introduced (McKenzie 1988) and have become enshrined in clinical practice without benefit of acceptable evidence of efficacy and effectiveness. Over the last 15 years, the rigor of clinical research methodology has advanced considerably (Spilker 1991). Valid and reliable outcome measures have been developed for many relevant aspects of CP ranging from electromechanical torque measures of spasticity (Price et al. 1991) and instrumented gait analysis (Sutherland 1988, Gage 1991, Perry 1992) to measures of functional ability (Russell et al. 1989, Haley et al. 1991, Msall et al. 1997), and quality of life (Landgraf and Abetz 1996).

'Selective' dorsal rhizotomy (SDR) emerged as a popular surgical intervention for spasticity in North America and elsewhere since the early 1980s (Peacock and Staudt 1991, Park and Owen 1992, Abbott et al. 1993). History of the development of this procedure, including the introduction of electrophysiological criteria for 'selecting' dorsal root tissue for transection, has been reviewed repeatedly in the literature (Albright 1992, Park and Owen 1992, Hays et al. 1997). Many published results of open consecutive surgical series strongly suggested that SDR reduced spasticity substantially, improved function, and involved no unacceptable short-term risks when carried out by experienced interdisciplinary clinical teams (Peacock and Staudt 1991, Steinbok et al. 1992, McLaughlin et al. 1994, Nishida et al. 1995). Enthusiasm was tempered by concerns about long-term effects, questions about the validity of the root tissue selection process (Landau and Hunt 1990, Cohen and Webster 1991, Logigian et al. 1994, Steinbok et al. 1994, Hays et al. 1998), and recognition that uncontrolled clinical series are open to bias in favor of a positive outcome (Neville 1988, McLaughlin et al. 1994).

Three randomized clinical trials have been published: Steinbok et al. 1997 (Vancouver), McLaughlin et al. 1998, (Seattle), and Wright et al. 1998 (Toronto). Main results of these three studies are presented in Table I. All three studies confirmed that SDR consistently reduces or eliminates spasticity. There is a difference in the functional outcome with two studies showing a statistically significant advantage for SDR (Steinbok et al. 1997, Wright et al. 1998) and the third showing no advantage (McLaughlin et al. 1998). The major similarities and differences regarding the design of these studies are outlined in Table II.

This paper presents a comparative analysis and meta-analysis of these three studies. The primary aim of these analyses was to identify the factors responsible for the different outcomes of the studies and to clarify whether SDR makes a statistically significant contribution to the functional improvement of children with spastic CP up to 1 year after the operation.

Method

A search of Medline, the Cochrane Collaboration database, recent scientific meeting abstracts, and contacts with other researchers in the field did not reveal the existence of any other randomized clinical trials of SDR as of December 2000.

DATA COMPARISON

The senior study biostatistician reviewed the research protocols from each site to compare details of the study designs (Tables III and IV). Common definitions were agreed upon for key variables. The three studies all used the Ashworth scale for spasticity (Bohannon and Smith 1987) and the Gross Motor Function Measure (GMFM; Russell et al. 1989) as major outcome variables. The 12-month data from Seattle and Toronto and the 9-month outcome data from Vancouver were chosen for primary analysis.

The data were entered into SPSS software (version 7.5.3). Complete data were obtained for all variables reported except baseline ambulation status. No new data were collected for the present report. The original three studies were approved by the ethics committees of the respective institutions.

The developers of the GMFM have published an improved scaling method (GMFM-66) that addresses the linearity of the individual items scores across the entire range of GMFM scores (Russell et al. 2000). In these analyses we calculated both GMFM and GMFM-66 scores.

In the initial descriptions and single-center analyses, the markers of severity were the initial diagnosis (spastic diplegia), qualitative descriptors (mild, moderate, or severe), ambulatory status, and the baseline GMFM score. The Gross Motor Function Classification System (GMFCS) provides a means of rank-ordering the functional severity of cerebral palsy (CP) based on age-adjusted clinical descriptors (Palisano et al. 1997). A developmental pediatrician familiar with the GMFCS and masked with respect to participant identification and study group assignment, but not study site, retrospectively reviewed selected clinical descriptions of all participants. Data from each child were assigned a GMFCS baseline score, which was entered into the multivariate analyses.

Table I: Selective dorsal rhizotomy randomized clinical trials outcomes summary

	Study		
	Vancouver	*Toronto*	*Seattle*
Children (n)	28	24	38
Interval (mo)	9	12	24
Mean difference in Ashworth change scores	–1.1 (p<0.001)	–1.0 (p=0.002)	–1.0 (p=0.001)
Mean difference in GMFM change scores	6.1% (p=0.007)	7.7% (p=0.02)	0.2% (p=0.94)

Vancouver, Steinbok et al. 1997; Toronto, Wright et al. 1998; Seattle, McLaughlin et al. 1998.

