THE SPINE SCHOLAR VOLUME 1, NUMBER 2, 2017
SEATTLE SCIENCE FOUNDATION

REVIEW

Collateral Circulation of the Spinal Cord: A Review

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http:thespinescholar.com
https:doi.org/10.26632/ss.8.2017.1.2

Key Words: Adamkiewicz, anterior segmental medullary artery, intraspinous and paraspinous networks, anterior spinal artery, posterior spinal artery

ABSTRACT

Transabdominal aortic aneurysm repair and thoracic endovascular aortic repairs are associated with a high rate of spinal cord ischemia. Although the chance of this complication is rare, it is important to still recognize and address this problem as it is life changing. One of the ways to prevent this complication is to recognize and understand the arterial collateral circulation of the spinal cord. Herein, we review salient literature regarding the collateral blood supply to the spinal cord using standard search engines. Spine Scholar 1:90-92, 2017

INTRODUCTION

Infarction of the spinal cord is infrequent due to extensive collateral circulation (Fig. 1). Studies have found that of all central nervous system infarctions, the spine represents only 1% (Raz et al., 2006). Previous reports (Aydin, 2015) found the incidence of spinal cord ischemia during abdominal aortic surgery to range between 0.1-0.2% and to be most commonly due to anterior spinal artery hypoperfusion. Reports by Matsutani et al. (2013) revealed that common causes of spinal cord infarction are thoracic aorta surgery, aortic cross-clamping, and any disruption of the segmental spinal arteries. When the segmental arteries are sacrificed, it has been proposed that collateral circulation will take over to continue the perfusion of the spinal cord.

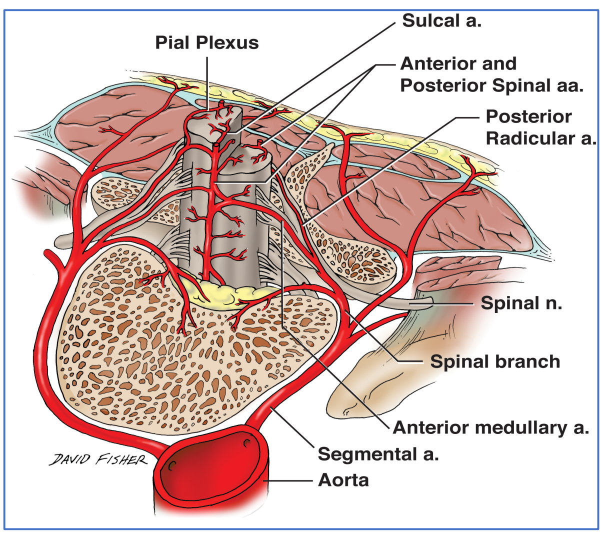

Figure 1: Schematic drawing illustrating the collateral circulation supplying the anterior spinal cord from segmental arteries and the anterior and posterior spinal arteries derived from the vertebral arteries

Uezu et al. (2003) demonstrated that when the segmental arteries were ligated in porcine models, the preserved ones would dilate allowing for continued perfusion. Methods suggested for preventing spinal cord injury during transabdominal aortic aneurysm repair (TAAA) are reconstruction of the segmental arteries, hypothermia, monitoring somatosensory evoked potentials, epidural cooling, steroids, barbiturates, maintenance of mean systolic pressure, segmental clamping of the aorta, reimplantation of the intercostal arteries, and preservation of the artery of Adamkiewicz (AKA) (Takayama et al., 2015; Fukui et al., 2016). One of the most important ways to prevent infarction to the spinal cord is to maintain blood flow to the AKA (Takayama, 2015). Prevention of damage to the segmental arteries during thoracic endovascular aortic repairs (TEVAR) for TAAA is imperative but sometimes futile. To further prevent complications, it is extremely important to understand the degree of collateral circulation, which becomes available after the loss of these segmental arteries (Shijo, 2011). To evaluate and prevent these complications following TEVAR and TAAA, we will review the anatomy of spinal cord circulation and discuss the collaterals that become available after injury to the segmental arteries. A review was conducted using PubMed, Google Scholar, and Google Books on all the collateral arteries supplying the spinal cord. Only humans were evaluated unless there was a variation in animals of equivalence to prove its ability to provide collateral circulation. Publications were excluded if not in English. There were no restrictions on the date of the publication reviewed. Inclusion criteria required that the artery must be a proven collateral of the spinal cord.

Normal Spinal Cord Vascular Anatomy - Overview

The majority of the spinal segmental arteries come from the subclavian artery in the cervical region, segmental medullary branches in the thoracic region, AKA of the lumbar region, and finally the lateral sacral and iliolumbar arteries of the sacral region to the spinal cord. These segmental arteries give off both anterior and posterior radicular branches, which will supply the spinal cord and eventually feed into the single anterior spinal artery and duel posterior spinal arteries respectively. The major direct supply to the anterior spinal artery is the segmental medullary artery from the posterior intercostal arteries. Cervical reinforcement of the anterior spinal artery also comes from the vertebral artery, ascending cervical artery, and inferior thyroid artery (Quiring, 1949). Similar branches also supply the posterior spinal arteries as the anterior spinal artery. Inside the spinal cord, the anterior and posterior spinal arteries anastomose and thus form a collateral blood supply (Quiring, 1949).

