Segmental vessel ligation in patients undergoing surgery for anterior spinal deformity

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Segmental vessel ligation during anterior spinal surgery has been associated with paraplegia. However, the incidence and risk factors for this devastating complication are debated.

We reviewed 346 consecutive paediatric and adolescent patients ranging in age from three to 18 years who underwent surgery for anterior spinal deformity through a thoracic or thoracoabdominal approach, during which 2651 segmental vessels were ligated. There were 173 patients with idiopathic scoliosis, 80 with congenital scoliosis or kyphosis, 43 with neuromuscular and 31 with syndromic scoliosis, 12 with a scoliosis associated with intraspinal abnormalities, and seven with a kyphosis.

There was only one neurological complication, which occurred in a patient with a 127° congenital thoracic scoliosis due to a unilateral unsegmented bar with contralateral hemivertebrae at the same level associated with a thoracic diastematomyelia and tethered cord. This patient was operated upon early in the series, when intra-operative spinal cord monitoring was not available.

Intra-operative spinal cord monitoring with the use of somatosensory evoked potentials alone or with motor evoked potentials was performed in 331 patients. This showed no evidence of signal change after ligation of the segmental vessels.

In our experience, unilateral segmental vessel ligation carries no risk of neurological damage to the spinal cord unless performed in patients with complex congenital spinal deformities occurring primarily in the thoracic spine and associated with intraspinal anomalies at the same level, where the vascular supply to the cord may be abnormal.

The spinal cord is supplied by two different arterial systems: three longitudinal arterial trunks lying within the spinal canal, and the segmental arteries, arising from the aorta. The longitudinal arterial trunks extend along the cord beneath the meninges from the medulla oblongata to the conus medullaris. They are the anterior median longitudinal spinal artery (anterior spinal artery) and the posterolateral spinal arteries. The arteriolar vessels that arise from these arteries encircle the spinal cord, forming the vasocorona, a fine pial plexus that provides limited anastomoses between the anterior and posterolateral spinal arteries.

Bilateral segmental vessels arise from the aorta and inferior vena cava and pass around both sides of each vertebra before entering the spinal canal through the intervertebral foramina. The arteries divide before entering the foramina and provide the nutrient vessels to the vertebral bodies, as well as a rich anastomotic network on the surfaces of the vertebral bodies, transverse processes and pedicles. These anastomoses are between ipsilateral and contralateral arteries. After entering the intervertebral foramen and penetrating the dura, the posterior branch of each segmental artery divides into dural arteries, which supply the spinal dura and root sleeve, and radicular arteries, supplying the anterior and posterior nerve roots. A second anastomotic network is formed in the extradural space within the spinal canal, with the greatest concentration in the cervical and lumbar regions. These anastomotic networks are believed to preserve spinal cord circulation by providing an alternative route for arterial flow during conditions of stress.

Also, the posterior branch of the segmental artery is the origin of the medullary feeders, which reinforce the longitudinal arterial channels in a sporadic fashion and at various levels. These medullary feeders are supplied mainly by the vertebral arteries in the cervical spine and by aortic segmental arteries in the thoracic
and lumbar regions. The medullary arteries enter the dura adjacent to the nerve root ganglion, after which they ascend and anastomose with an anterior or posterolateral spinal artery to supply the spinal parenchyma (medulla). The anterior spinal artery does not receive an afferent supply at each segmental level.

The medullary feeders, commonly labelled ‘radicular arteries’ reinforce the longitudinal arterial channels at various levels. The largest medullary feeder of the lumbar cord is the arteria radicularis anterior magna (great radicular artery, or artery of Adamkiewicz), which in 80% of cases originates from a left segmental artery between T7 and L4, with a predilection for the T9 to T11 levels. Biglioli et al reported the artery of Adamkiewicz to enter the spinal canal from the left side between T9 and L5 in 63% of patients, below T12 in 70%, and between L1 and L3 in 65%. These and other investigators have suggested that there may be more than one arteria radicularis anterior magna in 11% of patients.

In 1974, Dommisse defined the area between T4 and T9 as the ‘critical vascular zone of the spinal cord’, recognising that at these levels the spinal canal was narrowest and the blood supply least profuse. He concluded that this was the zone in which interference with the spinal circulation was most likely to result in paralysis.