Table II: Selective dorsal rhizotomy randomized clinical trials

Common features	*Differences*
Eligibility criteria	Primary outcome interval
Random assignment	Role of electrophysiological monitoring
SDR + PT	
PT-only	Dorsal root tissue transectioning rate
Outcome measures	
Spasticity: Ashworth	Objective measurement of spasticity
Function: GMFM	
Sample size	Physiotherapy regimen

PHYSIOTHERAPY REGIMENS

All three centers provided children in both the SDR with physiotherapy (SDR+PT) groups and the PT without SDR (PT-only) groups with physiotherapy programs of stretching, strengthening, and training in functional movements intended to enhance mobility (Tables IV and Va and b). The greatest number of planned treatment hours for both groups was provided in Seattle, and the fewest in Vancouver. Seattle and Vancouver physiotherapy protocols stressed equivalency of treatments for both groups. The Toronto protocol called for a stronger emphasis on strengthening and on postural control for the SDR+PT group as compared with the PT-only group based on the rationale that the anticipated weakening effect of the surgery would provide a negative bias. Treatment planning for the PT-only group in Toronto was based on written goals set by community therapists before the randomized group assignment. Postoperative protocols for the surgical groups in all three centers varied in emphasis and timing (Table Va and b).

DATA ANALYSIS

Characteristics of the three samples were compared using Kruskal–Wallis distribution-free analysis of variance (ANOVA) for continuous or ordered variables and χ^2 or Fisher's exact tests for unordered categorical variables. For each outcome, the change in the SDR+PT group was compared with that in the PT-only group using two methods: blocked Wilcoxon's test (blocking on site; Marascuilo and McSweeney 1997) and ANOVA including factors for treatment group, site, and a treatment by site interaction. To evaluate the effect of characteristics or the effect of SDR on outcome as measured by Ashworth, GMFM, and GMFM-66, separate multiple regression analyses were performed. These analyses used backward selection and the following additional predictors: age, sex, birthweight, ambulatory status, baseline GMFM-66, and baseline lower-extremity Ashworth score. Regardless of significance, site was included in the models; all other variables required a significance level of $p<0.05$ to be retained. Once significant main effects were identified, two-way interactions among the included variables were evaluated. Effects of percent of root tissue transected were studied in the same fashion, except site was not automatically retained as a factor.

Results

A descriptive summary of the samples from the three studies and the pooled data is presented in Table VI. The Seattle study was the only one to include children (n=8) who were 8 years of age or older at baseline. The Vancouver study had an unusual sex ratio (17/28 were female) for a sample of children with CP. The three samples were similar with respect to prematurity. The children in the Seattle sample were slightly more heterogeneous with respect to intellectual function and cause of CP. At baseline, the children in the Toronto sample had what appeared to be somewhat more severe CP as judged by the GMFCS, GMFM, and clinical rating of ambulatory status, although the amount of spasticity as judged by the baseline Ashworth scale was not greater. The children in the Seattle sample had noticeably lower baseline Ashworth scores and had less dorsal root tissue transected (25%) than was the case in the other two studies (41 and 45%). In each of the three original studies, there were no differences in baseline characteristics between treatment groups so the corresponding analysis is not presented here for the pooled data.

