The Effect of Two Surgeons on Operative Time, Anesthesia Time, and Blood Loss in Pediatric Patients with Neuromuscular Scoliosis Undergoing Posterior Spinal Fusion Surgery

A Thesis submitted to the University of Arizona College of Medicine - Phoenix
in partial fulfillment of the requirements for the Degree of Doctor of Medicine

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Abstract:

Objective

The goal of this study was to investigate the effect of using a two attending surgeon approach on operative time, anesthesia time, and estimated blood loss in patients with neuromuscular scoliosis undergoing posterior spinal fusion surgery.

Methods

This was a retrospective chart review study of patients with neuromuscular scoliosis who underwent posterior spinal fusion surgery at Phoenix Children's Hospital in 2011 and 2012.

Results

Results from 70 patients showed a significant reduction in operative and anesthesia times for patients with two attending surgeons as opposed to one. Mean operative time for the two surgeon group was 3 hours 30 minutes (SD = 49 minutes) and was significantly shorter than 4 hours 26 minutes (SD = 1 hour 22 minutes), the mean operative time for the one surgeon group, $t(56) = 3.44$, $p = .001$. Mean anesthesia time for the two surgeon group was 5 hours 28 minutes (SD = 55 minutes) and was significantly shorter than 6 hours 9 minutes (SD = 1 hour 28 minutes), the mean anesthesia time for the one surgeon group, $t(57) = -2.34$, $p = .023$. There was no significant difference in estimated blood loss found between the groups. The mean blood loss for the two surgeon group was 1202.1 ml(SD = 1033.1) versus 1042.1 ml (SD = 959.41) for the one surgeon group, $t(68) = .671$, $p = .50$. This pattern of results remained the same in subgroup analysis designed to compare cases with similar severity of presentation.

Significance

Patients with neuromuscular scoliosis may benefit from a two attending surgeon approach to posterior spinal fusion. More studies are needed to determine modifiable risk factors for excessive blood loss in neuromuscular scoliosis patients as well as to investigate the effect of using a two surgeon approach on specific post-operative complications.

Table of Contents

Page

List of Tables and Figures

Page

Introduction and Significance:

Background

Neuromuscular scoliosis can be defined as a coronal and sagittal plane deformity of the spine in patients with abnormalities in myoneural pathways. It has a variety of causes including cerebral palsy (CP), spina bifida, muscular dystrophy, and spinal muscular atrophy. Because neuromuscular scoliosis has many causes, the reported patterns and incidence in the literature vary.[12] However in general, the prevalence of spinal deformity, particularly scoliosis, is much higher in patients with neuromuscular disorders than in the general population.[4] Some studies estimate that the prevalence of severe spinal deformity in patients with neuromuscular disorders is as high as 50% to 80%.[1-3] Neuromuscular scoliosis deformities typically involve the entire thoracic and lumbar spine, often creating pelvic obliquity and postural problems. This deformity interferes with a variety of functions including sitting, balance, ambulation, and wheel chair use. The deformity may also result in pain and worsening of pulmonary function.[13] It is difficult, if not impossible, to control many of these scoliosis deformities with bracing, and there is high risk of progression of scoliosis even after skeletal maturity is reached in these patients.[14-17] For these reasons, patients with neuromuscular scoliosis frequently require surgical interventions including posterior spinal fusion surgery.[18-21] Long term studies have shown improvements after surgery in spinal deformity and pelvic obliquity. The posterior spinal fusion surgery results in improvements in balance, sitting position, quality of life, patient and caregiver satisfaction, and pulmonary function.[4, 21, 22-31]

Although many patients with neuromuscular scoliosis frequently require scoliosis surgeries, they often have significant medical comorbidities that make their treatment and surgeries especially challenging. These comorbidities include poor mobility, seizure disorders, cognitive impairment, gastrostomy tubes, reflux, and high risk of aspiration.[5- 6, 8, 11, 32-33] Because of these co-morbidities, scoliosis surgeries in patients with neuromuscular scoliosis have been associated with high complication rates.[5- 7] Indeed, in studies of the risk factors for perioperative and postoperative complications following scoliosis surgeries, the diagnosis of neuromuscular scoliosis itself was found to be the most significant risk factor.[6, 8-10] Patients with

neuromuscular scoliosis undergoing surgery have significantly higher rates of morbidity and mortality compared to patients with scoliosis from other etiologies.[5, 11] For example, one study reported complication rates of 17.9% for neuromuscular scoliosis followed by 10.6% for congenital and 6.3% for idiopathic scoliosis. Mortality rates showed a similar pattern.[5, 11] Furthermore, some studies report a significant risk with up to 1% perioperative mortality rate and a 5 fold post-operative death rate increase.[5, 7, 22, 33-34]

For patients with neuromuscular scoliosis undergoing scoliosis surgeries, the reported rates of complications in the literature range between 17.9% and 75%. These complications include most commonly pulmonary, followed by GI, infectious, and more rarely, neurologic complications.[5, 7-8, 11, 22, 34-41] Pulmonary complications were the most reported, perhaps because patients with neuromuscular scoliosis frequently have decreased pulmonary function to begin with.[11, 33, 38, 40, 42-44] Pulmonary complications have been associated with longer total operative time and increased total blood loss.[8, 41] The longer operative time factor may be linked to an increased risk of atelectasis due to longer periods of artificial ventilation. Longer operative times also indicate longer amounts of time spent prone, which may predispose patients to atelectasis and pneumonia.[8] Unfortunately, morbidity and mortality following surgery most frequently occur due to pulmonary compromise in patients with neuromuscular scoliosis.[11, 38, 41-42, 45]

Blood loss is another significant risk associated with scoliosis surgeries in patients with neuromuscular scoliosis.[19, 32, 38] This risk of blood loss has been demonstrated to be greater in patients with neuromuscular scoliosis as opposed to scoliosis due to other etiologies.[8, 11, 19, 32, 38] For example, Edler et al. in a study of 163 patients with neuromuscular scoliosis noted that more than 65% of these patients had blood loss greater than 50% of their estimated blood volume. They also found that there was an almost seven times greater risk of losing greater than 50% of blood volume during scoliosis surgery in patients with neuromuscular scoliosis as opposed to scoliosis due to other etiologies.[8]

Scoliosis surgeries in children with neuromuscular scoliosis often involved increased complexity. Due to the medical co-morbidities, the increased risks involved, and the frequent

need to operate on children with severe curves involving many spinal levels, surgeons at Phoenix Children's Hospital opted to treat some children utilizing a two attending surgeon approach as opposed to one attending surgeon with a non-attending physician first assist. The goal of this study is to investigate the effect of using two surgeons on the amount of blood loss, operative time, and anesthesia time in children with severe neuromuscular scoliosis.

