Intraoperative electrophysiologic monitoring in thoracoabdominal aortic aneurysm surgery

Present by Hung Nguyen, MD, CNIM

Disclosure

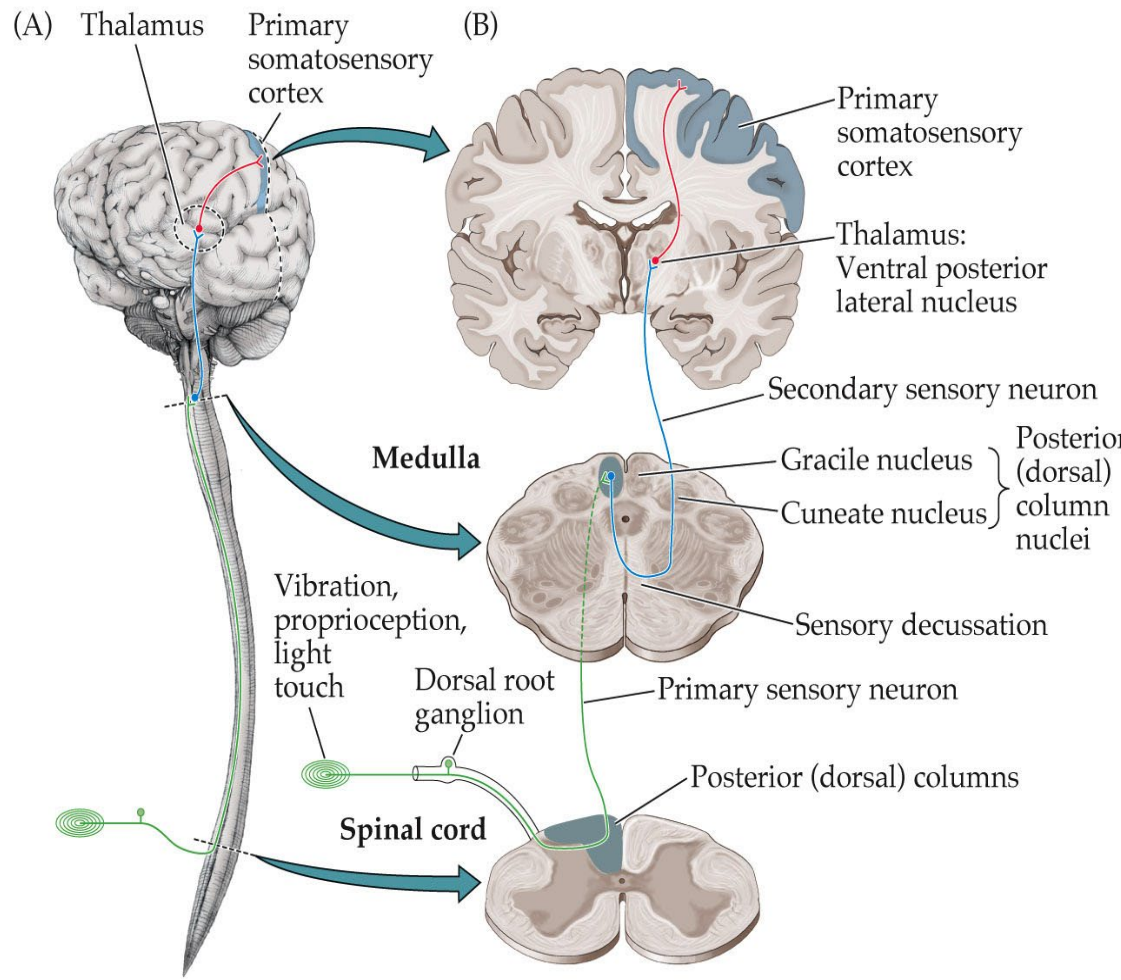
- None

Introduction

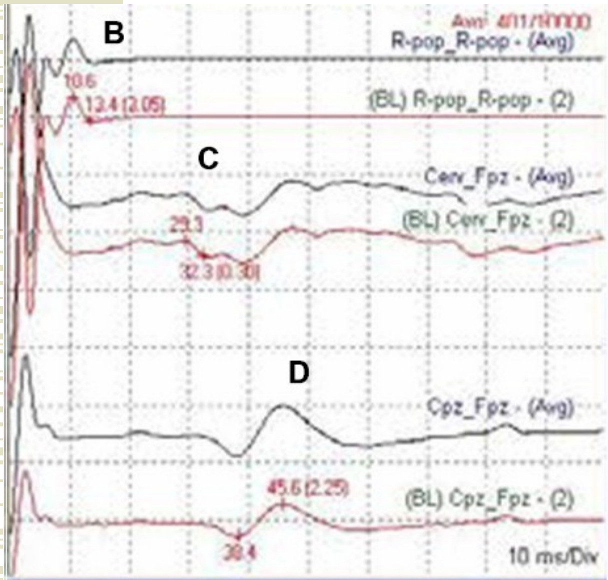
- Immediate or delayed paraplegia or paraparesis remain complications.
- Intraoperative spinal cord monitoring with SomatoSensory Evoked Potentials (SSEPs) and Motor Evoked Potentials (MEPs) will give Anesthesiologist and Surgeons an estimate of spinal cord perfusion, implement aggressive intervention before treatable spinal cord injury evolves into irreversible neuronal ischemia.
- Reperfusion injury, apoptosis or new postoperative spinal ischemic events may still lead to delayed paraplegia.

Ascending Somatic sensory pathway
Posterior columns white matter of spinal cord
Posterior spinal arteries

Axons of somatic sensory ascending tract travel through the dorsal column white matter of the spinal cord