The main results comparing the magnitude of change in

Table III: Selective dorsal rhizotomy study design comparison

	Vancouver	*Toronto*	*Seattle*
Treatment	SDR+PT vs PT	SDR+PT+OT vs PT+OT	SDR+PT vs PT
Randomization	Yes, no blocking	Yes, block age <6, ≥6	Yes, block age 3–11, 12–18y; ambulatory status
Blinding	Single	None	Single
Follow-up	9 months	1 year	1 and 2 years
Participants	15, 15[a] randomized 14, 14[a] followed	12, 12[a] randomized and followed	21, 22[a] randomized 21, 17[a] participated and followed to 2 years
Entrance criteria	Spastic diplegia without athetosis or ataxia. Age: 3 to 7 years	Spastic diplegia interfering with functional tasks and limiting factor to gross motor progress Age: 3.5 to 7 years	Spastic diplegia without athetosis, dystonia, ataxia. Age: 3 to 18 years
	Gross motor impaired due to spasticity	Walk ≥3m with support	Good prognosis for ambulation
	Stand holding on	Trunk control and balance at least fair	Fair to good trunk, head control
	Sit with arms up	Sit ≥60 s	
		No major leg contractures (>30°)	No contractures >15° hip, knee, >30° ankle
	No other planned surgery	No major orthopedic surgery	
	No progressive hip subluxation		No progressive hip subluxation
			Intellectual and language ability at ≥36 mo level
Criteria for dorsal root tissue transection	Preoperative clinical assessment, altered by electrophysiological recordings	50% average per root, electrophysiology used only to differentiate dorsal and ventral roots	Electrophysiologic recordings and intraoperative clinical findings
Postoperative management	48 hours' bed rest, discharge 6th day	3–4 days' bed rest, ROM 2nd day, 6 weeks inpatient therapy	Hospitalized 5–7 days, inpatient PT postop day 2
Time of assessment	Base, 3, 6, 9 mo	Base, 2, 6, 12 mo	Base, 6, 12, 24 mo
Primary outcome variables	GMFM-total. Spasticity: myometry and Ashworth Scale (lower extremities)	GMFM-total. Spasticity: Ashworth Scale (unmasked; upper and lower extremities)	GMFM-total and diplegia composite. Spasticity: Electromechanical torque measurement (gastrocnemius)
Secondary outcome variables	Ambulatory status ROM (lower extremities)	Distance walked (60 s) ROM (active+passive – unmasked; lower extremities)	Ambulatory status Spasticity (Ashworth Scale and clinical assessment – unmasked)
	Muscle strength (myometry+manual)	Isometric contraction test	
	Physiologic Cost Index[b] Peabody fine motor[c] Self-care	Gait analysis with EMG Stretch reflex	
Difference to detect	Planned to detect a 5.1 point change in GMFM with 90% power	Not reported	Planned to detect 10 point difference on GMFM with 90% power
Data analysis in primary outcome papers	2-sample *t*-test on change –4 measures, Bonferroni correction	ANOVA adjusting for baseline GMFM	2-sample *t*-test, Wilcoxon on change, χ^2, Fisher's exact (both intent-to-treat and as-treated done, as-treated reported)

[a]Note: first number is number of children in SDR+PT group, second number is number of children in PT-only group; [b]Butler et al. 1984; [c]Stokes et al. 1990. SDR, selective dorsal rhizotomy; PT, physiotherapy; OT, occupational therapy; ROM, range of motion.

weaker direct correlation that remained statistically significant ($p=0.02$). The potential effects of outliers and of sectioning S2 root tissue were examined by eliminating relevant data from the analyses. No appreciable effects were identified.

There was a consistent and statistically significant ($p=0.0002$) inverse correlation between the baseline GMFM-66 score and the percent of dorsal root tissue transected (Fig. 7), i.e. the lower the score, the more dorsal root tissue was cut, regardless of study site. Inclusion of baseline GMFM-66 score in the regression model did not change the relations of outcome variables to per cent of dorsal root tissue transected.

Discussion

Meta-analysis is a well established, if still evolving, methodology for synthesizing outcomes from existing studies of a single research question (Moher et al. 1999). The procedure remains counter-intuitive for clinicians and suffers from both uncritical acceptance and categorical disregard. The applicability of a given meta-analysis is best revealed by setting forth limitations and all differences among studies as we have endeavoured to do in this report. The strengths of this meta-analysis should not be overlooked. Many meta-analyses are carried out by investigators not involved in any of the original studies and who may not have clinical experience with either the disorder or the intervention being studied. As a consequence, the authors of a meta-analysis may have access only to published data, which are inevitably a summary of the raw data. This study is the product of close collaboration among the teams who published the original results of all randomized trials of SDR conducted and published to date. Unpublished raw data were pooled and all data was available for reanalysis. It was possible to ensure that all variables had common definitions across studies and to recalculate variables when necessary. In short, the circumstances of this meta-analysis assured that comparable data were pooled from the three studies. Many meta-analyses suffer from diminished specificity of outcomes arising from the need to reduce disparate outcome variables across multiple studies to a common proxy variable. In this study, identical outcome variables were used in the three original studies for

