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REVIEW

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Blood loss in pediatric spine surgery

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Abstract This article reviews the extent of blood loss in spine surgery for scoliosis corrections in the pediatric age group. An extensive literature review presents blood loss values in surgery for adolescent idiopathic scoliosis, cerebral palsy, Duchenne muscular dystrophy, spinal muscular atrophy, and myelomeningocoele. The underlying disorder plays a major role in determining the extent of blood loss. Blood loss is considerably higher in those patients with a neuromuscular scoliosis compared with adolescent idiopathic scoliosis. Within the neuromuscular group those with Duchenne muscular dystrophy demonstrate the highest mean levels of blood loss. Blood loss is also shown to be progressively greater with increasing numbers of vertebral levels incorporated into the fusion, with posterior fusions compared to anterior fusions, and in those patients having both anterior and posterior fusions.

Keywords Scoliosis surgery · Pediatric age group · Blood loss

Introduction

Blood loss is an important concern in performance of spinal surgery. This article will review the extent of blood loss in spine surgery for scoliosis and kyphoscoliosis corrections in the pediatric age group since these are the procedures which are most extensive and subject to the greatest amounts of loss.

The pediatric age group refers to the first two decades of life, with the majority of spinal surgical procedures done in the second decade. Distinction must be made between studies in pediatric and adult patients, since blood loss in the adult patient can be proportionately greater than in the pediatric age group for the same procedure. The modern era of scoliosis surgery will be reviewed involving procedures performed from the early 1960s onward using spinal instrumentation and spine fusion for correction and stabilization of deformity.

The underlying disorder plays a major role in determining the extent of blood loss. Blood loss is considerably higher in those patients whose scoliosis is associated with a neuromuscular disease compared with those in the idiopathic category. Blood loss is also shown to be progressively greater with increasing numbers of vertebral levels incorporated into the fusion and with posterior fusions compared to anterior fusions.

Considerations regarding literature reports of blood loss in scoliosis surgery

Blood loss determinations

Limitations must be recognized in the accuracy of intra-operative blood loss determinations and, therefore, in the value of comparing studies from one center to another. Blood loss is reported as "estimated blood loss" (EBL) since this represents the only practical way that operating room determinations can be made. Since these are estimates they are not rigidly accurate or reproducible as they are dependent on a combination of numbers including: volume of blood suctioned from the operative field (from which irrigating fluid must be subtracted), determination of blood loss collected on sponges (as determined by weighing by the operating room nurses), and estimates of blood loss on drapes, gowns, and floor (which is educated guesswork at best). To a great extent the value determined is dependent on the degree of rigor used by the operating room team in making the determination.

Measurement values used to present information

Different ways of presenting blood loss information are used in different papers reporting on scoliosis surgery. In almost all studies the extent of blood loss is reported in total milliliters (mL or ml) or cubic centimeters (cc). A second way is by determination of blood loss per vertebral level included in the fusion (total blood loss divided by number of vertebral levels in the fusion). A third way calculates the blood loss as a percentage in relation to the patient's estimated blood volume (EBV). The EBV is generally calculated to be 70 ml/kg (weight) [21]. For a 50 kg patient the EBV is 70×50=3,500 ml. A blood loss of 1,000 ml in that patient would represent a 28.6% loss. Wider presentation of blood loss as percent EBV would be helpful since this value provides the most physiologic indicator by taking patient size into account.

Diagnostic category of scoliosis

Awareness of the disorder associated with the scoliosis is essential since distinction must be made between idiopathic scoliosis and secondary scoliosis, which usually refers to neuromuscular disorders causing the scoliosis. Some reviews lump all types of neuromuscular deformity together but in many reports they are subdivided into the common variants of neuromuscular scoliosis which are cerebral palsy, myelomenigocoele, and Duchenne muscular dystrophy (DMD). Each of these disorders has differing responses regarding blood loss during surgery as well as differing needs for spinal correction and stabilization.