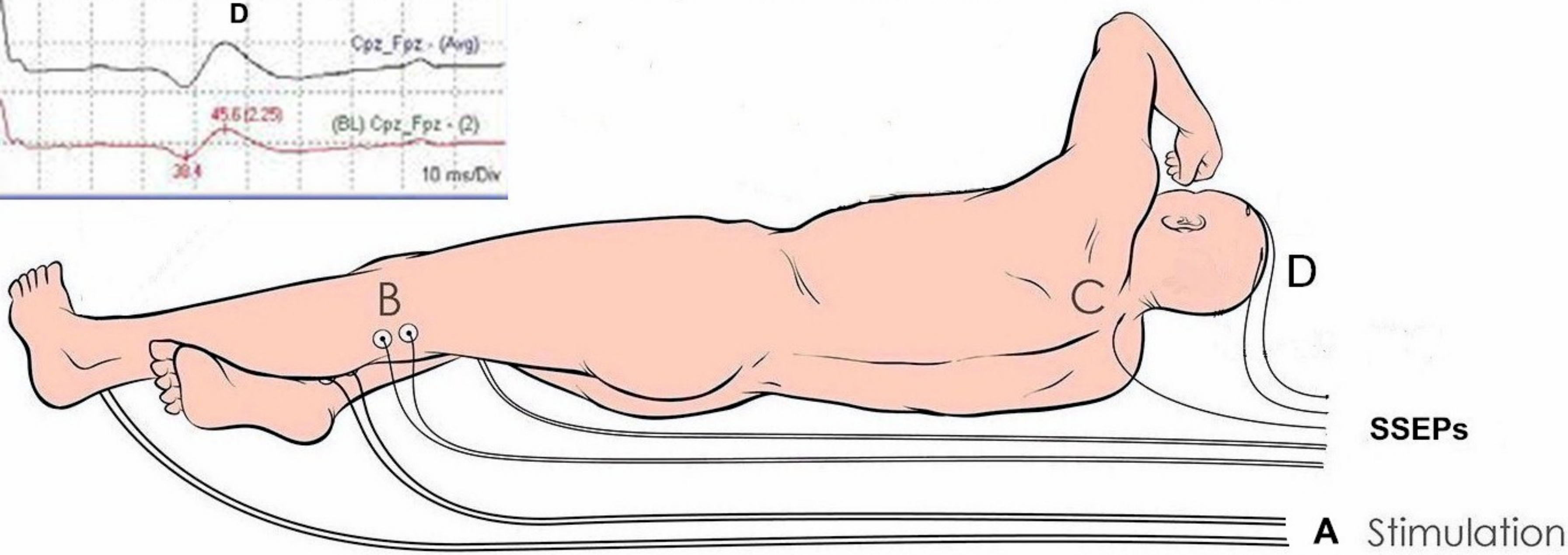


SSEPs
SomatoSensory Evoked Potentials



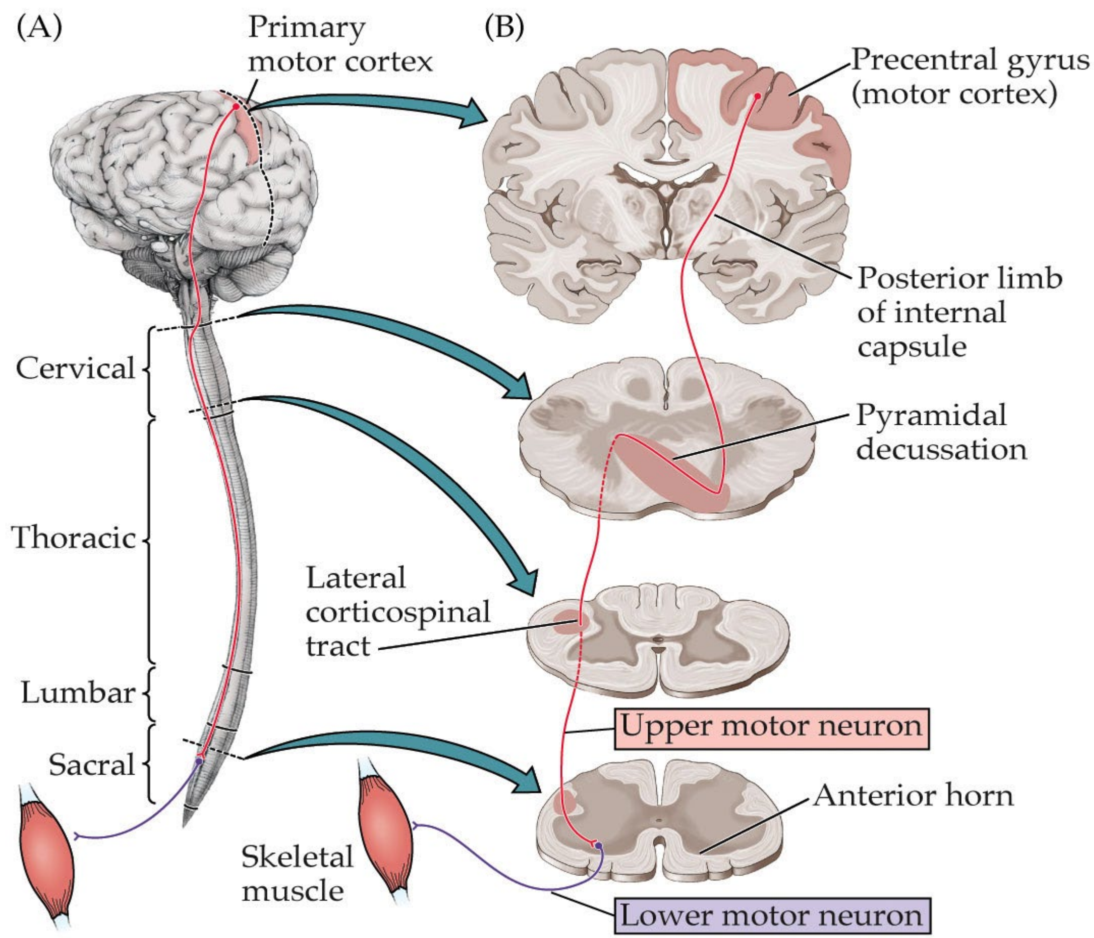
Evaluate the integrity of the somatosensory pathways
Provides information about Lower extremities and Dorsal column of spinal cord perfusion
Recording obtained from

- B - popliteal fossa (Pop)
- C- Cervical spine (Cerv)
- D- Cortical (Cpz)
- A- following stimulation of the PosteriorTibial nerve.

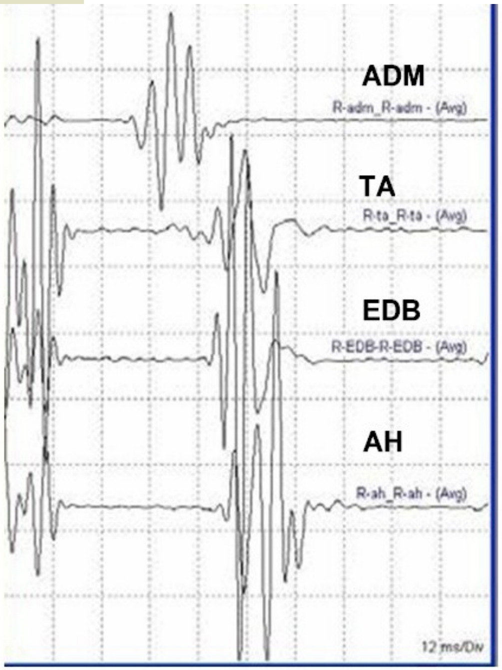


Descending motor pathway
Anterior lateral white mater , Anterior horn gray matter of spinal cord
Anterior spinal artery

Axons of the upper motor neuron corticospinal tract travel through the anterior lateral white matter and synapse with lower motor neuron in the anterior horn gray matter of the spinal cord

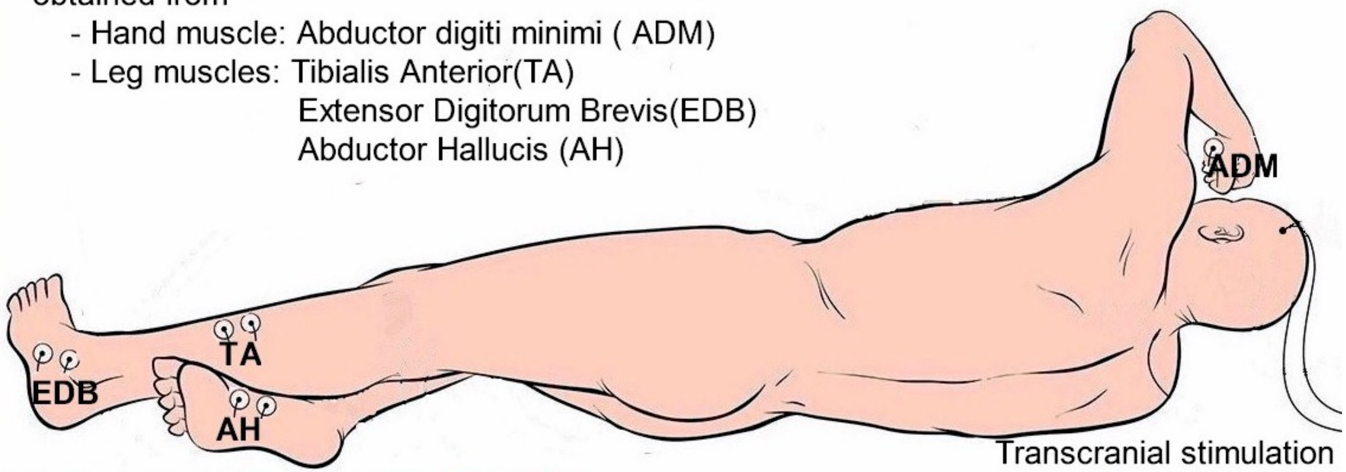


TcMEPs
Transcranial Motor Evoked Potentials



Evaluate the integrity of the motor pathways
Provides information about Grey matter and ventral white matter of spinal cord and extremities perfusion
CMAPs (Compound Muscles Action Potentials) Recording obtained from

