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The Risk of Spinal Cord Ischemia in Thoraco-Lumbar Spine Surgery: Attempt to Quantify Predictive Factor

Hallout Sabrina*

Department of Neurosurgery, Pitie Salpetriere Hospital, Paris 13, France

***Corresponding author:** Hallout Sabrina, Neurosurgery Department, Pitie Salpetriere Hospital, Paris 13, France, **E-mail:** sabrina.hallout@neurochirurgie.fr

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Abstract

Background: The anterior spinal network is a major vascular system irrigating more than ¾ of the spinal cord. The origin of Adamkiewicz's Artery (AKA) is located between the 9th thoracic (T9) segment to the 2nd lumbar (L2) segment, coming from the left side for 85% of cases; between T12- L3 for 84% of cases or between T9-T10 for 50% of cases. The anterior spinal artery's syndrome (ASA syndrome) is involved in more than 90% of cases of spinal cord ischemia. The spinal cord ischemia remains one of the most serious complications after thoracolumbar spine surgery. It is difficult to quantify the risk depending on the type of surgery, the vertebral level implicated in surgery, the patient's vascular network. During planification before an elective spine surgery, the patient must receive complete information about potential risk focused on neurological and vascular damage. The objective of this work is to provide a review of the literature relating the frequency to such complications in order to inform as precisely as possible to our patient about the risk of neurologic event. It seems to be difficult to assess the risk of paraplegia during thoracolumbar spine surgery or to predict the neurological impact of an arterial sacrifice of the anterior spinal artery system. Secondary aim of this work is a reporting of the spinal cord ischemia risk factors encountered in spinal surgery in the literature.

Methods: The inclusion criteria used are about patients who have suffered from neurovascular complications after thoraco-lumbar spine surgery, in relationship to the anterior spinal vascular system. We used the following key words in English: spinal cord ischemia, vascular surgical procedures, spine surgery and injury of Adamkiewicz's artery. We focused our review on major spinal surgery series of the literature which described neurologic and/or vascular complications occurring on deformity, tumoral or degenerative indications for spinal surgery. We excluded surgical complications related to traumatic spine, to another artery not directly involved in the anterior spinal network (aorta, iliac artery), to the vascular complications secondary to acute or chronic spinal vasculopathy or any ischemia not induced by spinal surgery.

Results: Focusing on spine thoracic vascularization, an area devoided of artery feedings towards the second and the third thoracic segments (T2-T3) is well identified as a high risk of spinal ischemia. If an injury occurred, this area has no vascular suppleance, a possible paraplegia due to hypoperfusion can't be avoided. The surgical approaches with a higher risk of AKA's meeting are vertebrectomies for spinal metastasis removing, anterior spinal approaches or transforaminal approach for performing an arthrodesis, surgical approaches for deformity spinal surgery (scoliosis) or herniated disc surgery in thoracolumbar spinal surgery (T7-L4). The rate of neurological complications in spinal surgery is less than 6% depending on the type of surgery.

Conclusions: The AKA is considered as a vascular moderator, associated with variation of blood flow from the aorta. It is involved in a spinal vascular network with a large number of anastomosis.

Keywords: Adamkiewicz's artery; Spinal cord vascularization; Thoraco-lumbar surgery; Ischemia; Paraplegia

Abbreviations: AKA: Adamkiewicz's Artery; ARMA: Anterior Radiculo-Medullar Artery; ASA: Anterior Spinal Artery; PRMA: Posterior Radiculo-Medullar Artery; PSA: Posterior Spinal Artery

Introduction

The anterior spinal network is a major vascular system irrigating more than ¾ of the spinal cord. The spinal cord ischemia remains one of the most serious complications after thoracolumbar spine surgery. It is difficult to quantify the risk depending on the type of surgery, the vertebral level implicated in surgery, the patient's vascular network. The mechanism inducing paraplegia may be directly secondary to spinal cord injury (stretching) or indirectly by hypoperfusion. An interruption of the spinal blood flow in ASA's territory can induce an ischemia of the ventral horn of the spinal cord, the ventral commissura or towards the sympathetic centers in the intermediolateralis column defined as the anterior spinal artery (ASA) syndrome. During planification before an elective spine surgery, the patient must receive complete information about potential risk focused on neurological and vascular damage. The objective of this work is to provide a review of the literature relating the frequency to such complications in order to inform as precisely as possible to our patient about the risk of neurologic event. It seems to be difficult to assess the risk of paraplegia during thoracolumbar spine surgery or to predict the neurological impact of an arterial sacrifice of the anterior spinal artery system. Secondary aim of this work is a reporting of the spinal cord ischemia risk factors encountered in spinal surgery in the literature.