Types of surgical procedure

Distinction is made regarding blood loss in surgery between solitary posterior spinal fusions, solitary anterior spinal fusions, and combined anterior and posterior spinal fusions (including consideration of whether the anterior-posterior procedures are done as a single operation or separately with 1–2 weeks between stages).

Primary reason for the report from which blood loss information is abstracted

A few papers in this review were directed specifically to determining blood loss, usually comparing one anesthetic method to another or the use of a particular blood loss reducing agent. Since this article provides an overview of the problem of blood loss in pediatric spine fusion surgery, we have used the control group values from such studies but have usually also presented findings with the particular modification used.

Since limiting intra-operative blood loss is universally recognized as highly important, essentially all procedures done since the 1970s have incorporated several control mechanisms without necessarily indicating so in reports. These include: minimizing abdominal pressure with positioning, some form of hypotensive anesthesia, blood transfusion at pre-determined levels of hemoglobin, early replacement of platelets and fibrinogen, and surgical techniques stressing rigorous mechanical wound hemostasis [21, 26, 47, 57, 67]. For these reasons, most comparative studies relating to methods diminishing intra-operative blood loss are not scientifically controlled.

The large majority of papers in this review addressed problems relating to surgical technique, stabilization systems, and concerns specific to particular disorders and types of scoliosis. We have abstracted blood loss data as presented in each paper and derived EBL/vertebral segment and percent EBV numbers if sufficient information was provided.

The paper is designed to review intra-operative blood loss data. Some reports also assess post-operative blood loss but usually as separate determinations. In the few instances where combined data only were provided we have indicated that fact, and have used such studies only if the author indicated that post-operative loss was negligible.

Review of blood loss data from the literature

Blood loss data from the literature are presented in Tables 1, 2, 3, 4, 5 and 6. In each table we have listed the study (article) with year of publication and year(s) when surgery was performed, estimated mean blood loss (ml or cc) with ranges and/or standard deviations, the number of operative procedures in the study, surgical technique with bone

Table 1 Blood loss data from studies on posterior spinal fusions for AIS. *C-D* Cotrel-Dubousset (instrumentation), *H-rod* Harrington rod, *TSRH* Texas Scottish Rite Hospital (instrumentation), *L-rod* Luque rod

Study [reference] (date of publication)/(date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss/individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss/total estimated blood volume (EBL/EBV)	Comments
Shufflebarger et al. [62] (2004)/(1998)	500 (200–800)	55 (Lenke5)	Posterior shortening, posterior segmental pedicle screws with 5 mm rods (Moss-Miami)	-	-	No iliac crest graft
	627 (350–1500)	7 (Lenke 6)		-	-	
	675 (500–750)	3 (Lenke 3c)		-	-	
DuToit et al. [18] (1978)/	567	27	Harrington rod	-	-	Use of acute hemodilutional autotransfusion intraoperatively
Copley et al. [16] (1999)/(1995–1997)	608 (hemodilution)	43	Posterior fusions, systems not described	608/10.7=57	608/3780=16%	Comparison of hemodilution technique to control group, iliac crest bone graft, multicenter
	672 (control)	43		672/10.2=66	672/3774=18%	
Guidera et al. [32] (1993)/	660	-	-	660/7=94	-	Smaller curves <60º, levels=7
	1696	34		1696/8.8=193	-	Larger curves >60º, levels=8.8 [numbers per group not listed]
Erwin et al. [20] (1976)/(1966–1972)	743	187	Harrington-rod, no iliac crest bone graft	-	-	-
	840	177	Harrington rod, iliac crest bone graft	-	-	
Harrington and Dickson [33] (1973)/(1961–1972)	748 (110–3480)	578	Harrington rod, iliac crest bone graft	748/10=75	-	Hypotensive anesthesia, systolic 85–95 mmHg
Youngman and Edgar [71] (1985)/(1974–1982)	779 (<200–>1400)	319	Harrington rod, iliac crest bone graft, multiple ancillary procedures (operation in cast, sublaminar wires, etc)	779/11.9=65	-	Induced hypotension, systolic 60–65 mmHg
Lawhon et al. [39] (1984)/(1972–1978)	801	120	Harrington rod technique	-	-	Induced hypotension, mean arterial pressure (diastolic pressure + 1/3 of pulse pressure) less than 90mmHg
	1583	31	Harrington rod technique	-	-	Normotensive anesthesia
Siller et al. [63] (1996)/(1991)	823 (186–1587)	55	C-D, iliac crest bone graft	1084/11.1=98	-	Hypotensive anesthesia
Florentino-Pineda et al. [26] (2004)/(1999–2001)	893 +/– 220	19	Posterior spinal fusion with segmental instrumentation; allograft only	893/12=74	893/3095=29%	ε-aminocaproic acid group
	952 +/– 372	17		952/12=79	952/3153=30%	Control group