Impact

Patients with neuromuscular scoliosis often have spinal deformities requiring surgical correction through posterior spinal fusion.[1-4] Unfortunately, although patients with neuromuscular scoliosis often require this surgery, complication rates are high, and are exacerbated by prolonged operative/anesthesia time and blood loss.[5-11]

Aims/Goals/Hypothesis

The purpose of this study is to investigate the effect of using a two surgeon approach on the amount of blood loss and operative time in children with severe neuromuscular scoliosis undergoing posterior spinal fusion at Phoenix Children's hospital in 2011 and 2012. This is a retrospective chart review of all children with severe neuromuscular scoliosis over a 2 year time period who had posterior spinal fusion surgery for scoliosis at Phoenix Children's Hospital.

Research Materials and Methods:

The following study is a retrospective chart review of all children with neuromuscular scoliosis during 2011 and 2012 who underwent posterior spinal fusion surgery at Phoenix Children's Hospital. All patients with neuromuscular scoliosis who underwent posterior spinal fusion surgery for the correction of scoliosis during the study period were included. The subjects were identified by a search of the hospital's ICD9 codes and discharge diagnoses. Patients with neuromuscular scoliosis undergoing non-posterior spinal fusion procedures were excluded. Patients with scoliosis from non-neuromuscular causes, such as idiopathic scoliosis, were also excluded. This study was a chart review only, and did not involve contacting any patients.

Data collected included patient pre-operative diagnosis, name of surgeon(s), name of first assist, total operative and anesthesia times, and amount of blood loss. In order to protect against potential confounds, patient demographic data collected also included patient age, gender, height, weight, whether or not (and how much) cell saver was used, whether or not Amicar was used, intraoperative complications, and number of transfusion units given. Pre-operative Cobb angle was also recorded. [Briefly, a Cobb angle is a standard measure used to determine and track progression of scoliosis. The angle of curvature is measured by drawing lines parallel to the upper border of the upper vertebral body and the lower border of the lowest vertebra of the curve in question. Perpendiculars from these lines are created which cross each other. The angle between these perpendiculars is the angle of curvature or the Cobb angle.] Post-operative data collected included length of PICU stay, length of hospital stay, post-operative complications, and need for any re-operations. Additionally, data was collected to create a 0 through 12 pre-operative REACTS score as shown in Table 1: Reacts score. The REACTS score represents severity of patient disability preoperatively. It is calculated as the sum total of 0 to 2 possible points (with 0 being normal and 2 being most severe) for each of 6 patient function characteristics: respiratory, eating, ambulation, cognition, talking, and seizures.

Table 1: REACTS score.

	0	1	2	Subscore
Respiratory	Normal	Occasional oxygen at home	Trach/vent	
Eating	Normal oral intake	Supplemented, thickened oral intake	G-tube	
Ambulation	Walking	Walks with gait aids	Wheelchair	
Cognition	Normal	Mild mental retardation/cognitive impairment	Profound mental retardation	
Talking	Normal	Uses some words	Non-verbal	
Seizures	No seizure disorder	Seizure disorder well controlled, 1 medication	Poorly controlled seizure disorder, multiple medications	
			Sum = REACTS score →	

Data was stored electronically within a database. Access to the data was restricted to Phoenix Children's Hospital investigators and study personnel. Patients' names and medical record numbers were stored in a secure location separate from the data. Information linking the data to patient identifiers was also stored in a separate, secure location and was protected by the principal investigator of the study. Personnel involved with data entry were trained in correct data procedures and the database access was password protected. This study was carried out in compliance with the Phoenix Children's Hospital Institutional Review Board (IRB).

The data were analyzed using Excel. Analysis examined the difference in total operative time, total anesthesia time, and estimated blood loss between cases involving one attending surgeon and cases involving two attending surgeons. Two-tailed t-tests assuming unequal variances were used. Additional analyses were performed on subgroups of patients based on severity of presentation. Patient subgroups with pre-operative Cobb angles greater than or equal to 50, 60, and 70 degrees were analyzed for differences in total operative time, total anesthesia time, and estimated blood loss between cases involving one attending surgeon and cases involving two attending surgeons. Additionally, patient subgroups with REACTS scores greater than or equal to 6 were degrees were analyzed for differences in total operative time, total anesthesia time, and estimated blood loss between cases involving one attending surgeon and cases involving two attending surgeons.

Results:

Patient Demographics

Seventy patients with neuromuscular scoliosis were included in the study. There were 36 males and 34 females. Patient diagnoses included cerebral palsy, Duchenne muscular dystrophy, spinal muscular atrophy, Rett syndrome, chromosomal abnormalities, and other neuromuscular diagnoses. See Table 2: Pre-Operative Diagnosis Patient Count.

Table 2: Pre-operative Diagnosis Patient Count.

	All patients (n)	2 surgeon group (n)	1 surgeon group (n)
Number of Patients	70	35	35
Cerebral Palsy	22	18	4
Duchenne Muscular Dystrophy	6	1	5
Spinal Muscular Atrophy	1	0	1
Rett Syndrome	4	2	2
Chromosomal Abnormality	6	3	3
Other Neuromuscular Scoliosis Diagnosis	31	11	20

The average age of the patients overall was 13.7 years with a standard deviation of 3.15 years and range of 8 to 23 years old. Patients in the 1 surgeon versus 2 surgeon groups did not vary significantly in age with a mean age of 13.1 (SD = 2.89) in the 1 surgeon group and a mean age of 14.4 (SD= 3.32) in the 2 surgeon group. The two-tailed t-test assuming unequal variances showed $t(67) = 1.69$, $p = .095$. See Table 3: Pre-Operative Patient Characteristics.

Table 3: Pre-Operative Patient Characteristics.

	All patients	2 Surgeon group	1 Surgeon group	Significance
Average age (years ± SD)	13.7 ± 3.15	14.4 ± 3.32	13.1 ± 2.89	t(67)=1.69, p = .095
Average Cobb angle (degree ±SD)	75.61± 20.1	83.42 ± 18.37	68.03 ± 18.91	t(65)= 3.38, p = .001**
Average Total REACTS score (score ±SD)	75.61± 20.1	7.2 ± 3.31	5.06 ± 3.32	t(68) = 2.71, p =.009**

SD =standard deviation, * = $p < .05$, ** = $p < .01$

Analyses of Differences between 1 and 2 Surgeon Approach in Total Operative Time, Total Anesthesia Time, and Estimated Blood Loss

Analysis was performed examining the difference in total operative time between cases involving one attending surgeon and cases involving two attending surgeons. The mean operative time for the 2 surgeon group was 3 hours 30 minutes with standard deviation of 49 minutes (range of 2 hours 19 minutes to 5 hours 45 minutes). The mean operative time for the 1 surgeon group was longer with an average of 4 hours 26 minutes with standard deviation of 1 hour 22 minutes (range of 2 hours 18 minutes to 7 hours 25 minutes). A two tailed t-test assuming unequal variances showed a significant difference in mean operative time between the 1 and 2 surgeon groups with $t(56) = 3.44$, $p = .001$. See Table 4: Operative Time, Anesthesia Time, and Estimated Blood Loss for Patients in the 2 Surgeon and 1 Surgeon Group. See also Figure 1: Total Operative Time.