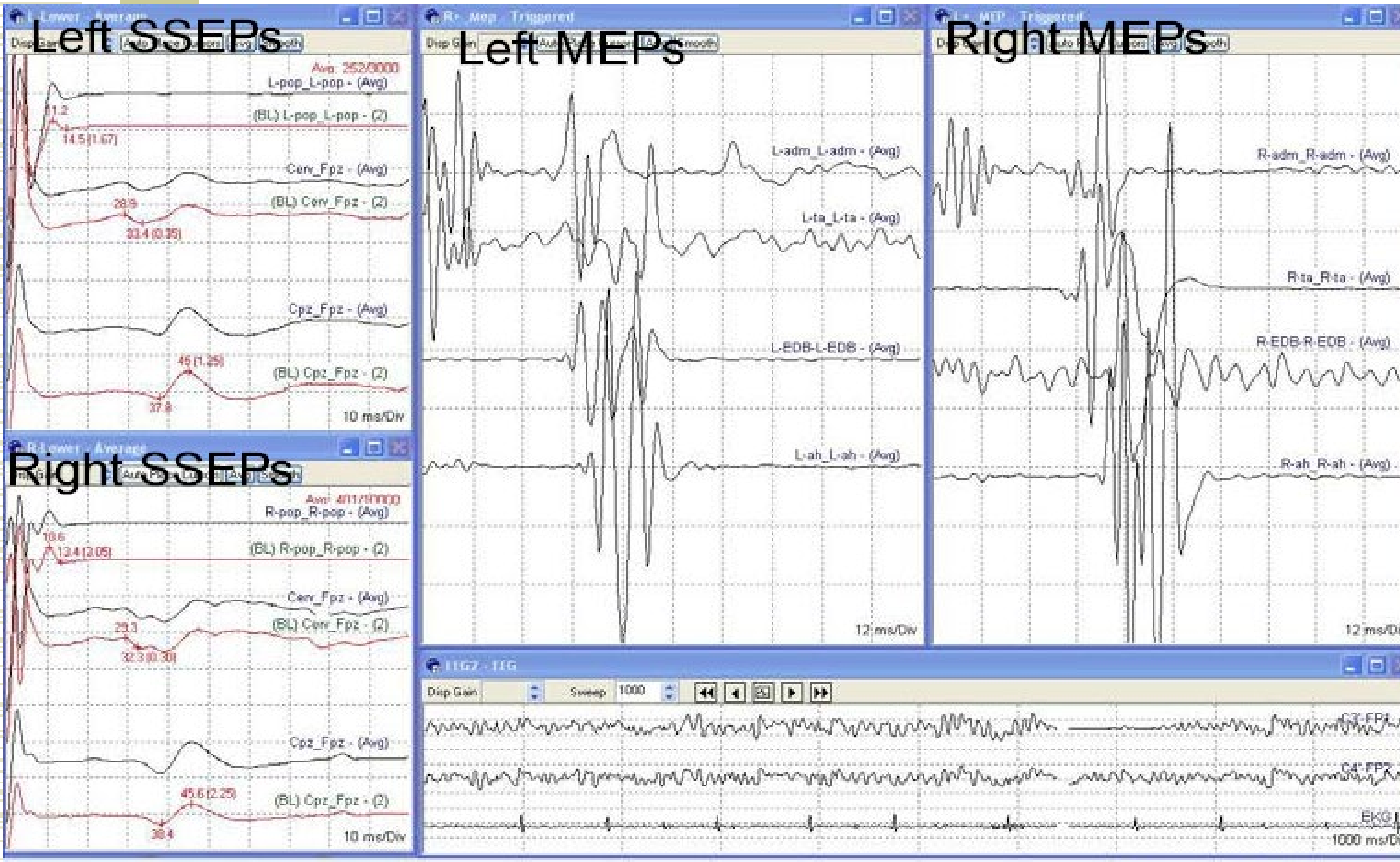
- Hand muscle: Abductor digiti minimi (ADM)
- Leg muscles: Tibialis Anterior(TA)
  Extensor Digitorum Brevis(EDB)
  Abductor Hallucis (AH)



Transcranial stimulation

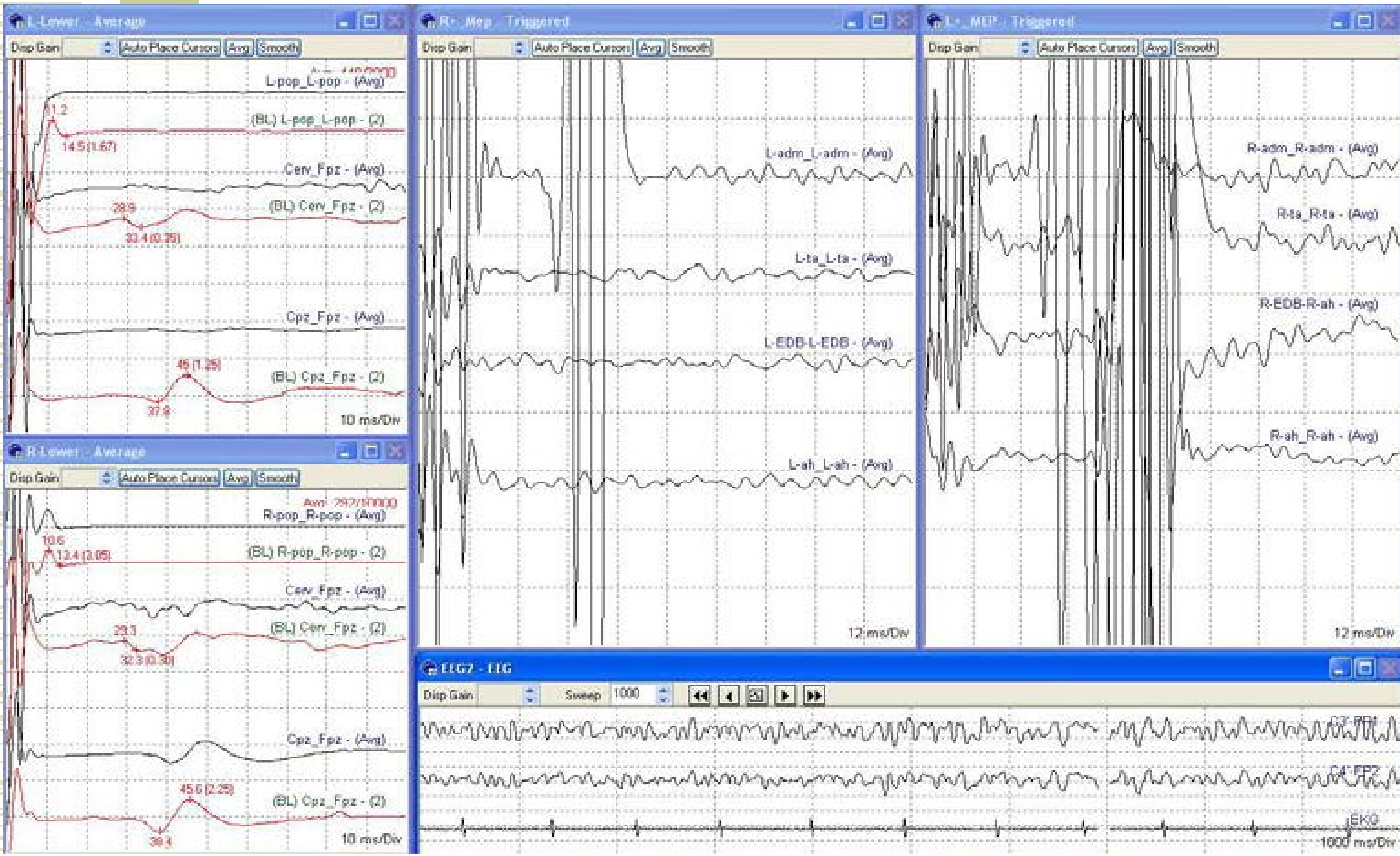
SPINAL CORD ISCHEMIA

- Early detection of spinal cord ischemia is important as it permits early intervention before ischemia evolves into irreversible neuronal ischemia..
- Decreased amplitude and increase latency of Evoked Potentials has proved to neuronal tissue ischemia.
- FP, FN, The Sensitivity, Specificity, Negative predictive value and Positive predictive value of SSEPs and MEPs! …