Table VI: Selective dorsal rhizotomy study sample characteristics

	Vancouver n=28	*Toronto n=24*	*Seattle n=38*	*Pooled n=90*
Sex: female/male	17/11	10/14	15/23	42/48
Age: y (SD)	4.1 (1.0)	5.2 (1.3)	6.8 (3.7)	5.5 (2.8)
Range: y	3–6.5	3.5–7.6	3.3–18	3–18
Ethnicity: white/other	25/3	24/0	26/12	75/15
Gestational age: wk (SD)	31.4 (4.8)	31.9 (4.0)	31.9 (4.8)	31.7 (4.6)
Birthweight: g (SD)	1768 (878)	1956 (691)	1842 (1081)	1849 (921)
Preterm/term	22/5[a]	17/6[a]	30/7[a]	69/18[b]
Cognition: normal/abnormal	24/4	22/1[a]	25/13	71/18[a]
Prenatal cause of CP/other	28/3	21/5[b]	29/19[b]	78/27[b]
Baseline lower extremity Ashworth scale (SD)	3.4 (0.6)	3.1 (0.5)	2.3 (0.6)	2.9 (0.8)
Baseline: Total GMFM (SD)	56.4 (15.2)	52.7 (12.1)	70.7 (14.7)	62.5 (16.0)
Baseline: Total GMFM-66 (SD)	51.2 (8.0)	46.9 (6.0)	57.8 (10.1)	52.8 (9.6)
Baseline GMFCS (%)				
Level I	3	0	13	7
Level II	36	13	24	24
Level III	43	54	58	52
Level IV	18	33	5	17
Level V	0	0	0	0
Baseline ambulation (%)				
Non-ambulator	46	83	47	57
Assisted ambulator	29	4	26	21
Independent ambulator	25	0	26	19
Missing	0	13	0	3
Dorsal root tissue: % transected (SD)	45 (5)	41 (7)	25 (8)	35 (11)

[a]Information missing on one patient; [b]information missing on three patients; [c] information missing on eight patients (some of these were adoptions or other circumstances where we were unable to determine cause.

Table VII: Selective dorsal rhizotomy multivariate analysis: main results

Outcome measures	*Change scores*	*Standard error*	*ANOVA F*	*Significance*
Ashworth	–1.23	0.11	123.10	<0.001
GMFM	4.53	1.44	9.92	0.002
GMFM-66	2.66	0.82	10.53	0.002

the SDR+PT versus PT-only groups for the pooled three-study sample are presented in Figures 1, 2, and 3. Ashworth scale change scores were clinically robust and similar across all three studies with a mean difference in change between groups of −1.2 points which was statistically significant using the Wilcoxon's blocked on site ($p<0.001$). Mean difference in change score in the GMFM (4.0) was statistically significant ($p=0.008$) by Wilcoxon's blocked on site. When the GMFM-66 scores were used, the mean difference in change score for the pooled data was smaller (2.6) and remained statistically significant ($p=0.002$) by Wilcoxon's blocked on site.

Multivariate analysis was carried out to detect effects attributable to site-related differences in baseline variables presented in Table VI and to look for interactions suggesting subgroup effects (e.g. younger versus older participants). Baseline characteristics were chosen as clinically plausible candidate variables. The analyses were done with and without the data for the eight children from the Seattle study, who were 8 years of age or more at baseline. No differences in results were seen, and age was not a significant covariate. Subsequent analysis excluded these older children. As shown in Table VII, the effect of SDR was significant on all outcomes. There was no evidence that this effect differed by baseline characteristics or by study site (i.e. there was no significant treatment by site interaction). Based on the lack of interactional effects in the multivariate model, no subgroup defined by baseline characteristics was identified for which SDR is particularly effective. This was confirmed by looking at mean effects within and across sites in subgroups defined posthoc (analysis not presented). Retrospective GMFCS classification of baseline severity was not related to outcome.

Regression analysis of the outcomes for the SDR+PT groups at the three study sites and the pooled data reveal a weak inverse correlation ($p=0.03$) between percent of dorsal root tissue transected and change in Ashworth scores (Fig. 4). There was a statistically significant direct relation ($p<0.001$) between GMFM change score and percent of dorsal root tissue transected (Fig. 5). The regression lines for the individual sites appear to be very similar. There was an apparent direct effect of site ($p=0.005$) that disappeared after adjustment for percent of dorsal root tissue transected ($p=0.6$). There was no interaction effect with study site. The same analysis was performed for GMFM-66 change score (Fig. 6) and revealed a

Table IV: Physiotherapy by treatment group

	SDR+PT	*PT only*
Physiotherapy schedules		
Vancouver	3 h/wk/3 mo	3 h/wk/3 mo
	2 h/wk/6 mo	2 h/wk/6 mo
Toronto	45 min/day/6 wk (in-patient)	2 h/wk/12 mo
	2 h/wk/10.5 mo	
Seattle	2 h/d/1 mo	2 h/d/1 mo
	4–5 h/wk/5 mo	4–5 h/wk/5 mo
	1–4 h/wk/6 mo	1–4 h/wk/6 mo
Proposed physiotherapy		
Vancouver	84 h (9 mo)	84 h (9 mo)
Toronto	114.5 h (12 mo)	104 h (12 mo)
Seattle	144 h (12 mo)	144 h (12 mo)
Physiotherapy actual		
Vancouver	81.8 h (9 mo)	81.3 h (9 mo)
Toronto	110.6 h (12 mo)	87.4 h (12 mo)
Seattle	152.6 h (12 mo)	137.5 h (12 mo)