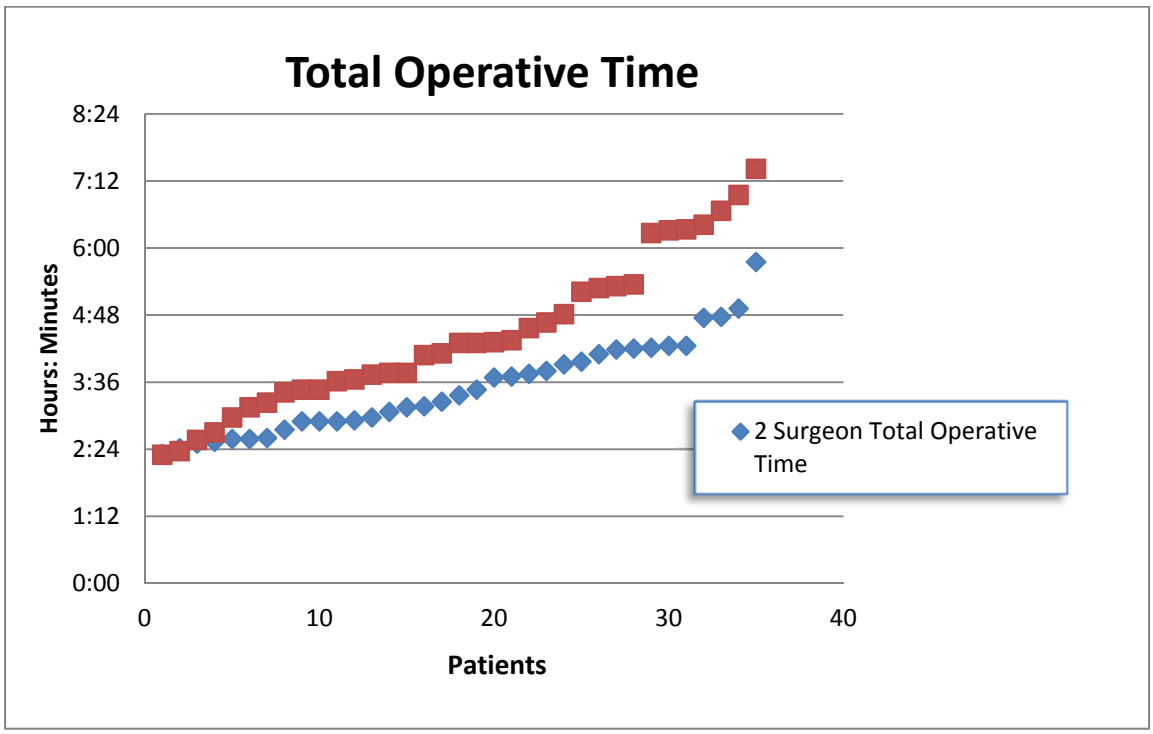
Table 4: Operative Time, Anesthesia Time, and Estimated Blood Loss for Patients in the 2 Surgeon and 1 Surgeon Groups.

	2 Surgeon				1 Surgeon						
	M	SD	n	Range	M	SD	n	Range	t	df	p
Total Operative Time	3:30	0:49	35	2:19-5:45	4:26	1:22	35	2:18-7:25	-3.44	56	**.001
Total Anesthesia Time	5:28	0:55	35	4:02-7:50	6:09	1:28	35	3:56-9:44	-2.34	57	*.02
Estimated Blood Loss	1201.1	1033.1	35	200-5000	1042.1	959.41	35	225-6000	.671	68	.46

M = mean, SD= standard deviation, * = $p < .05$, ** = $p < .01$

Figure 1: Total Operative Time.

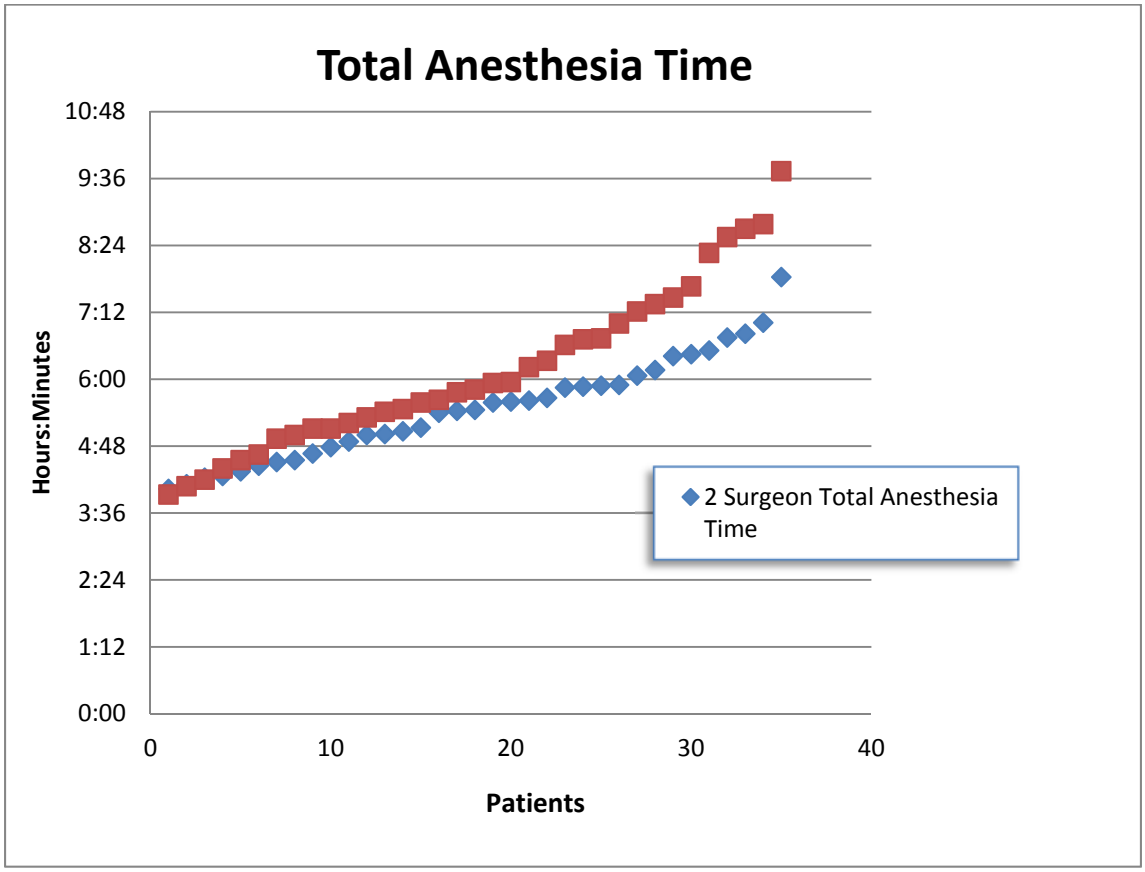
Total operative time for all patients in the 1 and 2 surgeon approach groups shown in hours and minutes. The 1 surgeon group (red) had consistently longer operative times than the 2 surgeon group (blue) (source: chart review Phoenix Children's Hospital).