Background

The vascularization of spinal cord depends of three longitudinal systems: the anterior spinal artery (ASA) and the two posterolateral spinal arteries. The ASA is strengthened by radiculomedullary arteries which arise from the aorta. The AKA is the most important of these arteries and the main vascular supply of the ASA [1-4]. The origin of AKA is variable, it arises between the 9th to the 12th intercostal artery in 75% of cases or between the 5th to the 8th intercostal artery in 15% of cases or towards the first or second lumbar artery in 10% of cases. It penetrates into the spinal canal in 75% of cases accompanied by one of four spinal nerves T9, T10, T11 or T12; in 10% of cases with L1 or L2; in 15% of cases with T5, T6, T7 and T8 [3,4].

According to Adamkiewicz's publication, AKA is located between T8 and L2, accompanying a thoracic root in 76% of cases or a lumbar root in 24% of cases [5,6].

There are anatomical variations about the number of anterior radiculospinal arteries (ARSA): presence of at least two different pattern of spinal blood supply towards thoracolumbar level with different origin of the ARSA [3,4,7,8]:

- Presence of two ARSA, one artery lower than the 12th thoracic segment, and the other between T6 to T10 in 48% of cases.
- Presence of only one ARSA towards the 9th thoracic segment (T9) in 45% of cases.
- Presence of three ARSA in 7% of the cases.
- Presence of two AKA: duplication in 11% of cases.

The origin of AKA is located between the 9th thoracic segment (T9) to the 2nd lumbar segment (L2), coming from the left side for 85% of cases; between T12- L3 for 84% of cases or between T9-T10 for 50% of cases [9-11].

Lazorthes [3,4] established an anatomical and functional classification of spinal cord vascularization. Focusing on spine thoracic vascularization, an area devoided of artery feedings towards the second and the third thoracic segments (T2-T3) is well identified as a high risk of spinal ischemia [12-14]. If an injury occurred, this area has no vascular suppleance, a possible paraplegia due to hypoperfusion can't be avoided [5,13-15]. The anterior spinal artery's syndrome (ASA syndrome) is involved in more than 90% of cases of spinal cord ischemia. The main etiologies are secondary to: arteriosclerosis (23.6%), aortic dissection (11%), dissection of the vertebral artery (11%), aortic surgery (11%). Deformity spinal surgeries represent less than 2% of spinal cord infarction [15,16].

The ASA syndrome is diagnosed when flaccid paresis (lesional syndrome) is associated to para- or tetraparesis below the level of infarction, positive Babinski sign, dissociated sensitive deficit (loss of pain and temperature sense), bladder and bowel dysfunction, possibly vegetative dysfunctions and Horner's syndrome [16]. The AKA's syndrome is an incomplete transverse spinal cord syndrome including a flaccid paresis at the level of infarction and paraparesis below the level of infarction, positive Babinski sign, (in-) complete loss of sensation, bladder and bowel dysfunction [16]. The neurological deficit induced by an hypoperfusion or an interruption of spinal blood flow may occur in the range from 30 minutes to 7 or 8 hours after the ischemic event [17].

Identifying the vertebral level of AKA's entry in the spinal canal, its side, its penetration is recommended before spine surgery that could cause ischemic damage if this artery was not visualized.

Using neuroradiologic tools for AKA's mapping, it is important to determine the spatial configuration of this artery for planification of surgical approach and preventing ischemic events and neurological risk [18]. The Magnetic resonance angiography (MRA) with CT angiography is a noninvasive examination for establishing an angiogram of the spinal blood flow [19,20]. The AKA is angiographically detectable in 83% of cases, between T9 and T11, from the left side in 95% of cases [21]. The spinal tomodensitometry studies the permeability of the intercostal and lumbar arterial system and allows visualization of arterial anastomosis. The AKA's detection rate varies from 68 to 90% [7]. It establishes a preoperative mapping specifying the course of the radiculo-spinal arteries, identifying AKA's entry into the foramen and joining the anterior spinal vascular area with a "hairpin turn" aspect. The spinal angiography remains the gold standard for AKA's detection. It is a selective catheterization of intercostal lumbar arteries. The iatrogenic risk secondary to the catheterization procedure reported in the literature are less than 1% [22]. This tool can influence the surgical approach by choosing the opposite side of artery's localization in 54% of cases [18].