Paraplegia may occur following impairment of the segmental vessels. The incidence of paraplegia was 8% in a study of 138 patients undergoing resection of a thoracic or thoracolumbar aneurysm necessitating bilateral ligation of the segmental vessels without spinal cord monitoring. This was reduced to 2% in a subsequent group of 95 patients using spinal cord monitoring, in whom the segmental vessels were first sequentially clamped and only ligated if there was no change in the somatosensory evoked potentials within eight to ten minutes of occlusion.

Patients with severe or rigid spinal deformities often require anterior spinal surgery to release, decompress or fuse the spine, with or without internal fixation. This usually requires ligation of the segmental vessels over the length of the deformity. A vascular insult following disruption of the blood supply to the cord is recognised as a possible factor leading to permanent neurological compromise in these patients.

The purpose of this study was to record the prevalence of neurological complications in a large number of paediatric and adolescent patients with spinal deformities undergoing anterior surgery performed through a thoracic or thoracoabdominal approach using the same technique of segmental vessel ligation throughout, and to assess any neurophysiological changes occurring as a consequence of ligating these vessels.

**Patients and Methods**

We reviewed the medical records and spinal radiographs of 346 consecutive paediatric and adolescent patients with a scoliosis or kyphosis who underwent anterior surgery through a thoracic or thoracoabdominal approach (Table I). Patients with myelomeningocele or spinal cord injury with pre-operative neurological deficits were excluded. The mean age at surgery was 12.3 years (3 to 18). The senior author (MJM) operated on 319 patients with the remaining 27 anterior or anteroposterior procedures performed by the first author (AIT) using the same technique of anterior approach and ligation of the segmental vessels.

There were 173 patients (50%) with an idiopathic scoliosis, 80 (23%) with a congenital scoliosis or kyphosis, 43 (12.5%) had a neuromuscular scoliosis, 31 (9%) had a syndromic scoliosis, 12 (3.5%) had a scoliosis associated with intraspinal abnormalities but without neurological deficits and seven (2%) had kyphosis. There were no cases of revision surgery. The deformity was thoracolumbar or lumbar in 240 patients (69%) and thoracic in 106 (31%).

All the patients with a congenital spinal deformity had a pre-operative myelogram or MR scan of the whole spine to assess the presence of intraspinal anomalies. There were 29 patients with a congenital scoliosis or a scoliosis associated with a Chiari malformation, diastematomyelia or other intraspinal anomaly. They were defined as having a ‘spinal cord at risk’ during surgery because of spinal dysraphism.
A total of 250 patients (72.3%) underwent a combined anterior and posterior spinal fusion, with posterior instrumentation in 150 patients, anterior and posterior instrumentation in 38, and no instrumentation in the remaining 62. The other 96 patients (27.7%) had only an anterior spinal fusion, with instrumentation in 74 cases. A total of 2651 segmental vessels were ligated; a mean of 7.7 vessels per operation (6 to 9).

Early in the series, 15 patients underwent correction of scoliosis without intra-operative neurophysiological monitoring. In these patients spinal cord function was assessed after correction of the deformity using a wake-up test. Between 1985 and 1999, 168 patients were operated on using cortical or epidural somatosensory evoked potentials. Between 2000 and 2007, 163 patients underwent their surgery with the addition of motor evoked potential, to the somatosensory (cortical and spinal) evoked potential recording. This provided a more complete neurophysiological evaluation of neural function during surgery, with the aim of detecting impending spinal cord injury while it remained potentially reversible.

A significant neurophysiological change, indicating potential or actual spinal cord damage, was defined as a reduction in the amplitude of the somatosensory evoked potentials by > 50% and/or altered latency of > 10% compared with the baseline, as well as intra-operative loss of the motor evoked potentials.5

Operative technique. The anterior procedure was performed in the lateral decubitus position, using a thoracic or thoracoabdominal retroperitoneal approach. Hypotensive anaesthesia was used in all cases, the mean blood pressure being maintained intra-operatively at 60 mmHg. After
exposure of the lateral aspect of the vertebral bodies on the convexity of the scoliosis, the segmental vessels were separately released and ligated with silk sutures where they crossed the mid-portion of the vertebral body, avoiding proximity to the neuroforamen, where important collateral vessels may exist. The segmental vessels were never ligated on both sides at the same level. In none of our patients was soft clamping of the vessels before ligation performed.