Similarly, analysis was performed examining the difference in total anesthesia time between cases involving one attending surgeon and cases involving two attending surgeons. The mean operative time for the 2 surgeon group was 5 hours 28 minutes with standard deviation of 55 minutes (range of 4 hours 2 minutes to 7 hours 50 minutes). The mean operative time for the 1 surgeon group was again longer with an average of 6 hours 9 minutes with standard deviation of 1 hour 28 minutes (range of 3 hours 56 minutes to 9 hours 44 minutes). A two tailed t-test assuming unequal variances showed a significant difference in mean anesthesia time between the 1 and 2 surgeon groups with $t(57) = -2.34$, $p = .023$. See Table 4 and Figure 2: Total Anesthesia Time.

Figure 2: Total Anesthesia Time.

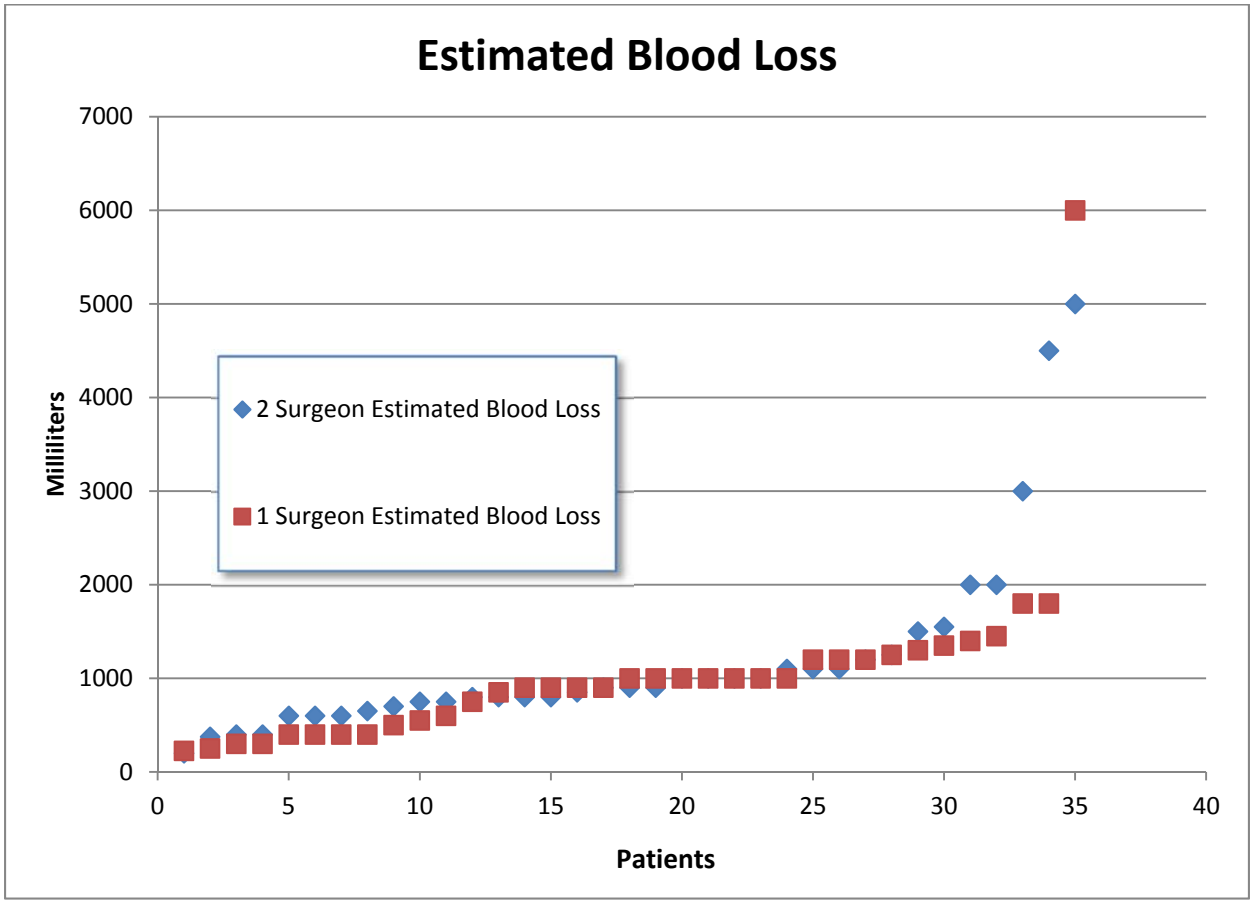
Total anesthesia time for all patients in the 1 and 2 surgeon groups shown in hours and minutes. The 1 surgeon approach group (red) had consistently longer total anesthesia times than the 2 surgeon approach group (blue) (source: chart review Phoenix Children's Hospital).



Analysis was also performed examining the difference in estimated blood loss between cases involving one attending surgeon and cases involving two attending surgeons. The mean estimated blood loss for the 2 surgeon group was 1202.1 mls with standard deviation of 1033.1 mls (range of 200 to 5000 mls). The mean estimated blood loss for the 1 surgeon group was 1042.1 mls with a standard deviation of 959.41 mls (range of 225 to 6000 mls). A two tailed t-test assuming unequal variances did not show a significant difference in estimated blood loss between the 1 and 2 surgeon groups with $t(68) = .671$, $p = .504$. See Table 4 and Figure 3. Estimated Blood Loss.

Figure 3: Estimated Blood Loss.

Estimated blood loss for all patients in the 1 and 2 surgeon groups shown in milliliters. There was no significant difference in blood loss between the 1 surgeon group (red) and the 2 surgeon group (blue) (source: chart review Phoenix Children's Hospital).



Preoperative Differences in Cobb Angles between 1 and 2 surgeon groups

Examining the data, mean Cobb angles for the 1 surgeon and 2 surgeon groups were significantly different from the beginning with a mean of 68.03 degrees with standard deviation of 18.91 degrees in the 1 surgeon group (33 cases with a range of 50-130 degrees) and a larger mean angle of 83.42 degrees with standard deviation of 18.37 degrees in the 2 surgeon group (34 cases with a range of 30- 125 degrees). A two tailed t-test assuming unequal variances showed the mean angles to be significantly different with $t(65) = 3.379$, $p = .001$. Given that the patients were assigned to a 1 or 2 surgeon approach based on global severity of presentation, including pre-operative Cobb angle (i.e. non-randomized), this result was expected.