The prevention of paraplegia during aortic surgery requires the identification of AKA which plays a major role in the vascularization of the ASA. The preoperative detection of AKA influenced the surgical strategy of thoracoabdominal aorta aneurysm replacement [7,18]. The visualization of the AKA predicts the number of anastomoses of intercostal or lumbar arteries and minimize clamping time by focusing on the essential arterial segment in the vascularization of the AKA according to its origin. The risk of neurological complication is two times higher than when the AKA is not identified [23].

According to the series of thoracoabdominal aneurysm surgery, the incidence of neurological deficit like paraparesis/paraplegia varies between 5-16% of patients [24,25]. After sacrifice of the of thoracoabdominal segmental arteries during an aortic surgery, the spinal cord blood flow has been explored during 72 hours after arterial sacrifice on level from T4 to L5 on animal model (Pig Yorkshire).

During surgery and up to one hour after sacrifice, spinal blood flow remains unchanged; spinal cord ischemia is delayed between 1-5 hours after clamping [26].

The collateral network

Biglioli and colleagues have described the anterior spinal artery (ASA) as a continuous and uninterrupted vessel receiving arterial afferents of the vertebral arteries, the AKA and ARMA. All these arteries are interconnected forming an extended network browsing the entire spinal cord, named (the collateral network) [10]. The traditional point of view that the spinal perfusion depends mainly to one artery (AKA) is exceeded; instead we must consider an extensive network including all the intercostal and lumbar segmental arteries, in relationship to ASA. In addition to arterial multiple entries, the ASA is powered by a dense network of vessels which are interconnected [27]. The blood pressure measurements within this collateral network were used to assess the hemodynamic response secondary to sacrifice of segmental arteries. The value of the pressure is about 60 to 80% of the mean arterial pressure and drop during five hours after the sacrifice. A hypothesis has been advanced in order to explain absence of neurological deficit when the spine blood flow is interrupted. The vasodilation secondary to ischemia occurs to widen the diameter of the SAA. The AKA is considered as a vascular moderator, associated with variation of blood flow from the aorta. Recently, some surgeons have proposed to form a collateral pathway as a substitute for the Adamkiewicz's artery by parent artery's ligation in order to increase the perfusion pressure of collateral network [28].

Materials and Methods

We conducted a literature review on the last twenty years of spinal surgery complications. We analyzed all available information on the neuro-vascular risk during thoracolumbar spine surgery from clinical series or clinical case report(s). The inclusion criteria used are about patients who have experienced a transient or permanent neurological deficit during a spine surgery, the anterior spinal vascular area and neurovascular complications following surgery of thoracolumbar spine. We used the following key words in English: spinal cord ischemia, vascular surgical procedures, spine surgery, injury of Adamkiewicz's artery.

We identified through the search engine Pubmed the "MeSH Terms": "Aortic aneurysm", "thoracic/physiopathology or thoracic/surgery", "spinal cord/blood supply/etiology/physiopathology", "spinal cord ischemia/prevention and control", "vascular surgical procedures/adverse effects", "paraparesis/etiology" paraparesis/prevention and control"; "Paraplegia/etiology"; "Paraplegia/prevention and control".

We excluded surgical complications related to traumatic spine, to another artery not directly involved in the anterior spinal network (aorta, iliac artery), to the vascular complications secondary to acute or chronic spinal vasculopathy or any ischemia not induced by spinal surgery. We focused on complications described in three main surgical approaches for spinal tumor or degenerative or deformity surgery.

Results

In Roy-Camille's spine surgery records, 2855 patients were included, 170 neurovascular complications (6%) were observed; complications including complete tetraplegia are estimated about 1.4% [29]. Arthrodesis anterior approach is responsible for 0.9% of intraoperative neurological deficit [30].

Deformity spine surgery

Ligation of the segmental vessels of the spine is often used in the prior surgery of scoliosis. In Winter's series of 1197 patients who underwent thoracolumbar anterior approach (T1-L3), none cases of paraplegia due to a segmental arterial ligation is reported [31]. Therefore, it concluded that there is no risk when blood is unilateral ligation and/or carried out to the convexity of the deformity and/or carried out in the middle of the vertebral body [29,30]. The kyphosis is a risk factor of neurological deterioration. A retrospective study of 45 consecutive patients in the surgical series of vertebral column resection with correction of a rigid severe kyphosis was performed. The intraoperative monitoring was disrupted in 22% of cases during surgery. Only one patient (2.2%) had a complete paraplegia [32].