Table 1 (continued)

Study [reference] (date of publication)/ (date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss/ individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss/ total estimated blood volume (EBL/EBV)	Comments
Florentino-Pineda et al. [25] (2001)/ (1996–1998)	988 (+/– 411)	29	Multiple instrumentations	988/12=82	988/2973=33%	Pre-operative autologous blood and controlled hypotension (systolic 20% less than pre-induction value) ε-aminocaproic acid (EACA)
	1405 (+/– 671)	31		1405/12= 117	1405/3188= 44%	No EACA
Patel et al. [56] (1985)/(1977–1980)	1102 (+/– 72)	27	H-rod, autologous iliac crest bone grafts	46	1102/3836= 29%	Induced moderate hypotensive anesthesia (Systolic blood pressure 20–30 mmHg < preoperative systolic pressure)
	1541 (+/– 156)	22		84	1541/4186= 37%	
Moran et al. [48] (1995)/(1989–1993)	1113	84	C-D, iliac crest bone graft	-	-	Preoperative autologous blood donation
Richards et al. [59] (1994)/(1988–1991)	1122 (350–4000)	95	TSRH	-	-	-
Guadagni et al. [30] (1984)/(1979–1982)	1187	30	H-rod, L-rod with spinous process wiring H-rod	1187/11=108	-	-
	1543	31		1543/10=154		
McMaster [46] (1991)/(1975–1987)	1200 [a] (500–2458)	156	H-rod	1200/11+109 [a]	-	Same surgeon all cases, Autogenous iliac crest grafts
	1490 [a] (695–2945)	152	L-rod	1490/10.9= 137 [a]	-	
Lenke et al. [40] (1992)/(1985–1988)	1211 (300–3000)	95	C-D, autogenous bone graft iliac crest (occasional ribs)	1211/11=110	-	-
Albers et al. [1] (2000)/(1991–1995)	1421 (+/– 881)	21	Single rod TSRH, 11 iliac crest bone graft	-	-	-
	1801 (+/– 1201)	24	Dual rods (TSRH, C-D or Paragon) 17 iliac crest bone graft	-	-	
Lovallo et al. [42] (1986)/(1978–1982)	1500 (300–4000)	133	H-rod, autogenous iliac crest bone graft	1500/10=150	-	-
Barr et al. [3] (1997)/	1571 (550–3300)	39	C-D (thoracic) but lumbar pedicle hooks/ screws 20 and lumbar hooks only 19	1571/~10=157	-	Double major curves; blood loss same in two approaches
Guay et al. [31] (1994)/	1971 (+/– 831)	30	C-D, autogenous iliac crest bone graft	1971/9.3=212	61.5%	Low normotensive anesthesia

[a]Blood loss during and after surgery (post surgery loss negligible)

Table 2 Blood loss data from studies on anterior spinal fusions for AIS. *TSHR* Texas Scottish Rite Hospital (instrumentation), *C-D* Cotrel-Duboussett