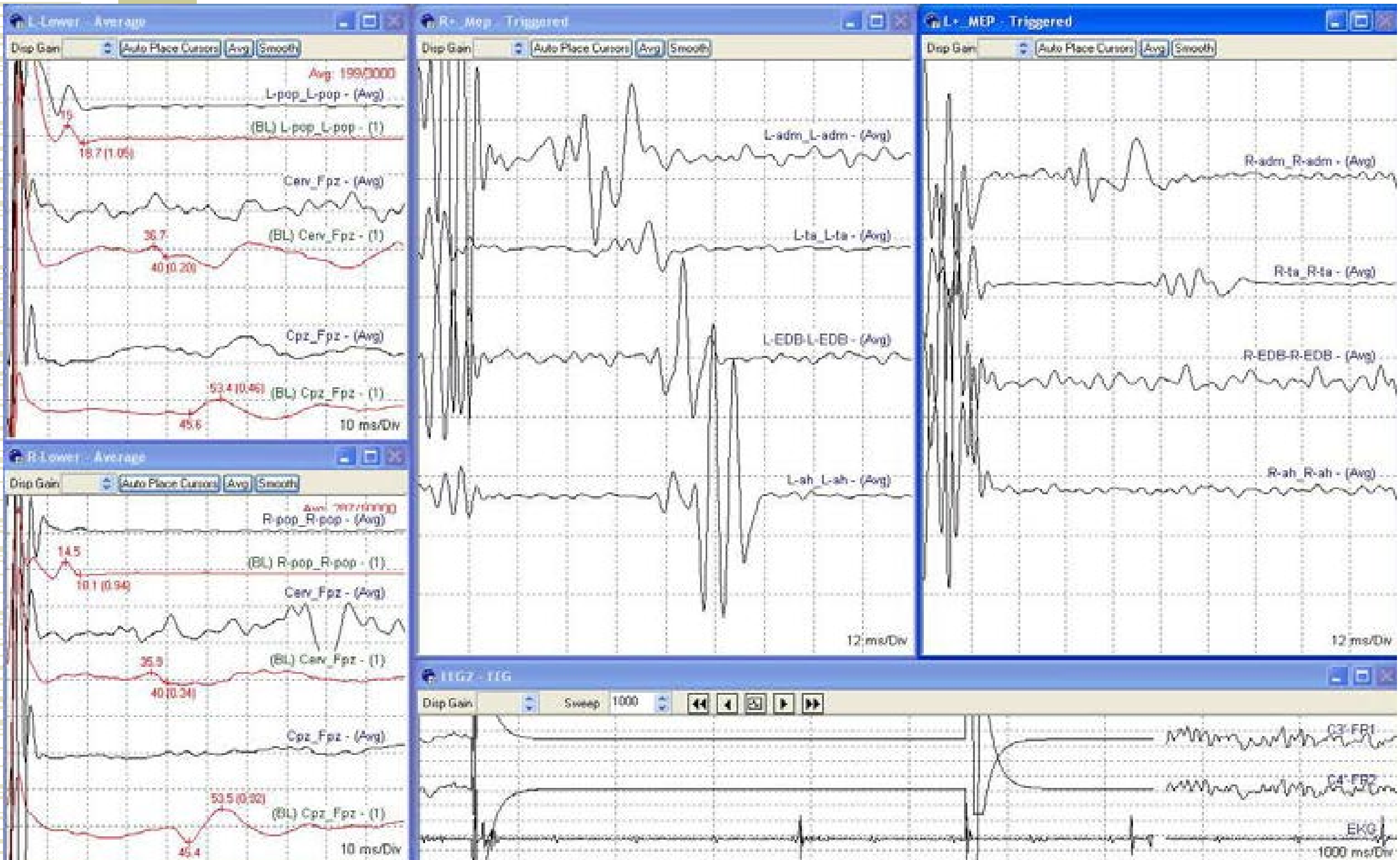


Left SSEPs
Left MEPs
Right MEPs
Right SSEPs
L-pop_L-pop - (Avg)
(BL) L-pop_L-pop - (2)
Cerv_Fpz - (Avg)
(BL) Cerv_Fpz - (2)
Cpz_Fpz - (Avg)
(BL) Cpz_Fpz - (2)
10 ms/Div
R-pop_R-pop - (Avg)
(BL) R-pop_R-pop - (2)
L-adm_L-adm - (Avg)
L-ta_L-ta - (Avg)
L-EDB-L-EDB - (Avg)
L-ah_L-ah - (Avg)
12 ms/Div
R-adm_R-adm - (Avg)
R-ta_R-ta - (Avg)
R-EDB-R-EDB - (Avg)
R-ah_R-ah - (Avg)
Disp Gain
Sweep
1000
EKG
1000 ms/Div