Ligation of the segmental vessels was followed by excision of the rib heads and a complete annulectomy and disectomy back to the posterior longitudinal ligament, in order to allow angular and rotational mobility of the spinal segments (Fig. 1). The application of morcellised autologous rib graft enhanced anterior fusion across the excised discs.

**Results**

Only one patient had neurological deterioration after anterior spinal surgery. This was a 14-year-old girl with a left-sided congenital thoracic scoliosis measuring 127° due to a unilateral unsegmented bar extending from T8 to T12 with three contralateral hemivertebrae at the same level (T9 to T11). She also had a diastematomyelia at the T11 to T12 level, with tethering of the spinal cord but normal pre-operative neurology. She underwent neurosurgical excision of the bony spur and a de-tethering procedure without neurological complications. This was followed six months later by a two-stage anterior and posterior scoliosis correction. The first stage was a convex vertebral body resection and an osteotomy of the unilateral unsegmented bar performed through an anterior left thoracic approach to the spine on the convexity of the scoliosis. The segmental vessels were ligated unilaterally at seven levels across the apex of the scoliosis. This patient was treated early in our series, when intra-operative spinal cord monitoring was not available.

Following the anterior surgery, there was a flaccid paralysis of the right leg. The second stage was delayed to allow possible neurological recovery, but this did not occur. After one month she underwent posterior spinal fusion with instrumentation to stabilise the spine, but with no attempt at further correction. There were no additional neurological complications.

Spinal cord monitoring with the use of either somatosensory evoked potentials or combined somatosensory evoked potentials and motor evoked potentials was performed intra-operatively in 331 anterior spinal procedures, including the remaining 28 patients with ‘a spinal cord at risk’. None of these patients underwent pre-operative spinal cord monitoring, and baseline traces were obtained when the patient was positioned on the operating table and before the administration of neuromuscular blockade. The intra-operative spinal cord monitoring showed no evidence of reductions in the recorded amplitude of the somatosensory evoked potentials, change in the latency of the somatosensory evoked potentials, or loss of the motor evoked potentials in any patient before or after ligation of the segmental vessels.

**Discussion**

Anterior approaches to the spine with or without instrumentation are occasionally recommended in the surgical treatment of severe types of spinal deformity, either in isolation or followed by a posterior spinal fusion.

Neurological complications can occur following corrective anterior spinal surgery and may be due to vascular or mechanical causes. Leung et al reviewed 871 patients who underwent anterior spinal surgery and reported five (0.6%) with significant post-operative neurological deficits. In a recent report by the Scoliosis Research Society Morbidity and Mortality Committee the neurological complication rates for all causes following anterior and combined anterior/posterior spinal procedures to correct an adolescent idiopathic scoliosis were 0.26% and 1.75%, respectively.

The anterior procedure usually requires ligation of the segmental vessels on the convex side of the vertebral bodies to provide access to the body and intervertebral disc. As the segmental vessels are part of the complex vasculature of the spinal cord, paraplegia with motor and sensory loss and incontinence could occur simply by ligating these vessels. This risk is reported to range between 0% and 0.86%.

The risk factors that have been suggested to potentially impair the blood supply of the spinal cord include segmental vessel ligation at multiple or bilateral levels, a kyphotic deformity, a neoplastic lesion or spinal dysraphism, a left surgical approach, hypotension induced during surgery, partial or complete vertebral column resection, previous anterior spinal surgery and increased patient age.

Our only post-operative neurological deficit, which affected one leg, occurred following an anterior convex vertebral column resection and concave spinal osteotomy with unilateral ligation of the segmental vessels performed through a left thoracic approach in a patient with a congenital thoracic scoliosis measuring 127° associated with a diastematomyelia at the level of the congenital vertebral abnormalities. In this patient, the congenital anomalies were in the lower thoracic spine at the critical vascular zone of the spinal cord as defined by Dommise. We believe this neurological complication occurred as a consequence of ischaemic damage to one stem of the diastematomyelia in the presence of a congenitally abnormal blood supply.