Study [reference] (date of publication) / (date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss / individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss/ total blood volume	Comments
Moskowitz, Trommanhauser [49] (1993)/(1983–1989)	330	13	Zielke, rib graft	330/4.4=75	-	-
Bernstein, Hall [9] (1998)/(1990–1993)	344	17	TSRH (anterior)	344/3.4=101	-	-
Turi et al. [69] (1993)/	401 (100–800)	14	TSRH (anterior), rib graft	401/5=80	-	-
Newton et al. [52] (2003)/(1991–2001)	424 (+/– 302)	38	Thoracoscopic anterior instrumentation Isolated structural thoracic curves-Lenke IA, IB, IC	424/7=61	-	An earlier study compared thorascopic anterior release and fusion (EBL 235 ml) with fusion by open thoracotomy (EBL 270 ml) (reference 53)
	551 (+/- 363)	68	Anterior open instrumentation (Depuy-Acro Med Harms Study group)	-	-	
Bullman et al. [14] 2003/	437 (+/– 221; 100–1000)	45	Anterior dual rod Halm-Zielke	437/4.7=93	-	-
Bitan et al. [11] 2003/	505 (150–1000)	24	TSRH, Moss-Miami and C-D Horizon rib graft	505/2.9=174	-	-
Majad et al. [44] (2000)/	590 (250–950)	22	TSRH, Moss-Miami, Isola/ rod (3–11 levels fused)	-	-	-
Lowe, Peters [43] 1993/	610	36	Zielke, rib graft	610/4.5=136	-	-
Hopf et al. [35] 1997/(1992–1994)	630 (400–1200)	16	C+D - Hopf anterior system	-	-	-
Kaneda et al. [37] 1997/(1992–1994)	650	20	Kaneda anterior spinal system	650/7.5=87	-	-
Betz et al. [10] (1999)/(1991–)	956 (+/– 857)	78	Flexible rods (Harms-Moss, DuPuy-Motech-Acromed)	-	-	-
Hsu et al. [36] (1982)/	1645 (440–3400)	28	Dwyer	1645/4.7=350	-	-

graft information, mean EBL per individual vertebral level in fusion, mean EBL as a percentage of total EBV, and additional comments. In each table the studies are listed in order of mean EBL, beginning with those with the least loss reported to those with the highest amounts.

Table 1 reviews posterior spinal fusions for adolescent idiopathic scoliosis (AIS), Table 2 reviews anterior spinal fusions for AIS, Table 3 reviews spinal fusions for cerebral palsy, Table 4 reviews posterior spinal fusions for DMD, Table 5 reviews spinal fusions for pooled neuromuscular disorders (both anterior and posterior approaches), and Table 6 reviews spinal fusions for other neuromuscular disorders including spinal muscular atrophy and myelomeningocoele.

Blood loss in scoliosis surgery assessed by underlying disorder

Awareness of potential blood loss problem with any spinal fusion surgery

The operating team must have a high degree of preparation for blood loss in any spinal surgery for scoliosis in the pediatric age group, regardless of etiology and surgical approach to correction. Although AIS treated by spinal fusion has the lowest mean values for blood loss in scoliosis procedures, the ranges of blood loss measurements in all studies are wide, and amounts necessitating blood transfusion are often noted for both anterior and posterior approaches (Tables 1 and 2).

Table 3 Blood loss data from studies on spinal fusions for cerebral palsy. *P* posterior spinal fusion, *A* anterior spinal fusion, *P/a* posterior spinal fusion with some cases having anterior spinal fusion, *H-rod* Harrington rod system, *L-rod* Luque rod system, *DDAVP* desmopressin acetate