Intraspinous and Paraspinous Networks

In cases where the intraspinal cord collaterals are not able to fully compensate, preservation of these arteries is key to maintaining the function of the spinal cord as well as preventing paralysis (Takayama et al., 2015). It is these collaterals from the intraspinous and paraspinous networks that are imperative to maintaining systolic blood flow during TAAA and TEVAR surgeries. The paraspinous vessels feed the erector spinae, iliopsoas, and other adjacent muscles with a mean diameter of 134 ± 20 μm. Two paraspinal compartments and one intraspinal compartment that feed the arteries of the spinal cord have been described (Meffert et al., 2013). It has been proposed by Meffert et al. (2013) that the paraspinal network is the main source of blood supply to the spinal cord in the long-term after TAAA or TEVAR due to their dilation, increase in length of the preexisting arterioles, as well as their realignment into a parallel orientation. The thoracic spinal arteries as well as the lumbar segmental arteries supply both the paraspinous network and the anterior spinal artery. The paraspinous muscles that are extensively supplied by these vessels contribute to the collateral supply of the spinal cord during decreased blood supply (Takayama et al., 2015).

In a study of pigs with all the segmental arteries occluded, within 24 hours, the diameter of the anterior spinal artery increased significantly as well as the epidural arterial network. By five days, the intramuscular paraspinous vessels had also increased significantly. This intraspinal collateral circulation has also been seen giving significant circulation to the AKA (Domoto et al., 2016). It has been thought that these develop via the pial network, which will form a secondary anastomotic system between the anterior and posterolateral longitudinal vessels (Melissano et al., 2010; Domoto et al., 2016). It has also been proposed that these arteries are perarteriogenic natively nonconducting arterioles that take approximately one week to undergo complete arteriogenesis for collateral circulation to the segmental vessels (Etz et al., 2011). It is recommended that Near-Infared Spectroscopy be used to image these vessels as it is a valuable strategy for noninvasive real time monitoring (Luehr et al., 2015). It has even been recommended that selective segmental artery endovascular coil embolization be undertook before surgical procedures to allow for arteriogenic preconditioning of the paraspinal arterial collateral network (Etz et al., 2015).

Immediate reperfusion is achieved by the intraspinal circulation. These include the epidural arcades which connect indirectly with the anterior spinal artery as well as the anterior radiculomedullary arteries which were described previously as branching from the segmental arteries and anastomosing to the anterior spinal artery. However, due to its small diameter, collateral flow through the anterior spinal artery may be unable to compensate for critical hypoperfusion with bilateral vertebral artery stenosis/occlusion (Fukuda et al., 2015)
The circular arteries or epidural arcades are also present on the back of each vertebral body and connect longitudinally and laterally. Although they are present, the functional significance of these circular arteries is not well studied but is also presumed to be useful in the immediate reperfusion of the cord (Meffert et al., 2013; Kari, 2015). “Hexagonal connections” proposed by Meffert et al. (2013) will help keep the cord perfused during infraction however, due to their low resistance, they can also worsen the ischemia by stealing their perfusion supply. It is proposed that ligation of the spinal artery prior to the TAAA can help prevent this “stealing.” The final highly variable part of the spinal arterial collateral network is the anterior radiculomedullary arteries (Meffert et al., 2013). These arteries are significant in that the distance between the inflow and the next anterior radiculomedullary artery correlate to the risk of spinal cord ischemia in patients with aortic aneurysms (Meffert et al., 2013; Kari, 2015).

The Artery of Adamkiewicz

The AKA most frequently arises from the left side of the patient (81%) and most frequently between T8 and L1 with the highest frequency of collateral segmental arteries at T10. A small percentage of patients will have segmental arteries that will be found one or two levels above and below the AKA preoperatively (Fukuda et al., 2015). Branches of the left subscapular and left external iliac arteries were also commonly seen to feed the AKA (Fukuda et al., 2015). Arteries supplying the spinal cord that arise at the level of the first or second lumbar artery pass through an osteotendinous passageway between the vertebral body and the diaphragmatic crus. This passage can compromise the arterial supply to the spinal cord (Thron 2016). Iliac branches to the lower spinal cord (conus) are referred to as the arteries of Desproges-Gotteron (Tubbs et al., 2011). Occlusion of the internal iliac and subclavian arteries have been shown to negatively affect the recovery time after TEVAR as anastomoses between the paraspinal vessels is at the subclavian cranially and iliac arteries caudally (Griepp, 2012). Those whose arteries were preserved had a decreased chance of paralysis while occlusion during or after surgery led to severe side effects. Further proof of the importance of critical segmental arteries comes from a study in which patients who had identified and preserved them before and during surgery for thoracic aortic repair had a drastically reduced chance of developing paralysis (Griepp et al., 2007). In patients where these critical segmental arteries were occluded, they received collateral circulation from the left and right lateral thoracic arteries, left pericardiacophrenic artery, left first lumbar artery, and right internal thoracic artery. Other collateral branches to the AKA have been discovered arising from the proximal intercostal, lumbar, thoracodorsal, and internal thoracic arteries (Melissano et al., 2010).

CONCLUSION

The spinal cord usually has sufficient collateral circulation which allows for protection during procedures such as TAAA and TEVAR. The primary blood supply to the spinal cord is the AKA, anterior segmental medullary branches, and the anastomoses inside the spinal cord between the anterior and posterior spinal arteries. Therefore, these branches must be protected during invasive procedures in order to minimize the chance of paralysis or sensory loss.

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The authors report no conflict of interest concerning the material or methods used in the findings specified in this paper.

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