Spinal deformity surgery is the one of the most surgery with a higher risk of spinal cord infarct; its incidence is estimated about 1.8% over a period of 20 years [16]. The French scoliosis group study reported an incidence of neurological complications about 1.8% [33]. A review of the literature about thoracic pedicle screw fixation surgery of deformation allowed the analysis of 21 clinical series on 1666 patients and 4570 pedicle screws. No vascular complications with neurological consequences have been reported in this analysis [34]. The neurological deficit rate after an unilateral arterial ligation toward T10-T12 is about 0.75%; the risk factors identified are a history of kyphosis correction, revision surgery, a surgical approach lateralized to the left side and a 360° combined surgery [35].

Tumoral spine surgery

The effect of a total spondylectomy on the cat's spinal cord perfusion was studied under conditions of laminectomy and ligation of AKA. There is a decreased blood flow in the order of 22% after laminectomy and 19% after ligation [36]. The vertebrectomy is associated with a high rate of complications, the predictive risk factors of neurological morbidity reported after 1035 spine tumor surgeries are multi-segmental resection and surgical approaches requiring a circumferential approach [37]. In the animal model, AKA's ligation reduced spinal blood flow about 81% of total perfusion (in cats) and 85% (in dogs) compared to spinal blood flow of control subject. The hypoperfusion does not affect evoked potentials. Therefore, a phenomenon of compensation occurs after bilateral ligation of the segmental AKA. The longitudinal arterial trunks and/or the anastomotic arterial network can compensate and maintain the spinal blood flow after bilateral ligation of the segmental arteries [38]. In vertebrectomy surgical series, although few postoperative paraplegia (less than 1%) have been described, the authors report an improvement of Franckel grading scale after spine surgery [39-43].

Degenerative spine surgery

The risk factors of spinal cord ischemia during thoracolumbar instrumentation with anterior thoracotomy are the presence of kyphosis, circumferential surgical approach, partial or complete vertebrectomy, multiple and bilateral ligation of AKA, any systemic hypotension event during surgery. The occurrence of neurological deficit during anterior approach is estimated inferior to 0.75% until more than 5% for vascular complication rates [44,45]. Regarding arthrodesis by posterior surgical approach, the rate of vascular and neurological complications varies respectively from 0.4 to 1.2% and 0.3 to 1.3% [29].

Discussion

The incidence of ischemic complications regarding a spinal segment including AKA has not been studied specifically in literature about spine surgery. The objective of this study was to assess the frequency of ischemic events and specify the contributing factors. The heterogeneity of the studied population, the surgical indication and approaches seems insufficient to obtain statistically strong data. The animal model series have shown the feasibility of ligation of the anterior spinal network without neurological consequences in the majority of cases [38]. However, it is not possible to extrapolate this experience to human cases. It seems that when the ligature is indispensable, neurological deficit is not systematic. The discovery of an earlier radiculomedullary artery toward "surgical" level is not a non-indication for total vertebrectomy. The spine surgeon must establish surgical planification with angiogram which can influence surgical decision in more than 50% of cases of literature [12].

Conclusions

Adamkiewicz's highlights about spinal vascular network with a large number of anastomosis and under physiological conditions, blood flow is centrifugal to the gray matter, whereas under pathological conditions, the flow is disturbed, particularly in the thoracic segment. The thoracic area between the 2nd and 3rd thoracic segments (T2-T3) is bankrupt blood feeding. The angiograms influence the surgical decision in 54% of cases. The surgical approaches with a higher risk of AKA's meeting are vertebrectomies for spinal metastasis removing, anterior spinal approaches or transforaminal approach for performing an arthrodesis, surgical approaches for deformity spinal surgery (scoliosis) or herniated disc surgery in thoracolumbar spinal surgery (T7-L4).

The anterior spinal artery is only one component of an extensive paraspinous and intraspinal collateral vascular network. Spinal cord ischemia is rarely reported after segmental vessel ligation. Spinal surgery approaches may be complicated by spinal cord ischemia. The rate of neurological complications in spinal surgery is respectively for spinal tumor removing (around 1%), deformity spinal surgery (0.75% to 1.8%), and degenerative anterior approach (0.75% to 5.8%) or degenerative posterior approach (0.3% to 1.3%)

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