Study [reference] (date of publication) / (date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss / individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss / total blood volume	Comments
Bulman et al. [15] 1996/(1988–1993)	P/a 1325 (350–4000)	15	Luque-Galveston (15) plus anterior release, disk excision, arthrodesis (7)	1325/14.5=91	-	Same day procedures; blood loss for total approach
	P/a 1240 (300–3400)	15	Unit rod (15) plus anterior release, disk excision, arthrodesis (4)	1240/15=83	-	
Sponseller et al. [64] 1986/1982–1984	P 1681 (hypotensive anesthesia)	20	H-rod/L-rod, 1 or 2 with spinous process wiring, iliac crest bone graft; anterior release 2 weeks pre posterior fusion in 21–13 with Dwyer instrumentation	1681/15=112	-	Blood loss only for posterior procedures
	P 2200 (normotensive anesthesia)	14		2200/15=147	-	
Swank et al. [66] 1989/(1981–1985)	P 1760 (600–3000)	10	Luque or Luque-Galveston, autogenous iliac crest bone graft	1760/12=147	-	
	A 906 (200–3600)	21	Anterior fusion, Zielke system	906/5=181	-	Two week interval between anterior and posterior stages
	P 2040 (600–6490)	-	Posterior fusion, Luque system, autogenous iliac crest bone graft	2040/14=146	-	
Allen, Ferguson [2] 1982/(1977–1980)	P 2086 (550–3900, both)	7	Luque rods to L5 or above	2086/10.7=195	-	-
	2267	3	Luque rods to pelvis. Both with iliac crest autografts	2267/14.7=154	-	
Gersoff, Renshaw [28] 1988/ (1979–1983)	P 2125	33	Luque rod, bone bank bone graft	2125/14=152	-	Hypotensive anesthesia not used. No anterior approaches
Lonstein, Akbarnia [41] 1983/ (1948–1979)	I: A 1919	3		1919/7=274	58% EB volume	Group I - double balances curves
	P 2215	41	Harrington system, autogenous iliac crest bone graft	2215/13=170	79% EB volume	
	II: A 1803	>25	Dwyer or Zielke systems	1803/7=258	54% EB volume	Group II - large unbalanced thoraco-lumbra or lumbar curves
	P 2629	99	Harrington system, multiple other methods	2629/15=175	84% EB volume	Some posterior fusions without instrumentation
Bonnett et al. [13] (1976)/(1960–1972)	P 2230	10	Harrington rod system	2230/7.4=301	-	Many revisions subsequently needed with both approaches. Eventually recommended both anterior and posterior – improved results.
	A 1500	18	Dwyer anterior fusion system only	1500/5.5=273	-	

Table 3 (continued)

Study [reference] (date of publication) / (date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss / individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss / total blood volume	Comments
Dias et al. [17] (1996)/(1988–1991)	P 2149	31	Unit rod to pelvis local autogenous bone graft plus bone back allograft. T1 to sacrum	2149/17=126	-	7 patients had anterior release with rib graft 1 week before posterior fusion
Theroux et al. [68] (1997)/	Not reported	21	Unit rod fusion T1 to sacrum	-	DDAVP group Median loss 148% (range 57–425) EBV Placebo group Median loss 111% (range 65–240) EBV	-

Adolescent idiopathic scoliosis

AIS patients have the lowest amount of mean blood loss per procedure of all operative scoliosis groups. In the group treated by posterior spinal fusion (Table 1) in several studies the mean EBL ranges between 600 and 1,000 ml, and most studies document mean ranges between 750 and 1,500 ml. Treatment of AIS by anterior spinal fusion (Table 2) yields even lower mean EBL values, with most studies ranging between 350 and 650 ml and almost all less than 1,000 ml.

While the ranges of EBL per vertebral level included in the fusion in AIS are similar for posterior approaches (65–150 ml) and anterior approaches (60–135 ml), the overall blood loss is considerably less in the anterior group because fewer levels need to be fused to gain acceptable correction. The number of levels fused in the anterior surgery group is usually between 4 and 7 while the posterior group involves 9 to 12 (Tables 1 and 2).