Table Va: Comparison of postoperative physiotherapy protocols: timing of intervention

Functional target	*Vancouver*	*Toronto*	*Seattle*
Positioning	Prone, supine, long-sit Wheelchair limited early	Prone, supine, sitting Tricycle use instead of wheelchair emphasized	Prone emphasized 3 h/d for 3 wk 1 h/d after as needed
Start transition movements (to sit, side-sit, all fours, kneel, and stand)	2nd wk postop	2nd wk postop	2nd wk postop
Start weight bearing	Day 6 or as tolerated	Day 8 in Flexistander	3rd wk postop
Start walking	2nd week postop if tolerated	As appropriate from 3rd week	4th week postop

Table Vb: Comparison of physiotherapy protocols: muscle groups treated

	SDR+PT	*PT only*
Stretching protocols		
Vancouver	Hip adductors, flexors, hamstrings, and heel-cords	Hip adductors, flexors, hamstrings, and heel-cords
Toronto	Hip adductors, flexors, hamstrings, and heel-cords	As indicated by individual goals
Seattle	Hip adductors, flexors, hamstrings, and heel-cords	Hip adductors, flexors, hamstrings, and heel-cords
Strengthening protocols		
Vancouver	Glutei, quadriceps, tibialis anterior	Glutei, quadriceps, tibialis anterior
Toronto	Lower extremity muscle groups, abdominals, and trunk extensors	Strengthening through functional activities
Seattle	All lower extremity muscle groups	All lower extremity muscle groups

both spasticity and functional outcomes. The only loss of rigor is that the Ashworth scale measurements were not collected by masked observers in two of the studies. The critically important functional outcomes were measured by masked assessment of GMFM scores in all participants.

The primary conclusion supported by the meta-analysis is that the pooled results of the three studies show a small but statistically significant advantage to SDR+PT compared with PT-only that is independent of any site-specific differences among the studies. It is difficult to know the clinical importance of a mean difference in change score of 4 percentage points on the GMFM. It was not possible to identify any subgroups of children with specific characteristics who benefited more than others included in the studies.

It was expected that the multivariate analysis would identify a specific reason for the difference in outcome among the three studies. Several of the differences in the studies seemed likely to explain the divergent outcomes. The most obvious difference is the surgical technique. The Seattle study used the electrophysiological monitoring technique and criteria for transecting dorsal root tissue popularized by Peacock (Staudt et al. 1995) and other clinicians. The Vancouver study utilized similar criteria for root tissue assessment, but the primary basis for root tissue transection was preoperative clinical assessment. The Toronto study used electrophysiological monitoring only to differentiate dorsal from ventral roots. The amount of dorsal root tissue transected was 25% in the Seattle study and was 41% and 45% respectively in the other two studies. If these apparently major differences were responsible for the difference in outcome, one would expect the study site by treatment interaction variable to be statistically significant in the multivariate analysis model. No such finding is apparent in the results.

The regression analysis of outcome change scores on per cent dorsal root tissue transected (Figs 4 to 6) of the SDR+PT group data provides further insight. Patients who had a larger amount of dorsal root tissue transected had more improvement on GMFM ($p<0.001$), GMFM-66 ($p=0.02$), and Ashworth score ($p=0.03$). As seen in the figures, the effect is modest for GMFM, smaller for GMFM-66, and perhaps inconsistent across sites for the Ashworth scale. Adjustment for per cent

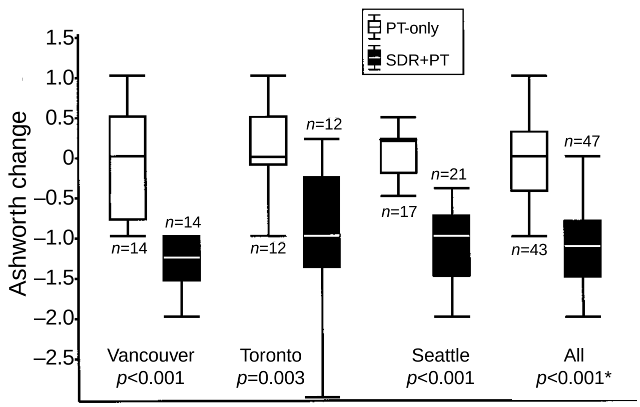

Figure 1: *Ashworth change score. PT Only and SDR+PT group data for individual studies and pooled meta-analysis. Interval is from baseline to 12 months after beginning treatment (9 months for Vancouver). Boxes represent the 25th, 50th, and 75th centiles. Whiskers represent minimum and maximum values excluding outliers beyond 1.5 times the interquartile range. *p values are based on Wilcoxon's tests, with blocking on site for combined test.*