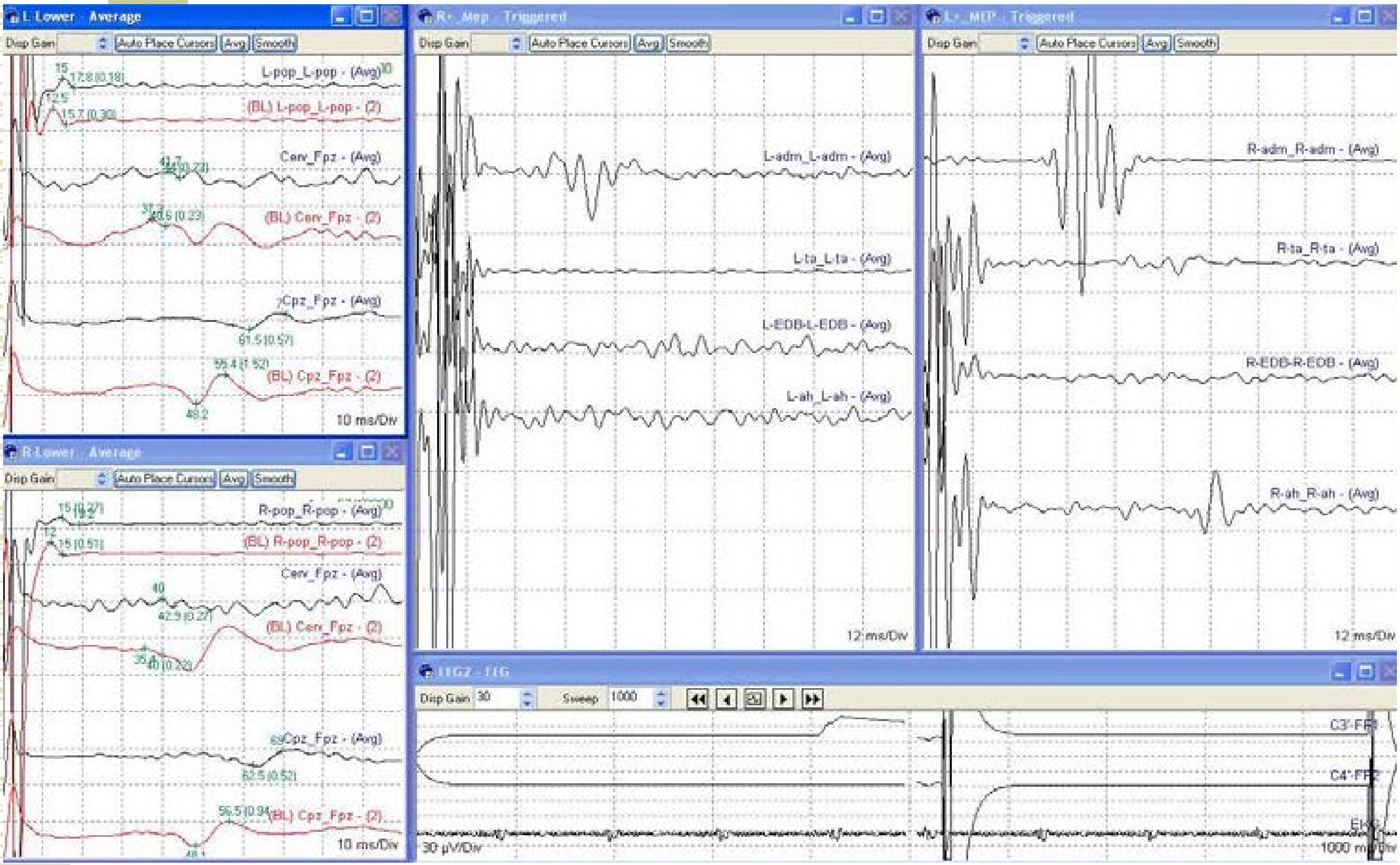
Left leg ischemia



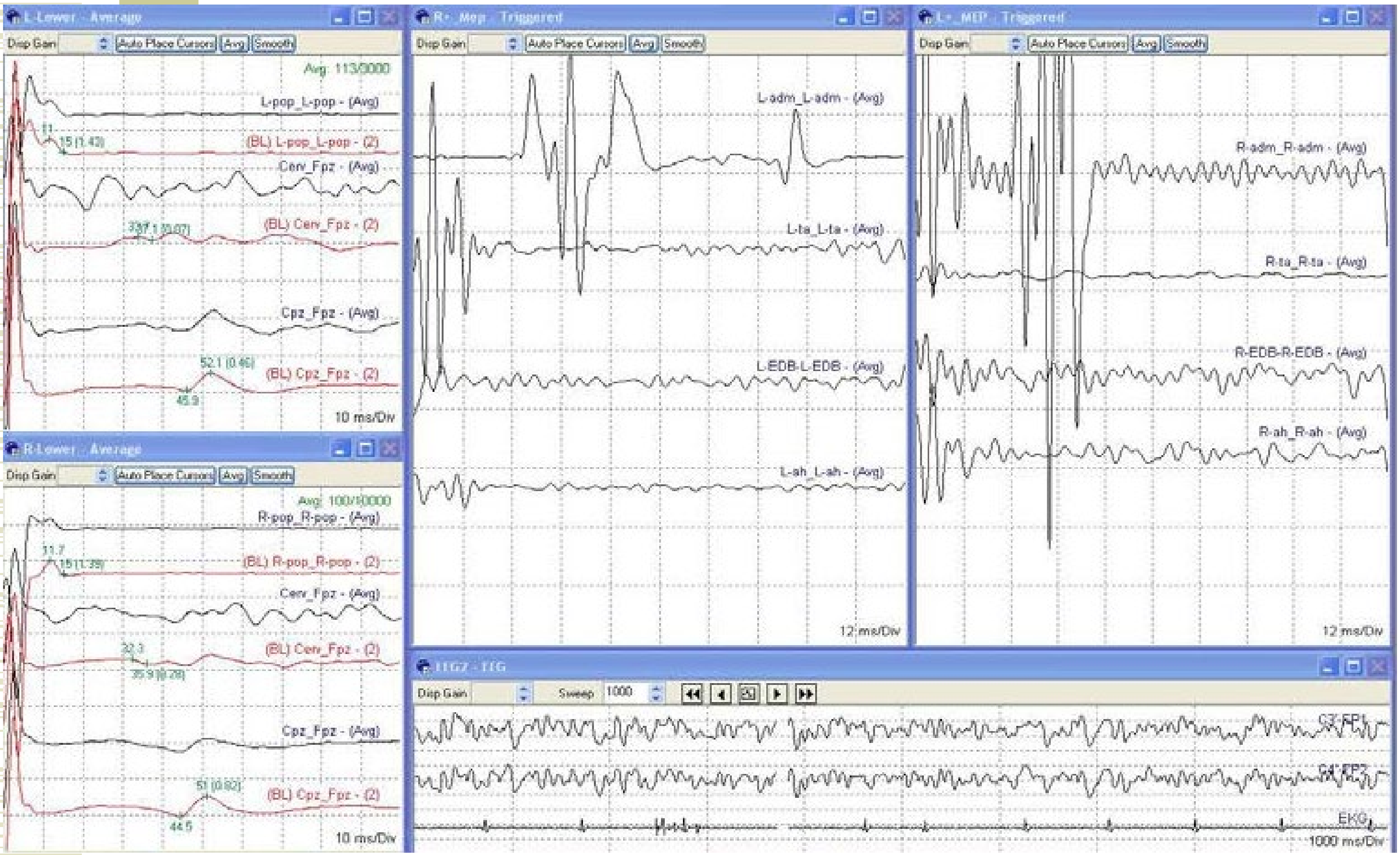
Right Leg ischemia



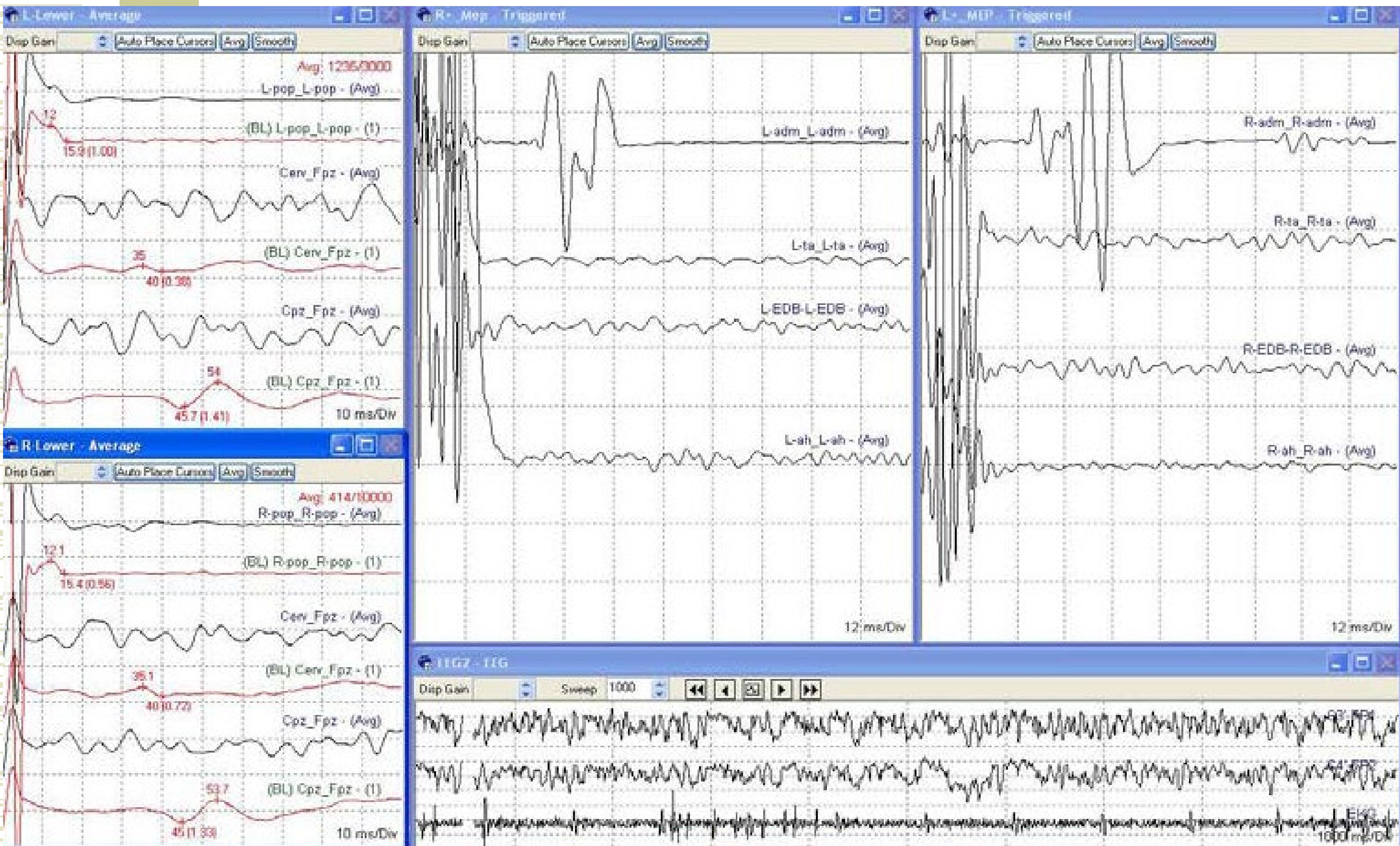
Peripheral ischemia, Spinal cord ischemia



Anterior spinal ischemia



Anterior and Posterior Spinal ischemia:



Time of loss response to complete ischemia

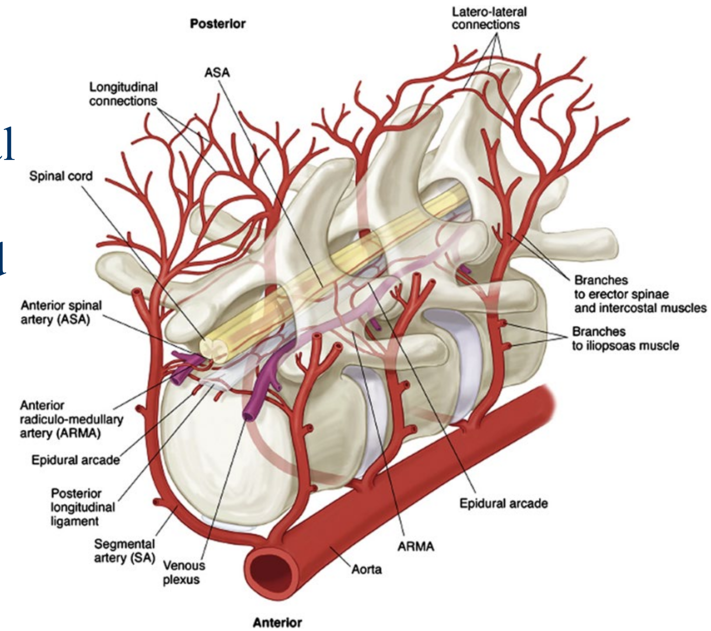
- Cortex: 20-30 seconds (EEG)
- Spinal cord sensory white matter: 7-17 minutes (SSEP)
- Spinal cord motor white matter : 5-17 minutes (MEP)
- Spinal cord gray matter : 2-3 minutes (MEP)
- Peripheral nerve (Limb ischemia): 20-25 minutes (SSEP-MEP)

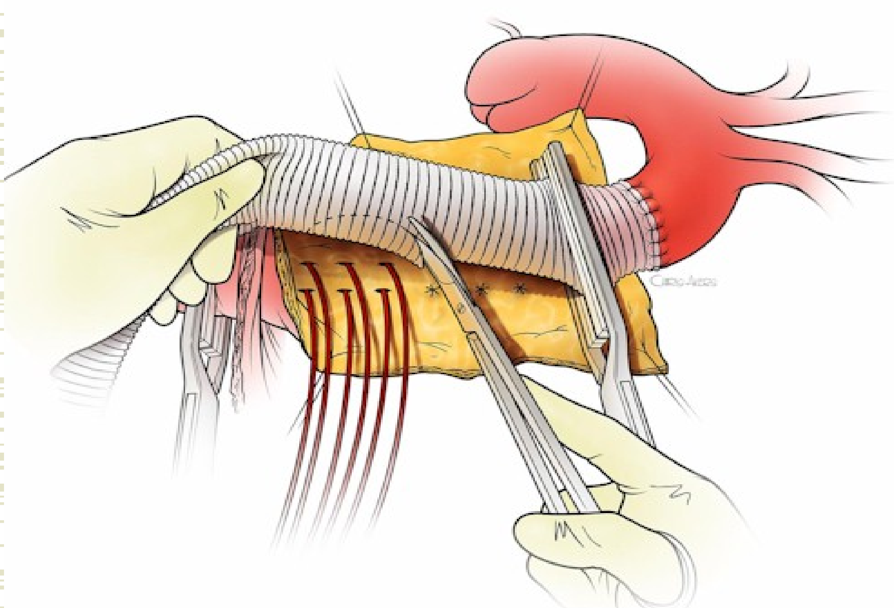
Anatomy and Physiology of spinal cord circulation

- A better understanding of anatomy and physiology of the spinal cord circulation have in recent years led to a reduction risk of postoperative spinal cord ischemia.
- The extensive network of extra- and intraspinal anastomoses protects the spinal cord against ischemia due to segmental arterial occlusion
- The extensive collateral network and The arterial basket of the conus medullaris allow compensatory flow to the spinal cord when some of the direct inputs to the ASA are compromised during Aortic cross-clamping.