Cerebral palsy

Blood loss is considerably higher in cerebral palsy patients undergoing scoliosis correction compared to patients with AIS (Table 3). The mean blood loss ranges in posterior approaches are concentrated between 1,300 and 2,200 ml, while many in the anterior group range from 900 to 1,800 ml. Blood loss per vertebral level fused is approximately similar for anterior and posterior approaches, although greater than AIS amounts, with most studies reporting losses between 100 and 190 ml per level. Blood loss amounts are much greater in posterior approaches primarily because of the larger number of vertebral levels involved; 13–15 with posterior procedures and 5–7 with anterior procedures.

Duchenne muscular dystrophy

Blood loss in DMD patients is even higher in most series than amounts reported for cerebral palsy patients. Several large studies have reported mean blood loss amounts from 2,500 ml to 4,000 ml+ (Table 4). Other studies have reported lower mean values of 930–1,680 ml but even these reports show some patients at the 3,000, 4,000 ml levels. The blood loss amounts are further magnified in effect since many DMD patients are small in stature with low body weight. Fusion is invariably performed from the upper thoracic region to the sacrum encompassing 13–16 levels. Mean values of EBL per vertebral level are in the 200–280 ml range, although more recent studies with less blood loss are being reported.

Studies on pooled neuromuscular disorders

Many studies on scoliosis surgery pool data from patients with neuromuscular disorders and do not distinguish between cerebral palsy, DMD, etc. Much valuable information is still provided, especially concerning blood loss with varying approaches. Most of these papers involve complex, severe deformities in which individual patients are treated by both anterior and posterior approaches. Mean EBL levels for anterior procedures are around 1,000 ml but posterior approaches range from 2,000 to 3,500 ml. The EBL per individual vertebral level in the fusion is correspondingly high as well.

Table 4 Blood loss data from studies on posterior spinal fusion for DMD. *CDI* Cotrel-Dubousset instrumentation, *TSRH* Texas Scottish Rite Hospital (instrumentation), *ISOLA* ISOLA instrumentation (Acromed)

Study [reference] (date of publication) / (date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss / individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss / total blood volume	Comments
Marchesi et al. [45] (1997)/(1988–1993)	930 (750–1500)	25	Luque-Galveston with sacral screws, local bone graft plus allogeneic bone	-	-	-
Fox et al. [27] (1997)/(1989–1994)	1028 (400–3000)	19	Hartshill rectangle, allograft bone graft	1028/12.5=82	30%	Hypotensive anesthesia
Mubarak et al. [50] (1993)/(1980–1987)	1680 (250–4000)	22	Luque system (10), Luque-Galveston (to pelvis, 12) autogenous iliac crest	168/15.5=108	-	-
Ramirez et al. [58] (1997)/(1980–1993)	2500 (1000–4500)	30	Luque or Luque-Galveston (23), CDI 6, TSRH1; half autograft and half allograft	-	-	-
Bellen et al. [6] (1993)/(1984–)	2633 (+/– 1100)	47	Luque (12), Luque-Galveston (22), Hartshill (13), fusion to pelvis 38 of 47, local bone graft and allograft	2633/136=194	84.5%	-
Noordeen et al. [54] (1999)/(1983–1993)	2977	48	Harrington system and Harrington-Luque system	2977/13=229	87%	-
Bentley et al. [8] (2001)/(1983–1996)	3034 (500–8700)	64	Luque, Harrington-Luque, or Luque-Galveston, local bone graft only	3034/13=233	-	-
Weimann et al. [70] (1983)/(1974–1978)	3067 (1830–4400)	24	2 Harrington distraction rods; autogenous iliac crest bone grafts	3067/12.8=240	-	-
Gibson et al. [29] (1978)	3132	10	Harrington rod	-	-	-
Heller et al. [34] (2001)/(1992–1998)	3373 (800–8500)	31	ISOLA system	3373/16=211	-	-
Shapiro et al. [61] (1992)/(1980–1990)	3640 (+/– 1905)	27	Luque or Harrington-Luque, iliac crest autograft (7), allograft (20)	3640/13=280	-	-
Swank et al. [65] (1982)/(1967–1979)	4064 (3300–6200)	13	7/11 with 2 distraction Harrington rods	4064/15=271	-	-
Sakai et al. [60] (1977)/(1972–1979)	4400	6	-	-	-	-