SubGroup Analyses for Cobb Angles greater than or equal to 50, 60, and 70 degrees

However, because the 1 surgeon and 2 surgeon groups had significantly different mean Cobb angles to begin with, subgroup analyses were done for only those cases with pre-operative Cobb angles greater than or equal to 50, 60, and 70 degrees. Cases with pre-operative Cobb angles lower than 50, 60, or 70 degrees respectively were excluded from the following investigation. These analyses were done in an attempt to compare cases of a similar severity of presentation. Results of two-tailed t-tests assuming unequal variance showed that for those cases with pre-operative Cobb angles greater than or equal to 50 and 60 degrees, the 2 surgeon group continued to have significantly larger mean Cobb angles than the 1 surgeon group. Only after excluding cases with pre-operative Cobb angles below 70 degrees did the 2 surgeon group cease to have a significantly larger mean pre-operative Cobb angle than the 1 surgeon group. See Table 5: Results of two-tailed t-tests comparing 1 and 2 surgeon groups' mean pre-operative Cobb angles for angles ≥ 50, 60, and 70°

Table 5: Results of two-tailed t-tests comparing 1 and 2 surgeon groups' mean pre-operative Cobb angles for angles ≥ 50, 60, and 70°

	2 Surgeon				1 Surgeon						
	M	SD	n	Range	M	SD	n	Range	t	df	p
Angles ≥ 50° Mean Pre Operative Cobb Angle	83.42	18.37	33	50-130°	73.29°	16.31°	28	50-125°	2.28	59	*.026
Angles ≥ 60° Mean Pre Operative Cobb Angle	86.20°	14.90°	30	60-130°	76.88°	14.75°	24	60-125°	2.17	52	*.034
Angles ≥70° Mean Pre Operative Cobb Angle	89.0°	14.70°	25	70-130°	81.27°	12.93°	16	70-125°	1.52	35	.137

M = mean, SD= standard deviation, * = p < .05, ** = p < .01

Analyses of cases with Cobb angles greater than or equal to 50, 60, and 70 degrees followed a similar pattern to the analyses of the total data comparing operative and anesthesia times and blood loss between 1 and 2 surgeon groups. For all subgroup analyses investigating total operative time and total anesthesia time, the difference between the mean times in the 1 and 2 surgeon groups remained significant. Analyses comparing estimated blood loss between the 1 and 2 surgeon groups remained insignificant for all subgroups (Cobb angles greater than or equal to 50, 60, and 70 degrees). See Table 6 for analyses of total operative time, Table 7 for analyses of total anesthesia time, and Table 8 for analyses of estimated blood loss.

Table 6: Results of two-tailed t-tests comparing total operative time for 1 and 2 surgeon groups with preoperative Cobb angles greater than or equal to 50, 60, and 70°

Total Operative Time (hours: minutes	2 Surgeon				1 Surgeon						
	M	SD	n	Range	M	SD	n	Range	t	df	p
For Pre-operative Cobb Angles ≥ 50°	3:25	0:46	32	4:02-7:01	4:05	1:09	27	3:56-8:42	-2.57	44	*.014
For Pre-operative Cobb Angles ≥ 60°	3:27	0:45	31	4:02-7:01	4:10	1:09	24	3:56-8:42	-2.66	38	*.011
For Pre-operative Cobb Angles ≥ 70°	3:31	0:46	25	4:02-7:01	4:34	1:11	16	4:05-8:42	-3.11	23	*.005

M = mean, SD= standard deviation, * = $p < .05$, ** = $p < .01$

Table 7: Results of two-tailed t-tests comparing total anesthesia time for 1 and 2 surgeon groups with preoperative Cobb angles greater than or equal to 50, 60, and 70°

Total Anesthesia Time (hours: minutes)	2 Surgeon				1 Surgeon						
	M	SD	n	Range	M	SD	n	Range	t	df	p
For Pre-operative Cobb Angles ≥ 50°	5:23	0:51	32	2:19-4:55	5:51	1:13	27	2:18-6:40	-1.67	46	*.05
For Pre-operative Cobb Angles ≥ 60°	5:24	0:51	31	2:19-4:55	5:53	1:16	24	2:22-6:40	-1.62	38	*.05
For Pre-operative Cobb Angles ≥ 70°	5:28	0:51	25	2:19-4:55	6:21	1:16	16	2:22-6:40	-2.43	24	*.011

M = mean, SD= standard deviation, * = p < .05, ** = p < .0

Table 8: Results of two-tailed t-tests comparing estimated blood loss for 1 and 2 surgeon groups with preoperative Cobb angles greater than or equal to 50, 60, and 70°

Estimated Blood Loss (mls)	2 Surgeon				1 Surgeon						
	M	SD	n	Range	M	SD	n	Range	t	df	p
For Pre-operative Cobb Angles ≥ 50°	1111.72	1017.05	32	200-5000	1032.41	1073.72	27	225-6000	.29	54	.77
For Pre-operative Cobb Angles ≥ 60°	1121.77	1032.25	31	200-5000	1115.63	1112.62	24	225-6000	.21	48	.98
For Pre-operative Cobb Angles ≥ 70°	1185.0	1139.40	25	200-5000	979.69	428.68	16	225-1800	.82	33	.42

M = mean, SD= standard deviation, * = $p < .05$, ** = $p < .01$

Preoperative Differences in REACTS scores

Examining the total data, mean REACTS scores for 1 surgeon and 2 surgeon groups were significantly different from the beginning with a mean score of 7.2 with standard deviation of 3.31 degrees in the 2 surgeon group (34 cases with a score range of 1-12) and a mean score 5.06 of with standard deviation of 3.32 in the 1 surgeon group (34 cases with a score range of 0-11). A two tailed t-test assuming unequal variances showed the mean angles to be significantly different with $t(69) = 2.75$, $p = .008$. Given that the patients were assigned to a 1 or 2 surgeon approach based on global severity of presentation (i.e. non-randomized), this result was expected.

Subgroup Analyses for REACTS scores ≥ 6

However, because the 1 surgeon and 2 surgeon groups had significantly different mean REACTS scores to begin with, subgroup analyses were done for only those cases with REACTS scores greater than or equal to 6, which represents patients on the more severe half of the 0-12 scale (the equivalent of 1 out of a possible 2 severity points in all 6 categories). This was done in an attempt to compare cases of a similar severity of presentation.

Analyzing only cases with REACTS scores greater than or equal to 6, mean REACTS scores for 2 surgeon and 1 surgeon groups were no longer significantly different with a mean score of 9.35 points with standard deviation 1.50 in the 2 surgeon group (22 cases with a range of 6-12 points) and a mean score of 8.5 points with standard deviation of 1.60 in the 1 surgeon group (14 cases with a range of 6-11 points). A two tailed t-test assuming unequal variances showed that pre-operative REACTS scores were not significantly different for 2 and 1 surgeon groups when considering REACTs scores greater than or equal to 6 (($t(26) = 1.60$, $p = .122$).