Vascular of the spine and spinal cord

- 31 pairs segmental arteries and their anastomoses: Supply to the spinal column, paraspinal muscles, dura, nerve roots and spinal cord.
- Anastomose extensively across the midline and between levels above and below
- Extraspinal longitudinal system connects the neighboring segmental arteries longitudinally
- Intraspinal extradural system has transverse anastomosis and longitudial interconnections
- Retrocorporeal and prelaminar arteries interconnect with neighboring and contralateral segmental arteries, provide an excellent collateral circulation.
- The extensive network of extra- and intraspinal anastomoses protects the spinal cord against ischemia due to segmental arterial occlusion





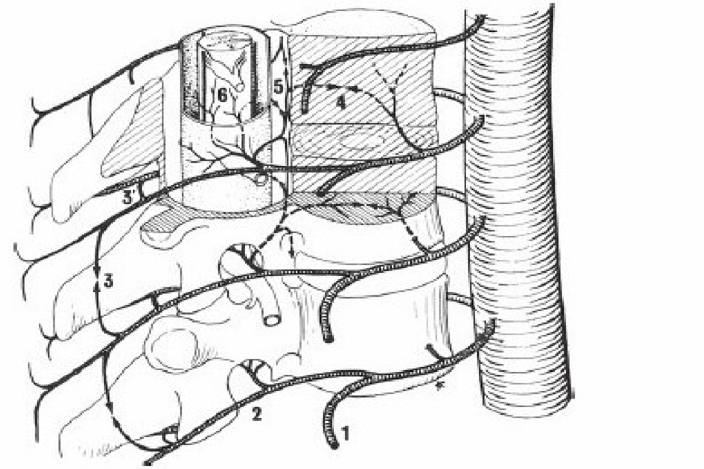
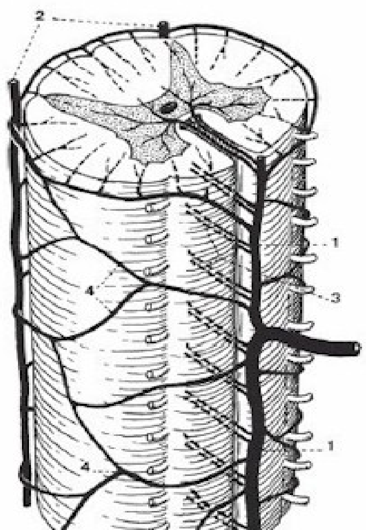


FIG. 7. Diagram showing anastomoses of the dorsal branches of the spinal artery. 1 = intercostal artery; 2 = dorsal branches of spinal artery; 3 and 3′ = posterior anastomosis; 4 = vertebral anastomosis; 5 = retrovertebral anastomosis; 6 = perimedullar anastomosis.

FIG. 3. Drawing showing the systems of the central and peripheral arteries. 1 = anterior spinal pathway; 2 = posterior spinal pathways; 3 = pathway from the central arteries or the anterior median sulcus; 4 = peripheral arteries.



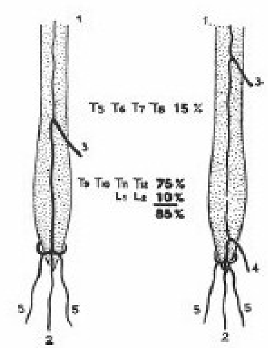


FIG. 2. Drawing showing the artery of the lumbar enlargement and its variations. 1 = superior end of the artery; 2 = inferior end of the artery; 3 and 5 = anastomotic loop of the *conus medullaris;* 4 = small arteries of the sacral spinal cord. Percentages refer to the occurrence of the artery of lumbar enlargement with specific spinal nerves in the vertebral canal.

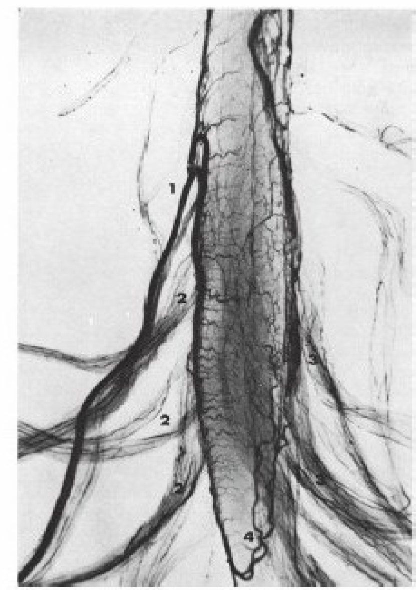


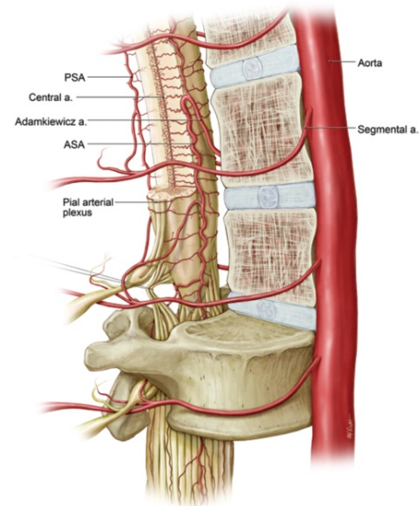
FIG. 9. Radiogram, lateral view, showing the lumbar enlargement of the human spinal cord. Note, on the left, the pathway of the anterior spinal artery and the anterior branches of the lumbar enlargement (1) and the spinal artery (2) from the roots of the cauda equina. Note, on the right, the pathway of the posterior spinal artery and its posterior branches (3) from the roots of the cauda equina. Note also, on the bottom, the anastomotic loop of the *conus medullaris* (4).

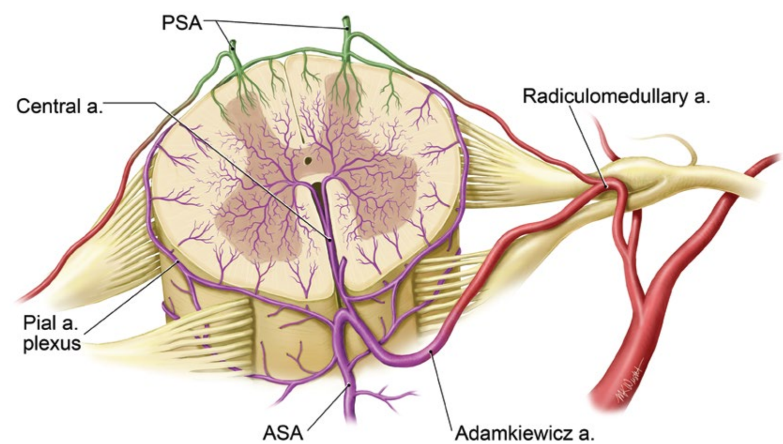
Vascular of the spine and spinal cord

Arteries of the spinal cord:

- The intrinsic arteries: Central and peripheral system
- The ASA supplies two-thirds of the ventral of the spinal cord

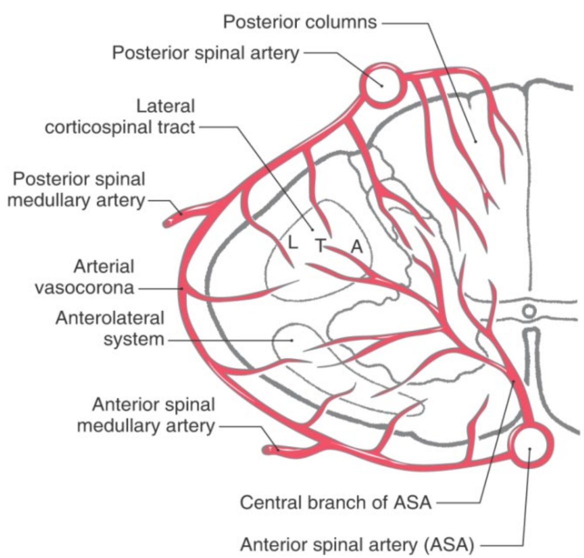
  The anterior gray matter, anterior portion of the posterior gray matter and inner half of the anterior and laterial white matter (Descending motor tract)
- The pairs of PSAs and pial arterial plexus supplies the outer portion of the anterior and lateral white matter and the posterior portion of the posterior gray matter and dorsal columns white matter.
- Their terminal branches overlap, because blood flows away from the center in the central system and toward the center in the peripheral system, their relationship is not truly compensatory