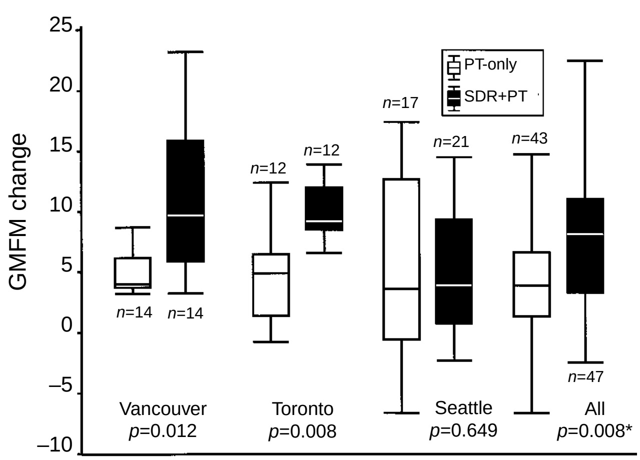

Figure 2: *Gross Motor Function Measure (GMFM) change score. PT Only and SDR+PT group data for individual studies and pooled meta-analysis. Interval is from baseline to 12 months after beginning treatment (9 months for Vancouver). Boxes represent 25th, 50th, and 75th centiles. Whiskers represent minimum and maximum values excluding outliers beyond 1.5 times the interquartile range. *p values are based on Wilcoxon's tests, with blocking on site for combined test.*

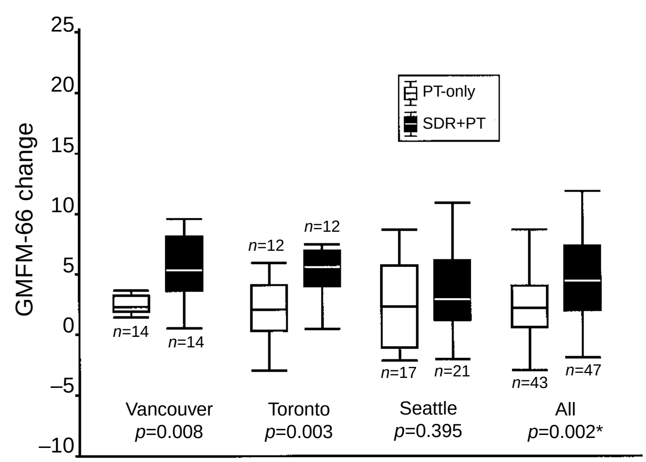

Figure 3: *GMFM-66 change score. PT Only and SDR+PT group data for individual studies and pooled meta-analysis. Interval is from baseline to 12 months after beginning treatment (9 months for Vancouver). Boxes represent 25th, 50th, and 75th centiles. Whiskers represent the minimum and maximum values excluding outliers beyond 1.5 times the interquartile range. *p values are based on Wilcoxon's tests, with blocking on site for combined test.*

of dorsal root tissue eliminated evidence of site effect (see Fig. 5) on GMFM change in the SDR+PT pooled data ($p=0.6$ after adjustment). The per cent of dorsal root tissue transected is related to baseline GMFM-66 (Fig. 7, $p<0.001$) which suggests that the initial functional level may have influenced the extent of transection. Including baseline GMFM-66 score in the regression did not change the models substantially. Although the relation of percentage of dorsal root tissue transected to outcome has biological plausibility, caution is essential in ascribing a causal effect to a factor that was not assigned at random. It is not possible to rule out a chance difference in functional outcome or some other undetected source of systematic bias.