Information concerning entities such as spinal muscular atrophy, myelomeningocoele, and anterior approaches alone for selected neuromuscular disorders

Table 6 provides information from smaller numbers of studies. Blood loss in spinal muscular atrophy surgery is considerable but distinctly less than in DMD. In one group of 26 the mean EBL was 1,437 ml with EBL/vertebral level 103 ml. Most reports on spinal fusion in myelomeningocoele have been pooled with other neuromuscular disorders and reported in the studies listed in Table 5. One study on this entity showed mean EBL levels of 1,960 ml for posterior fusion without instrumentation, 1,729 ml for posterior fusion with Harrington rod stabilization, and 1,841 and 2,134 ml for combined anterior fusion and posterior fusion with instrumentation. The use of improved anterior instrumentation for myelomenigocoele is shown by two studies using the Cotrel-Dubousset-Hopf instrumentation with a mean EBL of 800 ml in 16 cases in

Table 5 Blood loss data from studies on pooled neuromuscular disorders (anterior and posterior approaches). *A* anterior approach, *P* posterior approach, *AP* anterior and posterior approach, *CDI* Cotrel-Dubousset instrumentation

Study [reference] (date of publication) / (date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss / individual vertebral level in fusion (ml) (EBL/# levels=)	Estimated blood loss / total blood volume	Comments
Floman et al. [24] (1982)/(1972–1977)	A 1033 P 2200	73 -	Multiple techniques. Posterior procedure performed 2 weeks after anterior procedure	- -	- -	EBL in Dwyer procedures 1250
Neustadt et al. [51] (1992)/(1985–1988)	P 1945 (450–4500)	18	Posterior fusion to pelvis with CDI	-	-	-
Benson et al. [7] (1998)/(1990–1994)	P 1684 (450–4000) AP 2329 (550–6000)	P 38 AP 12	Luque-Galveston and 39/50 Anterior discectomy and fusion without instrumentation	- -	- -	43 with allograft only; hypotensive anesthesia and autologous blood retrieval
Boachie-Adjei et al. [12] (1989)/ (1979–1984)	A 1100 (300–2225) P 2639 (270–8000)	AP 11 P 35	Luque-Galveston. Anterior fusion without instrumentation; local bone graft with allograft	A 100/7.4=149 P 2639/15=176	- -	-
Ferguson et al. [22] (1996)/(1977–1991)	1. A 896 P 3360	1. 29 -	1. Two stages (anterior discectomy and fusion) rib with no instrumentation. Posterior Luque-Galveston	1. A 896/8=112 P 3360/15= 224	1. A 28% P 100.9%	-
	2. AP 2058	2. 16	2. Both procedures same day	2. 2058/14.9= 138	2. 83%	
Bell et al. [5] (1989)/(1983–1986)	P 3500 (800–11000)	34	Unit rod system T2-pelvis. Local bone graft only	-	-	-

one report and a value of only 539 ml in 21 neuromuscular patients, 12 of whom had myelomeningocoele, in another.

Key factors determining amount of blood loss during scoliosis surgery

The material presented above clearly documents the extent of intra-operative blood loss during scoliosis surgery in both AIS and secondary scoliosis in patients with an underlying neuromuscular disorder. It is evident that blood loss is increased in patients with a neuromuscular diagnosis and an increasingly large number of vertebral levels included in the fusion. Studies assessing patients by the specific neuromuscular disorder demonstrate increasing losses as one moves from the cerebral palsy group, to spinal muscular atrophy and myelomenigocoele, and then to DMD which has the highest mean blood loss values. Posterior spine fusion procedures tend to lose more blood than anterior procedures, although most of this loss is due to the considerably larger number of vertebral levels fused in posterior approaches.