Vascular of the spine and spinal cord

- Capillaries :The density of the capillary bed is 5 times greater in gray matter than in white matter
- The capillaries beds in white matter stretching longitudinally in the direction of the axon fibers
- Within the gray matter, the density of the beds depends on the location of the neuron cell bodies. This arrangement reflects the greater metabolic requirements of the cell bodies compared with axons



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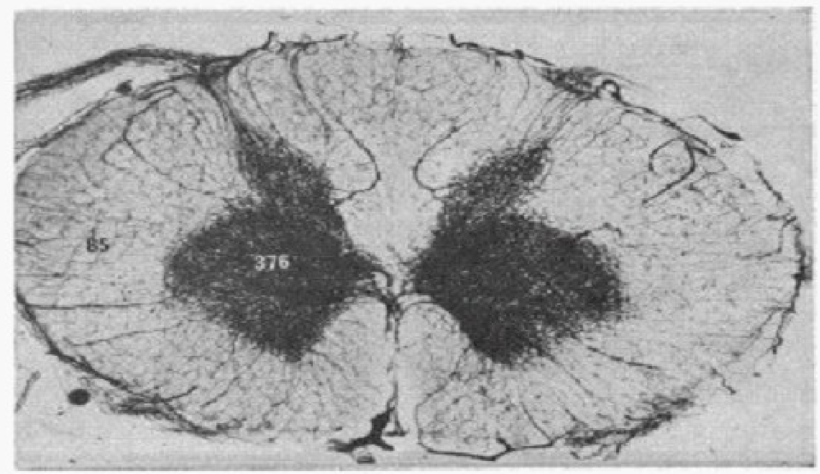


FIG. 2 *Capillary density of the spinal cord of a baboon (dorsal above, ventral below). The average number of capillaries per square millimetre in the grey and the white matter is indicated in figures. The blood flow in the grey matter is approximately 15 times greater than in the white matter, in response to metabolic demands. Because of the metabolic demands the intraneural plexus of small vessels compels 'absolute protection and preservation' (Dommisse (11)) section approximately 500 nm, prepared by the Spalteholz technique for clearing. (Reproduced by courtesy of Professor D P Knobel, Head, Department of Anatomy, University of Pretoria.)*

Watershed areas

- The watershed area, border-zone infarct occurs at the junction of two arteries territories and is precipitated by a hemodynamic impairment, although it cannot be excluded by specifically precipitating from micro-embolic etiology.
- 3 watershed zones.
- The first is along the longitudinal axis of the thoracic spinal cord between the arteries of the cervical and lumbar enlargements.

  At the union of a radiculomedullary artery and the ASA, the blood courses upward and downward from the entry point. Therefore, in the area of the ASA between neighboring radiculomedullary arteries, there is a dead point where blood flows in neither direction, that is, a watershed area.
- The second is over the anterolateral surface of the cord between circumferential pial branches of the anterior spinal artery and the posterior spinal arterial arcade.
- The third is along the gray/white junction between the intramedullary territories of the central arteries and the pial plexus. There is overlap between the pial plexus and central arteries, which produces a watershed zone

THE BLOOD SUPPLY OF THE HUMAN SPINAL CORD

BY

B. BOLTON

From the Research Unit and Pathological Department, National Hospital, Queen Square, London

(RECEIVED 6TH MARCH, 1939)

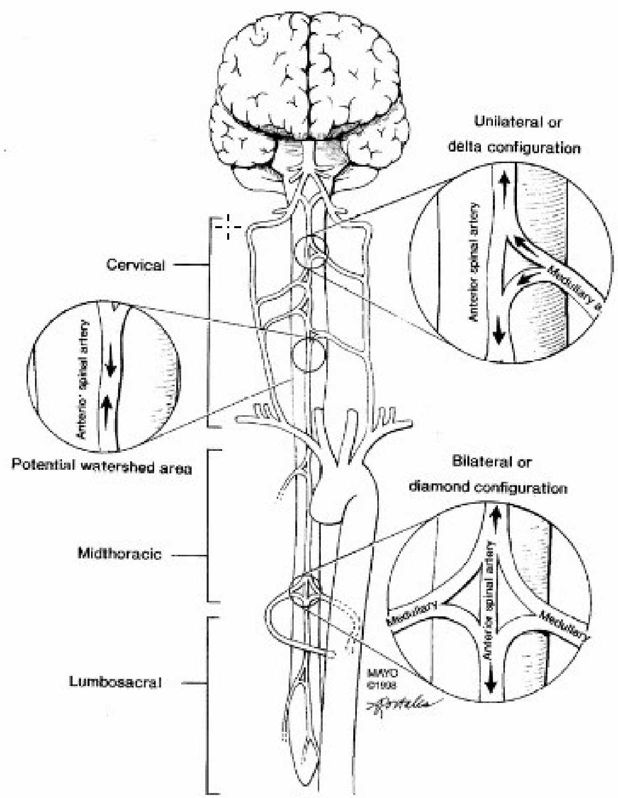
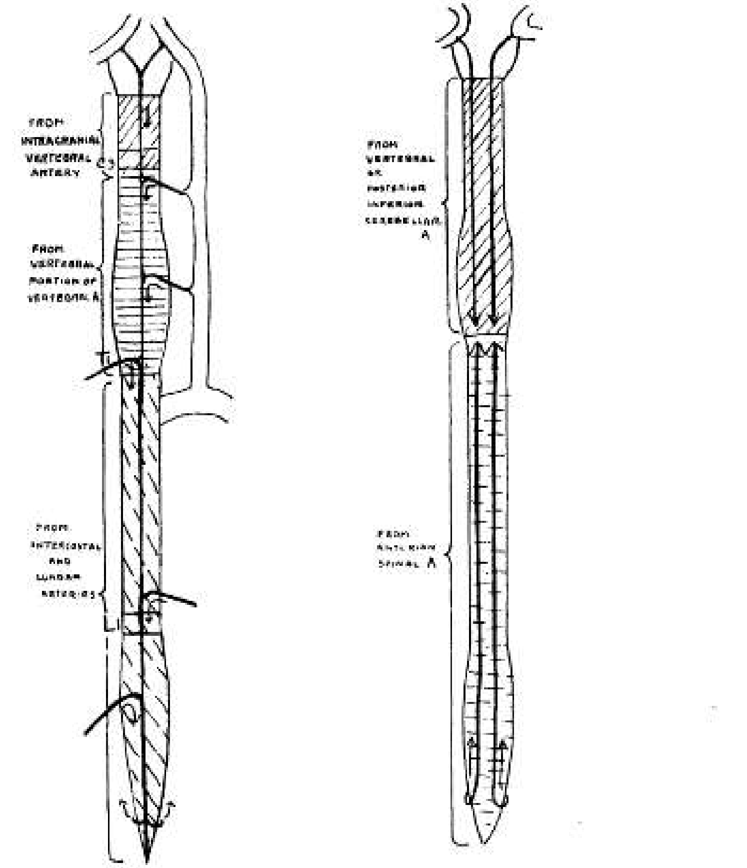


Figure 2. The unique configuration of the anterior spinal artery–medullary artery anastomosis. In addition, an area where flows meet from two adjacent anterior medullary arteries is illustrated. This is an area at potential risk for ischemia.



Anterior Posterior

Schematic drawing of cord showing source of supply and direction of flow of arterial blood in the spinal cord.

Blood flow currents in spinal cord arteries

Giovanni Di Chiro, M.D., and Larry C. Fried, M.D.

THE INTRODUCTION of selective technique[1] has established spinal cord angiography as a reliable diagnostic tool for the study of the spinal cord vessels and blood flow therein.

Very early in our clinicoradiological experience dealing with the angiographic aspects of spinal cord vascular disease, we were confronted with the problem of the direction of the blood flow in the anterior spinal artery. The concept of descending and ascending blood flow currents in the anterior spinal artery—what we refer to as the anterior spinal arterial axis—has been controversial. On the basis of anatomical observations in man and anatomical and experimental injection studies in animals, two conflicting theories have been advanced. A group of authors—Kadyi,[2] Bolton,[3] Mettler,[4] Mitchell,[5] and Kiloh[6]—sustains the theory of a blood flow current from above downward. On the basis of our angiographic observations, we are in agreement with the investigators—Adamkiewicz,[7,8] Suh and Alexander,[9] Woollam and Millen,[10] Coimbra,[11] Knox-McCaulay et al.,[12] Corbin,[13] and Gooding[14]—supporting the other theory that the blood flow from two adjacent radicular arteries takes place in opposite (converging) directions. Hence, several "watersheds" can be found at points equidistant from the bifurcations of the radicular arteries.

Regarding the posterior spinal arteries, Bolton[3] and Zülch[15] have postulated, and on the basis of our angiographic experience we support this concept, that in the cervical area the blood flows from the posteroinferior cerebellar arteries downward. In the lower cord, on the other hand, the direction of flow in the posterior spinal arteries is upward. In fact, at the tip of the conus, the anterior spinal artery anastomoses via the "rami cruciantes" (Adamkiewicz) or the caudal anastomotic loop—"anse anastomatique du cône" of Lazorthes et al.[16,17]—with the posterior spinal arteries. Thus, the descending blood current in the inferior part of the anterior spinal artery changes direction, reaching dorsally to the lower posterior spinal arteries, where the direction of flow is upward (Fig. 1).