Analyses of cases with REACTS scores greater than or equal to 6 followed a similar pattern to the analyses of the total data comparing operative and anesthesia times and blood loss between 1 and 2 surgeon groups. For subgroup analyses investigating total operative time and total anesthesia time, the difference between the mean times in the 1 and 2 surgeon groups remained significant. Analysis comparing estimated blood loss between the 1 and 2

surgeon groups remained insignificant. See Table 9 for results of two-tailed t-tests comparing total operative time, total anesthesia time, and estimated blood loss for 1 versus 2 surgeon groups with REACTS scores greater than or equal to 6.

Table 9: Results of two-tailed t-tests comparing total operative time, total anesthesia time, and estimated blood loss for 1 versus 2 surgeon groups with REACTS scores ≥ 6.

REACTS ≥ 6	2 surgeon				1 surgeon						
	M	SD	n	Range	M	SD	n	Range	t	df	p
Estimated Blood Loss (mls)	1328.3	1219.7	23	200-5000	880.4	492.7	14	225-1800	1.56	32	.13
Total Operative Time (hours:minutes)	3:26	0:50	23	2:19-5:45	4:23	1:11	14	3:14-7:25	-2.63	21	*.02
Total Anesthesia Time (hours:minutes)	5:24	0:58	23	4:07-7:50	6:09	1:18	14	4:33-9:44	-2.03	22	*.05

M = mean, SD= standard deviation, * = $p < .05$, ** = $p < .01$

Results Summary

In summary, the results of all analyses followed a similar pattern. Examining the data as a whole, results showed that mean operative and anesthesia times were significantly shorter in the 2 surgeon approach group as compared to the 1 surgeon approach group. This result held in subgroup analyses. Mean operative and anesthesia times for the 2 versus 1 surgeon group were significantly shorter in the 2 surgeon group for cases with pre-operative Cobb angles greater than or equal to 50, 60, and 70 degrees. Similarly, differences in mean operative and anesthesia times for the 2 versus 1 surgeon group were significantly shorter in the 2 surgeon group for cases with REACTS scores greater than or equal to 6.

The results also followed a consistent pattern in regard to estimated blood loss. Analysis of the data as a whole showed no significant difference in estimated blood loss between the 2 and 1 surgeon groups. This result also held in sub group analyses. For cases with pre-operative Cobb angles greater than or equal to 50, 60, and 70 degrees there was still no significant difference in estimated blood loss between the 1 and 2 surgeon groups. Similarly, there was no significant difference in estimated blood loss between the 1 and 2 surgeon groups for patients with a pre-operative REACTS score greater than or equal to 6.

In short, in all analyses, the 2 surgeon group had significantly shorter mean operative and anesthesia times than the 1 surgeon group. In all analyses, there was no significant difference found in estimated blood loss between the 1 and 2 surgeon groups.

Discussion and Future Directions:

Patients with neuromuscular scoliosis often have spinal deformities requiring surgical correction through posterior spinal fusion.[1-4] The surgeries often result in improvements in quality of life.[4, 21-31] Unfortunately, however, although patients with neuromuscular scoliosis often require this surgery, complication rates are high, and are exacerbated by prolonged operative/anesthesia time and blood loss. [5-11] Complication rates between 17.9% and 75% have been reported in the literature.[5, 7-8, 11, 22, 34-41]

Because of the special treatment challenges posed by patients with scoliosis secondary to neuromuscular conditions, surgeons at Phoenix Children's Hospital elected to treat some children utilizing a two attending surgeon approach as opposed to one attending surgeon with a non-attending physician first assist. The specific goals of this retrospective chart review study were to investigate the effects of using two surgeons on operative and anesthesia time as well as the effect on the amount of blood loss in children with severe neuromuscular scoliosis.

Cases were selected for a two attending surgeon approach specifically because of the severity of the patient's disease, the presence of co-morbidities, and higher surgical risks involved. One of the factors used to determine which patients might benefit from having two attending surgeons included the patient's pre-operative Cobb angle. Indeed, analysis showed that patients in the two surgeon group had significantly higher pre-operative Cobb angles than patients in the one surgeon group. Other factors used to determine patients' cases being handled by two attending surgeons included severity of the patient's disease and the presence of co-morbidities. Many of these factors may be accounted for in the pre-operative REACTS score. The REACTS score was composed of the patient's respiratory status, eating and nutritional status, ambulatory status, cognition, ability to talk or communicate, and the presence of and severity of a seizure disorder. Expectedly, patients in the two attending surgeon group as had significantly higher REACTS scores, signifying more medical co-morbidities and more severe disease. Recognizing the significant risks these patients face, the hope in utilizing two experienced attending surgeons for these cases would be to minimize some of the

risks involved. Specifically, we sought to clarify whether or not using two surgeons would indeed affect operative and anesthesia time as well as operative blood loss.

As stated above, patients were selected for the two surgeon approach group pre-operatively based on severity of presentation (reflected in more severe scoliosis/higher Cobb angles and more medical co-morbidities/higher REACTS scores). Patients that were deemed high risk for operative and/or post-operative complications were scheduled for surgeries with two senior attending surgeons rather than one senior attending surgeon with an assist from a non-attending surgeon. Therefore, our one surgeon and two surgeon approach groups were non-randomized. As can be expected with non-randomized groups, the one and two surgeon approach groups were significantly different to begin with in terms of average Cobb angles and average REACTS scores of medical co-morbidities.

We wish to emphasize that the finding that the two groups were different to begin with was expected, and does not detract from the importance of the results. Using special approaches for high risk patients, such as operating with two senior attending surgeons, is an intuitive approach that is already utilized, including at Phoenix Children's Hospital where this study was conducted. We sought to clarify what effect using this two surgeon approach was having (if any) with our patients. Specifically, we wanted to know if the fact that we were already using two surgeons for high risk cases was accomplishing the goals of reducing operative time, anesthesia time, and blood loss (and hopefully by extension – reducing complications). We found that using two surgeons for these higher risk cases did indeed reduce operative and anesthesia times, but not estimations of blood loss. These findings will be further discussed below.

Results did show that in cases involving two attending surgeons, operative times were consistently significantly shorter with shorter anesthesia times than cases involving only one attending surgeon. Recognizing that patients with more severe disease were naturally more likely to be in the two surgeon group, sub analyses were done to in an attempt to compare cases of more similar presenting severity. The results of these analyses also held true, with shorter anesthesia and operative times in the two surgeon group. Times were significantly

shorter using two surgeons for patients with pre-operative Cobb angles greater than or equal to 50, 60, and 70 degrees as well as for all pre-operative Cobb angles considered together. Similarly, times were significantly shorter using two surgeons for patients with REACTS scores greater than or equal to 6 as well as for all REACTS scores considered together.

These results suggest that using a two surgeon approach for patients with neuromuscular scoliosis may reduce operative and anesthesia times. This approach may be of exceptional benefit to patients that have especially high pre-operative risks due to disease severity and medical co-morbidities. The larger goal in reducing operative and anesthesia time would be of course to reduce complication rates and improve patient outcomes.