Several detailed papers have quantified the blood loss differences with statistical validation in relation to these matters. In one study neuromuscular patients had an almost seven times higher risk of losing greater than 50% of their estimated total blood volume during scoliosis surgery compared to idiopathic scoliosis patients when the extent of surgery (number of segments fused), age, weight, and pre-operative coagulation profile were controlled for statistically [19]. Another study showed that an underlying neuromuscular disease, lower body weight, and a higher number of vertebrae fused independently predicted a greater number of allogeneic red blood cell transfusions [47].

A large study of 319 patients operated between 1984 and 1993 clearly correlated the amount of bleeding with the disorder causing the scoliosis. The mean peri-operative bleeding was 9.8 ml/kg for idiopathic scoliosis (159 patients), 14.1 ml/kg for secondary scoliosis [including cerebral palsy (22 patients), myelomeningocoele (spina bifida)

Table 6 Blood loss data from studies on spinal muscular atrophy and myelomeningocoele. *C-D-Hopf* Cotrel-Dubousset-Hopf instrumentation, *H-rod* Harrington rod

Study [reference] (date of publication)/(date(s) of surgery)	Estimated blood loss (EBL) (ml) [mean (range)]	Number of procedures	Technique	Estimated blood loss / individual vertebral level in fusion (ml) (EBL/#levels=)	Estimated blood loss/ total blood volume	Comments
Noordeen et al. [54] (1999)/(1983–1993)	1437 (350–3500)	26	Luque and Harrington-Luque	1437/14=103	-	Spinal muscular atrophy cases
Basobas et al. [4] (2003)/(1988–)	539 (175–1000)	21	Moss-Miami (15), Zielke (4), others (2)	539/5.5=98	-	12/21 myelomeningocoele
Hopf et al. [35] (1997)/(1992–1994)	800 (350–2500)	16	C-D-Hopf	800/4.7=170	-	Posterior fusion also done in all myelomeningoceole patients
Osebold et al. [55] (1982)/(1960–1979)	1960 (550–3250)	13	Posterior fusion without instrumentation	1960/9=218	-	
	1729 (50–6500)	13 Patients (27 procedures)	Posterior fusion with H-rod instrumentation; 22/27 autogenous bone	1729/10=173	-	
	2134 (245–4500)	3	Anterior fusion without instrumentation and posterior H-rod fusion; 2 allograft, 1 autograft	-	-	Blood loss levels for combined surgery, not separated by site
	1841 (100–5200)	17 Patients (40 procedures)	Anterior fusion with Dwyer or Zielke; posterior H-rod fusion; 10 allograft, 7 autograft	-	-	

(18 patients) and vertebral malformations (18 patients)], and 29.3 ml/kg for muscular dystrophy and spinal muscular atrophy (31 patients) [23].

Other factors increasing blood loss are the length of time for the surgery to be done and the extra loss associated with harvesting autogenous iliac crest blood. In one study involving 145 patients undergoing Cotrel-Dubousset posterior fusions mean blood loss was 500 ml at 2 h, 1,500 ml at 3 h, and 2,400 ml at 4.5 h. The same study documented 1,828 ml blood loss with autogenous iliac crest grafts and 1,120 ml when autogenous bone was not used [57].

There are several reasons why blood loss is greater in the neuromuscular patients. Some are easy to understand and include: a larger number of vertebral levels fused, more frequent resort to both anterior and posterior procedures and the fact that the patients are often younger and of less weight than patients with idiopathic scoliosis. A recent study also documented a prolonged prothrombin time and decrease in factor VII activity greater than seen in idiopathic patients intra-operatively. The authors suggested that consumption of clotting factors during spinal surgery along with dilution of clotting factors further enhanced blood loss [38]. In addition, many neuromuscular patients are poorly nourished and have been on seizure medications, some of which can affect coagulation.

Awareness of the extent of blood loss with scoliosis surgery helps with pre-operative preparation and intra-operative management and should enhance the study and development of methods to decrease its occurrence.

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