Winter et al reviewed 533 paediatric and adolescent patients who underwent anterior procedures in the thoracic or thoracolumbar spine and reported no neurological complications. They concluded that there is no risk of paraplegia, provided the segmental vessel ligation is unilateral, performed at mid-vertebral body level on the convexity of the scoliosis and without hypotensive anaesthesia. In our series, hypotensive anaesthesia was used electively in all patients.

In contrast, Bridwell et al reported that four (1.1%) of 349 patients developed a neurological deficit after anterior
and posterior corrective spinal surgery. In three of these the neurological deficit was attributed purely to a vascular aetiology. In the fourth a combined vascular and mechanical aetiology was suggested. This study concluded that patients who undergo combined anterior and posterior spinal surgery for hyperkyphosis are at the greatest risk for developing neurological complications, and that this is due primarily to anterior interruption of the blood supply to the spinal cord.9

Mirovsky et al15 reported 29 patients who underwent anterior instrumented thoracolumbar fusion and were able to spare the segmental vessels in seven patients, in whom a single rod construct with transvertebral screws 6.25 mm to 7 mm wide were used. There were no neurological complications. In our series, 112 patients had anterior spinal instrumentation with unilateral ligation of the segmental vessels, also without neurological problems.

Bassett, Johnsen and Stanley16 reported 16 patients who underwent selective spinal angiography followed by anterior spinal surgery with temporary clamping of the segmental arteries and somatosensory evoked potentials monitoring. They recorded no loss of somatosensory evoked potentials after temporary unilateral occlusion of the segmental vessels, and postulated that there was sufficient perimedullary collateral circulation in the spinal cord to allow the routine unilateral ligation of the segmental arteries without increasing the risk of neurological damage.

Apel et al17 performed clamping of the segmental arteries and monitored somatosensory evoked potentials in 44 patients who underwent anterior spinal fusion to correct thoracic or thoracolumbar spinal deformities from various causes. They noted seven patients in whom there was an alteration in somatosensory evoked potentials after clamping the segmental vessels at or within one vertebral level of the apex of the curve. This reversed once the occlusion was released. From these findings, they recommended temporary segmental arterial occlusion with somatosensory evoked potentials monitoring during anterior thoracolumbar spinal fusion, especially in patients with a congenital kyphoscoliosis. None of our patients had temporary clamping of the segmental vessels before they were divided.

Leung et al8 monitored 871 patients who underwent elective anterior spinal deformity surgery with the use of intra-operative somatosensory evoked potentials. The incidence of significant somatosensory evoked potentials changes, as well as post-operative paresis, was much higher in patients who had associated intraspinal anomalies. The authors concluded that patients with cord abnormalities should undergo spinal cord monitoring with soft clamping of the segmental vessels during anterior spinal deformity surgery.

In our series, the patient who developed a neurological deficit after ligation of the segmental vessels was operated on prior to 1985, when spinal cord monitoring was not available. If this had been available, we believe it would have been helpful, based on the severity of the congenital vertebral and intraspinal anomalies and the extent of the surgery. Also, temporary occlusion of the segmental vessels combined with recording of somatosensory evoked potentials and motor evoked potential signals might have detected impending neurological injury. Pre-operative nerve conduction studies and somatosensory evoked potentials recording could also be helpful in establishing baseline function prior to spinal surgery in patients with intraspinal anomalies or abnormal neurological findings.

In conclusion, this review of 346 consecutive patients who had an anterior spinal procedure for deformity correction revealed only one case of neurological deficit related to segmental vessel ligation. In our experience, segmental vessel ligation appears to carry no risk of causing neurological compromise, unless performed in patients with complex congenital spinal deformities occurring primarily in the thoracic spine, especially those associated with spinal dysraphism at the same level. In this group of patients, intra-operative spinal cord monitoring with the use of somatosensory evoked potentials and preferably motor evoked potentials, as well as soft clamping of the segmental vessels before division, could possibly detect impending neurological injury at a stage when it is reversible.

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References


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