The finding that that two surgeon approach is associated with shorter operative and anesthesia times may have particular relevance to reduction of pulmonary complications. Patients with neuromuscular scoliosis frequently have preoperative pulmonary compromise which puts them at an even larger postoperative risk.[8, 43] As the most commonly reported complication and cause of morbidity and mortality postoperatively in patients with neuromuscular scoliosis, pulmonary complications are reported with rates up to 53%.[8, 11, 41, 46-47] Longer operative and anesthesia times are associated with pulmonary complications.[8, 11, 46-47] Longer time spent prone, increased length of artificial ventilation, and increased risks of atelectasis likely contribute to these pulmonary complications. Although this study did not directly address the effect of the two surgeon approach on pulmonary complications, this would be an interesting and relevant future direction for future studies.

In regard to estimated blood loss, study results showed that using a two surgeon approach versus a one surgeon approach did not have a significant effect. Even after performing sub group analyses to compare groups of patients with similar pre-operative disease severity and co-morbidities, no significant effects on estimated operative blood loss were found. Analysis of patients with pre-operative Cobb angles greater than or equal to 50, 60, and 70 degrees showed no significant difference in estimated blood loss between the 1 and 2 surgeon groups. Similarly, analysis of patients with pre-operative REACTS scores greater than or

equal to 6 showed no significant difference in estimated blood loss between the 1 and 2 surgeon groups.

It has been established that patients with neuromuscular scoliosis (as opposed to scoliosis due to other etiologies) are at a particularly high risk for excessive blood loss during surgery. One study comparing neuromuscular to non-neuromuscular scoliosis patients found that more than 65% of the patients with neuromuscular scoliosis lost greater than 50% of their estimated total blood volume. This amounted to a 7 fold higher risk of losing greater than 50% of their estimated total blood volume during surgery. [38] This finding has been supported by other studies also reporting higher blood loss in neuromuscular scoliosis patients than in idiopathic scoliosis patients.[19, 32]

Studies have reported that the increased risk of large amounts of blood loss is mainly due a higher number of vertebrae that need to be fused and longer operations in neuromuscular scoliosis patients.[19] Although the current study did not find a significant effect of using a two surgeon approach on estimated blood loss, it would be interesting for future studies to investigate specific factors that lead to increased risk of excessive blood loss in patients with neuromuscular scoliosis. There may be risk factors for excessive blood loss that can be modified in ways not explored by this study.

Conclusions:

The current study examined the effect of using a two surgeon approach for posterior spinal fusion surgery in patients with neuromuscular scoliosis. The specific goal of this study was to determine the effect of using two attending surgeons on total operative time, anesthesia time, and estimated blood loss. Results showed that the two surgeon approach significantly reduced operative and anesthesia times. There was no significant effect of the two surgeon approach on estimated blood loss. Additional studies are needed to determine modifiable risk factors for excessive blood loss in neuromuscular scoliosis patients as well as to investigate the effect of using a two surgeon approach on specific post-operative complications. Overall, we conclude that applying a two attending surgeon approach to high risk patients with neuromuscular scoliosis undergoing posterior spinal fusion may be a valuable strategy to improve patient outcomes.

References

1. Banta JV. Combined anterior and posterior fusion for spinal deformity in Myelomeningocele. *Spine*. 1990; 15:946–52. doi: 10.1097/00007632-199009000-00020.
2. Brown J, Zeller J, Swank S, et al. Surgical and functional results of spine fusion in spinal muscular atrophy. *Spine*. 1998;14:763–70. doi: 10.1097/00007632-198907000-00020.
3. Pehrsson K, Larsson S, Oden A, et al. Long term follow-up of patients with untreated scoliosis. A study of mortality, causes of death, and symptoms. *Spine*.1992;17:1091–1096.
4. Lonstein, JE, Akbarnia A. Operative treatment of spinal deformities in patients with cerebral palsy or mental retardation. An analysis of one hundred and seven cases. *J Bone Joint Surg Am*. 1983; 65:43-55.
5. Reames DL, Smith JS, Fu KM, Polly DW Jr, Ames CP, Berven SH, et al. Complications in the surgical treatment of 19,360 cases of pediatric scoliosis: a review of the Scoliosis. Research Society Morbidity and Mortality database. *Spine.* 2011; 36:1484–1491. doi:10.1097/BRS.0b013e3181f3a326.
6. Master DL, Son-Hing JP, Poe-Kochert C, Armstrong DG, Thompson GH. Risk factors for major complications after surgery for neuromuscular scoliosis. *Spine*. 2011; 36:564–571.
7. Lipton GE, Miller F, Dabney KW, Altiok H, Bachrach SJ. Factors predicting postoperative complications following spinal fusions in children with cerebral palsy. *J Spinal Disord* 1999;12:197-205.
8. Mohamad F, Parent S, Pawelek J, Marks M, Bastrom T, Faro F, Newton P. Perioperative complications after surgical correction in neuromuscular scoliosis. *J Pediatr Orthop*. 2007; 27: 392-397.
9. Hod-Feins R, Anekstein Y, Mirovsky Y, Barr J, Abu-Kishk I, Lahat E, Eshel G. Pediatric scoliosis surgery—the association between preoperative risk factors and postoperative complications with emphasis on cerebral palsy children. *Neuropediatrics*. 2007; 38:239–243.
10. Yuan N, Skaggs DL, Dorey F, Keens TG. Preoperative predictors of prolonged

postoperative mechanical ventilation in children following scoliosis repair. *Pediatr Pulmonol*. 2005; 40:414–419.

11. Sharma S, Wu C, Andersen T, Wang Y, Hansen ES, Bunger CE. Prevalence of complications in neuromuscular scoliosis surgery: a literature meta-analysis from the past 15 years. *Eur Spine J*. 2012; 22(6):1230-49. doi: 10.1007/s00586-012-2542-2.
12. Dobbs, Matthew, and Mary Ann Keenan, eds. Neuromuscular Scoliosis. *Medscape Reference*. http://emedicine.medscape.com/article/1266097-overview. Updated 8 Oct 2012. Accessed 27 May 2013.
13. Majd ME, Muldowny DS, Holt RT. Natural history of scoliosis in the institutionalized adult cerebral palsy population. *Spine.* 1997;22:1461-1466.
14. Saito N, Ebara S, Ohotsuka K, Kumeta H, Takaoka K. Natural history of scoliosis in spastic cerebral palsy. *Lancet.* 1998;351:1687-1692.
15. Thometz JG, Simon SR. Progression of scoliosis after skeletal maturity in institutionalized adults who have cerebral palsy. *J Bone Joint Surg Am.* 1988; 70:1290-1296.
16. Olafsson Y, Saraste H, Al-Dabbagh Z. Brace treatment in neuromuscular spine deformity. *J Pediatr Orthop* 1999;19:376-379.
17. Terjesen T, Lange JE, Steen H. Treatment of scoliosis with spinal bracing in quadriplegic cerebral palsy. *Dev Med Child Neurol.* 2000; 42:448-454.
18. Cambridge W, Drennan JC. Scoliosis associated with Duchenne muscular dystrophy. *J Pediatr Orthop.* 1987; 7(4):436-40.
19. Shapiro F, Sethna N, Colan S, Wohl ME, Specht L. Spinal fusion in Duchenne muscular dystrophy: a multidisciplinary approach. *Muscle & Nerve.* 1992, 15(5):604-14.
20. Stricker U, Moser H, Aebi M. Predominantly posterior instrumentation and fusion in neuromuscular and neurogenic scoliosis in children and adolescents. *Eur Spine Journal* 1996; 5(2):101-6.
21. Sussman MD, Little D, Alley RM, McCoig JA. Posterior instrumentation and fusion of the thoracolumbar spine for treatment of neuromuscular scoliosis. *J Pediatr Orthop.* 1996; 16:304-313.