The inverse relation of Ashworth score to percent of dorsal root tissue transected is statistically significant ($p=0.03$, see Fig. 4). However, the interaction with site showed a trend ($p=0.08$) and inspection of the individual regression lines in Figure 4 suggests that the Vancouver data are different from the other two in this respect. The Vancouver study reported the biggest mean percent of dorsal root tissue transected (45%) but was not dramatically different from the Toronto study (41%). The Seattle study (25%) was clearly different from the other two in this regard. There are at least two possible interpretations. First, the Ashworth scale is not known to have good interrater or test–retest reliability, so perhaps it is simply a problem of measurement. Using a quantitative electromechanical torque measure of spasticity in a larger group of children undergoing SDR, no relation could be demonstrated between spasticity and the percent of dorsal root tissue transected (Hays et al. 1998). Second, perhaps it takes a smaller amount of dorsal root transection to abolish deep tendon reflexes, clonus, and clinically detectable spasticity than it does to influence function. Perhaps the Vancouver investigators performed sufficiently extensive rhizotomies to get beyond a range of reduction in spasticity that would be expected to have a dose-response curve while the other two studies still show such a response. The amount of functional change may still show a strong dose–response correlation in

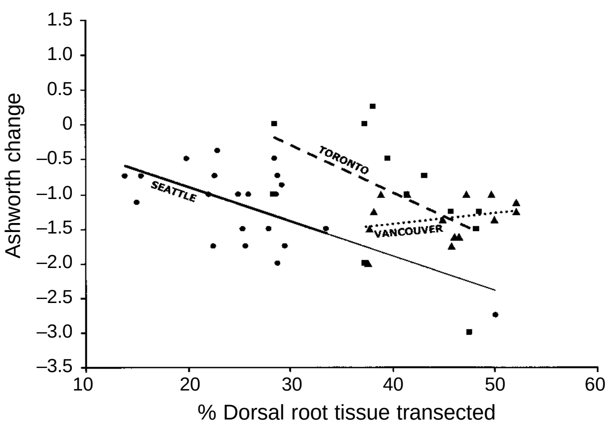

Figure 4: *Regression analyses of Ashworth change score by % dorsal root tissue transected. Linear regression analysis (p=0.03). ●—, Seattle; ■– –, Toronto; ▲---, Vancouver.*

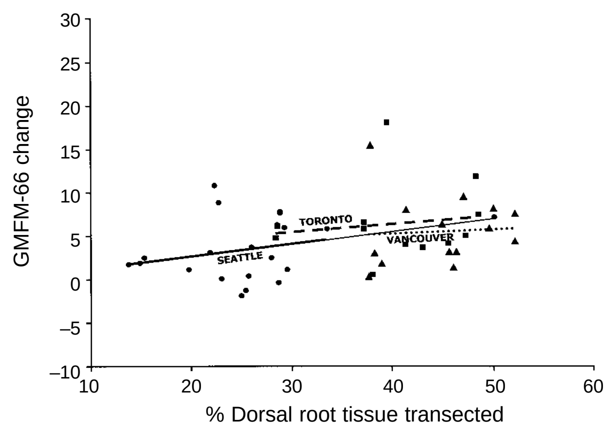

Figure 6: *Regression analyses of GMFM-66 change score by % dorsal root tissue transected. Linear regression analysis (p=0.02). ●—, Seattle; ■– –, Toronto; ▲---, Vancouver.*

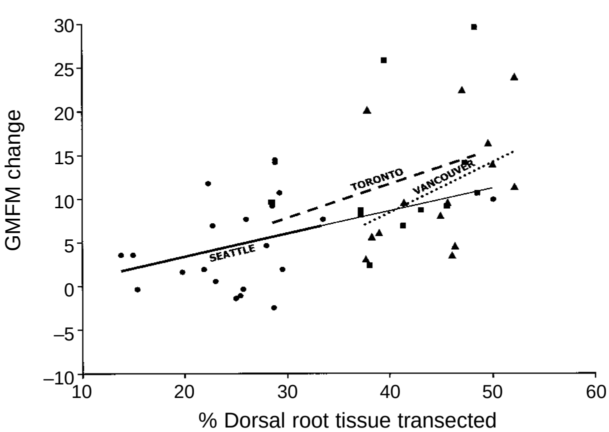

Figure 5: *Regression analyses of GMFM change score by % dorsal root tissue transected. Linear regression analysis (p<0.001). ●—, Seattle; ■– –, Toronto; ▲---, Vancouver.*

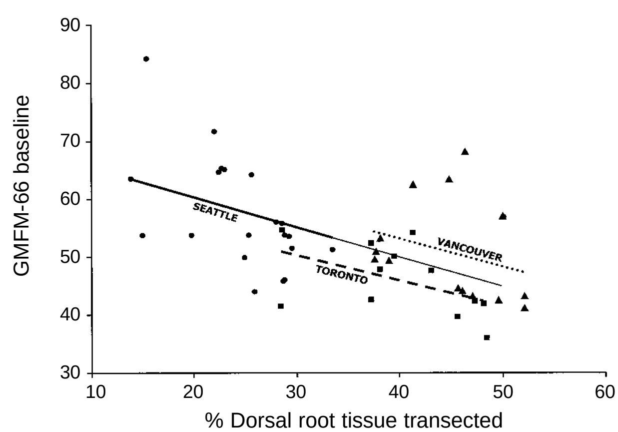

Figure 7: *Regression analyses of baseline GMFM-66 by % dorsal root tissue transected. Linear regression analysis (p<0.001). ●—, Seattle; ■– –, Toronto; ▲---, Vancouver.*

the range of tissue transection described in the Toronto and Seattle studies.

The severity of CP was retrospectively reclassified according to the GMFCS system from baseline clinical data. The amount and quality of clinical data available differed across studies, which limits the ability to make inferences based on GMFCS scores in the pooled sample. Changes in GMFCS classification determined prospectively might be another method for capturing global changes in response to specific interventions such as SDR.

Conclusions

This meta-analysis of the 9- to 12-month outcomes of three randomized clinical trials confirms a clinically important change in spasticity. With regard to function, a small but statistically significant advantage to SDR+PT (additional mean GMFM change of 4 percentage points) was shown when compared with PT-only. There appears to be a direct relation between the percent of dorsal root tissue transected and the magnitude of gain in function. The sectioning rate was not randomized and the sectioning technique varied across studies. This statistical correlation may not reflect a true cause and effect relation. There are no detectable subgroups that benefit more than others. The three original studies did not report any worrisome problems with adverse events. These are short-term outcomes applicable to a child who meets the criteria used for enrollment in these studies.

These results suggest that the decision whether or not to perform SDR on a similar child partly rests on whether or not an anticipated mean GMFM change score increment of 4 percentage points above the amount of change with non-invasive care justifies the time, effort, and risk involved. While an additional change of 4 percentage points over a year might be twice the change expected with non-invasive care, it is still a relatively small amount of change compared with some of the claims in uncontrolled studies (Peacock and Staudt 1991, Park and Owen 1992, Abbott et al. 1993, Nishida et al. 1995). These modest improvements in gross motor function are somewhat disappointing, but it should be noted that these results are short term and do not take into account other possible positive and negative long-term outcomes. In addition to improving ambulation, an effective surgical treatment for spastic diplegia should have beneficial long-term effects on gait parameters, pain reduction, and rate of acquired musculoskeletal deformity, function, participation, and quality of life. As was the case in these studies, there should be a low rate of serious adverse events attributable to the intervention. Answers to these important questions will not become available until a sizable well-studied cohort of individuals with spastic diplegia is followed to adulthood. There is serious doubt regarding the validity of the electrophysiological monitoring criteria that formed the basis for the 'selectivity' of dorsal rhizotomy (Cohen and Webster 1991, Steinbok et al. 1994, Logigian et al. 1996, Hays et al. 1998), yet this meta-analysis suggests that the percent of dorsal root tissue transected may be important. The correct method to determine where and how much dorsal root tissue to transect must be elucidated by rigorous studies.

Clinicians are faced with the practical problem of deciding whether or not to recommend treatments such as SDR for individual children. The results of this meta-analysis should be used with care in the clinical setting. These studies included primarily ambulatory children with spastic diplegia and excluded those with dystonia, athetosis, and ataxia. Children with severe visual impairment were excluded. All the children undergoing SDR in these studies had access to perioperative and postoperative care at a regional children's hospital in affluent societies, and access to expert pediatric physiotherapists for postoperative rehabilitation. Regular follow up by an experienced clinical team may have mitigated adverse events and motivated families in ways that were not measured. The effects of SDR on spasticity can probably be safely extrapolated to most children with spasticity, but this meta-analysis provides no comparison to other available effective treatments. The effects of SDR on function are modest and hard to extrapolate.

Based on clinical experience in addition to these data, we speculate that SDR might be most effective for a child between 3 and 8 years of age whose functional level falls into GMFCS levels III and IV. Children in this age range are easy to assess, tolerate the physiotherapy regimens, and have academic and social demands that can accommodate an intensive intervention. Children with more severe CP may have more potential gain from an invasive procedure.

Accepted for publication 17th August 2001.

Acknowledgments
Funding was generously provided by the United Cerebral Palsy Research & Educational Foundation. Funding for the original studies was provided by the National Institute for Neurological Disease and Stroke, RO1-NS27867 (Seattle), the British Columbia Health Care Research Foundation (Vancouver), and the Easter Seal Research Institute of Canada and the United Cerebral Palsy Research & Educational Foundation (Toronto). No author has a financial interest in any aspect of this study. Elaine Smith provided invaluable assistance with the manuscript. The authors gratefully acknowledge the assistance of colleagues at each of the three centers and the cooperation of the families.

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