22. Benson ER, Thomson JD, Smith BG, Banta JV. Results and morbidity in a consecutive series of patients undergoing spinal fusion for neuromuscular scoliosis. *Spine.* 1998; 23:2308-2317.
23. Bridwell KH, Baldus C, Iffriq TM, Lenke LG, Blanke K. Progress measures and patients/parents evaluation of surgical management of spinal deformities in patients with progressive flaccid neuromuscular scoliosis. (Duchenne's muscular dystrophy and spinal muscular atrophy). *Spine.* 1999; 24:1300-1309.
24. Comstock CP, Leach J, Wenger DR. Scoliosis in total-body involvement cerebral palsy: analysis of surgical treatment and patient and caregiver satisfaction. *Spine.* 1998; 23:1412-25.
25. Larsson EL, Aaro SI, Normalli HC, Oberg BE. Long-term follow-up of functioning after spinal surgery in patients with neuromuscular scoliosis. *Spine.* 2005; 30(19):2145-52.
26. Watanabe K, Lenke LG, Daubs MD, Bridwell KH, Stobbs G, Hensley M. Is spine deformity surgery in patients with spastic cerebral palsy truly beneficial?: a patient/parent evaluation. *Spine*. 2009; 34:2222–2232.
27. Mercado E, Alman B, Wright JG. Does spinal fusioninfluence quality of life in neuromuscular scoliosis? *Spine*. 2007; 32:120–125.
28. Jones KB, Sponseller PD, Shindle MK, McCarthy ML. Longitudinal parental perceptions of spinal fusion for neuromuscular spine deformity in patients with totally involved cerebral palsy. *J Pediatric Orthop*. 2003; 23:143–149.
29. Marsh A, Edge G, Lehovsky J. Spinal fusion in patients with Duchenne's muscular dystrophy and a low forced vital capacity. *Eur Spine J*. 2003; 12:507–512.
30. Tsirikos AI, Chang WN, Dabney KW, Miller F. Comparison of parents' and caregivers' satisfaction after spinal fusion in children with cerebral palsy. *J Pediatr Orthop.* 2004; 24:54-58.
31. Thomson JD, Banta JV. Scoliosis in cerebral palsy: An overview and recent results. *J Pediatr Orthop B*. 2001; 10:6-9.

32. Modi HN, Suh SW, Yang JH, Cho JW, Hong JY, Singh SU, et al. Surgical complications in neuromuscular scoliosis operated with posterior-only approach using pedicle screw fixation. *Scoliosis*. 2009; 4:11.
33. Erickson MA, Baulesh DM. Pathways that distinguish simple from complex scoliosis repair and their outcomes. *Curr Opin Pediatr*. 2011; 3:339-45.
34. Murphy NA, Firth S, Jorgensen T, Young PC. Spinal surgery in children with idiopathic and neuromuscular scoliosis: what's the difference? *J Pediatric Orthop*. 2006; 26:216–220.
35. BÖachie-Adjei O, Lonstein JE, Winter RB, Koop S, Brink K vanden, Denis F. Management of neuromuscular spinal deformities with Luque segmental instrumentation. *J Bone Joint Surg Am*. 1989; 71:548-562.
36. Broom MJ, Banta JV, Renshaw TS. Spinal fusion augmentaed by Luque-rod segmental instrumentation for neuromuscular scoliosis. *J Bone Joint Surg Am.* 1989; 71:32-44.
37. Gau YL, Lonstein JE, Winter RB, Koop S, Denis F. Luque-Galveston procedure for correction and stabilization of neuromuscular scoliosis and pelvic obliquity: a review of 68 patients. *J Spinal Disord.* 1991; 4:399-410.
38. Edler A, Murray DJ, Forbes RB. Blood loss during posterior spinal fusion surgery in patients with neuromuscular disease: is there an increased risk? *Paediatr Anaesth*. 2003; 13:818–822.
39. Smith JS, Shaffrey CI, Sansur CA, Berven SH, Fu KM, Broadstone PAet al. Rates of infection after spine surgery based on 108,419 procedures: a report from the Scoliosis Research Society Morbidity and Mortality Committee. *Spine*. 2011; 36:556–563. doi:10.1097/BRS.0b013e3181eadd41.
40. Szöke G, Lipton G, Miller F, Dabney K. Wound infection after spinal fusion in children with cerebral palsy. *J Pediatr Orthop.* 1998;18:727-733.
41. Sarwahi V, Sarwark JF, Schafer MF, Backer C, Lee M, King EC, et al. Standards in anterior spine surgery in pediatric patients with neuromuscular scoliosis. *J Pediatr Orhtop*. 2001; 21:756–60. doi: 10.1097/00004694-200111000-00010.

42. Barsdorf AI, Sproule DM, Kaufmaan P. Scoliosis surgery in children with neuromuscular disease: finds from the US National Inpatient Sample, 1997 to 2003. *Arch Neurolo*. 2010; 67: 231-235.
43. Kurz LT, Mubarak SJ, Schultz p, et al. Correlation of scoliosis and pulmonary function in Duchenne muscular dystrophy. *J Pediatr Orthop*. 1983; 3: 347-353.
44. Inal-Ince D, Savci S, Arikan H, et al. Effects of scoliosis on respiratory muscle strength in patients with neuromuscular disorders. *Spine J*. 2009; 9:981–986.
45. McDonnell MF, Glassman SD, Dimar JR, Puno RM, Johnson JR. Perioperative complications of anterior procedures on the spine. *J Bone Joint Surg Am*. 1996; 78: 839-847.
46. Winter RB. Spinal problems in pediatric orthopaedics. *Pediatr Orthos*. 1990; 2: 656-644.
47. Viviani Gr, RaducanV, Bednar DA, Gradwilewski W. Anterior and posterior spinal fusion: comparison of one stage and two stage procedures. *Can J Surg*. 1993; 36: 468-477.