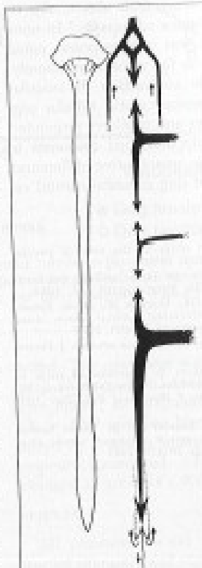


Fig. 1. Concept of blood flow direction in spinal cord arteries.

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Submitted for publication Jan. 25, 1971; accepted Feb. 3, 1971.

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Fig. 2. Contrast medium injected by selective arteriography into artery of Adamkiewicz (right arrow) flows in anterior spinal artery dividing into larger descending (lower left arrow) and thinner ascending currents (upper left arrow).

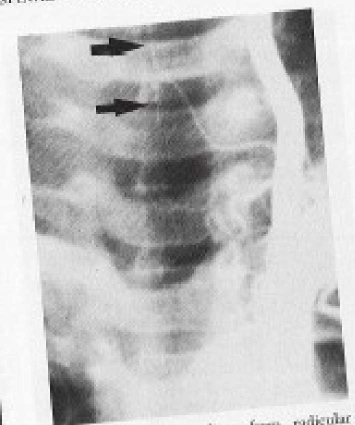


Fig. 3. Contrast medium from radicular branch of costocervical trunk divides into two diverging currents of equal size (arrows) in cervical segment of anterior spinal artery.

The importance of blood flow currents in the anterior and posterior spinal cord arteries is obvious, particularly if we keep in mind that these spinal arteries are, in fact, long—the longest in the entire body—anastomotic channels with multiple areas of diminished bulk flow (watersheds). The morphologic arrangement of these anastomotic arterial channels is such that one is logically led to consider the possibilities of compensatory flow reversals in pathological and perhaps even in some physiological situations. In experimental models, local changes in the spinal cord blood flow caused by compression have been demonstrated by Palleske and associates.[18] Tönnis,[19] in his monograph dealing with spinal cord injury, gives overwhelming pathogenetic importance to changes in blood flow. Virasami,[20] on the basis of postmortem investigations in man and in vivo experiments in rabbits, postulates that the direction of the blood flow might be considerably altered, not only in pathological conditions but also in different physiological situations, e.g., in changes in the posture of the

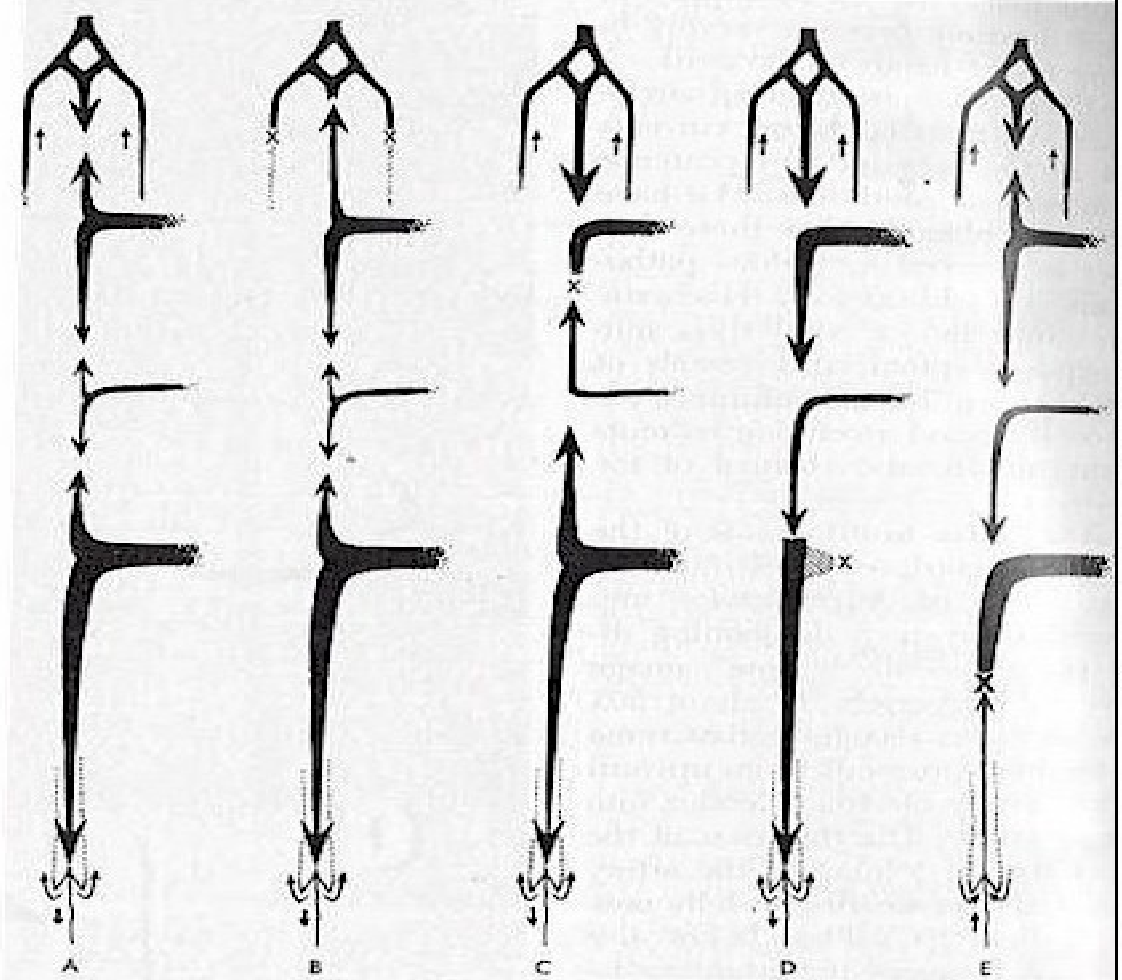


Fig. 7. Possible flow reversals in spinal cord arteries due to intrinsic or extrinsic obstructive vascular disease. [A] Normal; [B] obstruction of vertebral arteries; [C] obstruction of thoracic anterior spinal artery; [D] obstruction of artery of Adamkiewicz; and [E] obstruction of anterior spinal artery below artery of Adamkiewicz. X = site of obstruction.

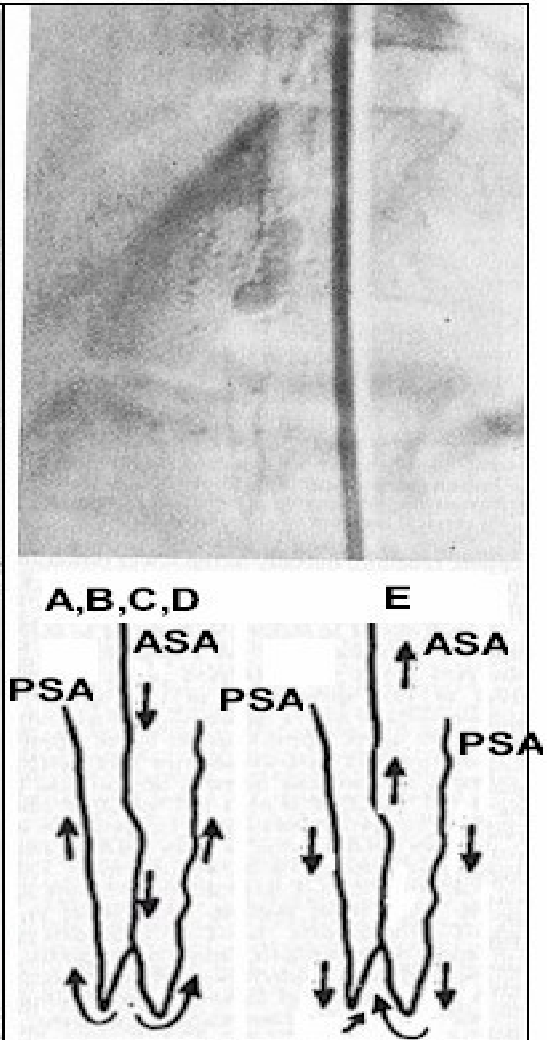


Fig. 4. [Top] Contrast medium flows down into lower anterior spinal artery to divide into rami cruciantes and reach posterolateral spinal arteries where flow direction is upward. [Bottom] Sketch of the direction of flow.

Direction blood flow of The ASA and anastomotic loop at the Conus

Giovanni Di Chiro , et al ; Neurology; Vol 21, 1971

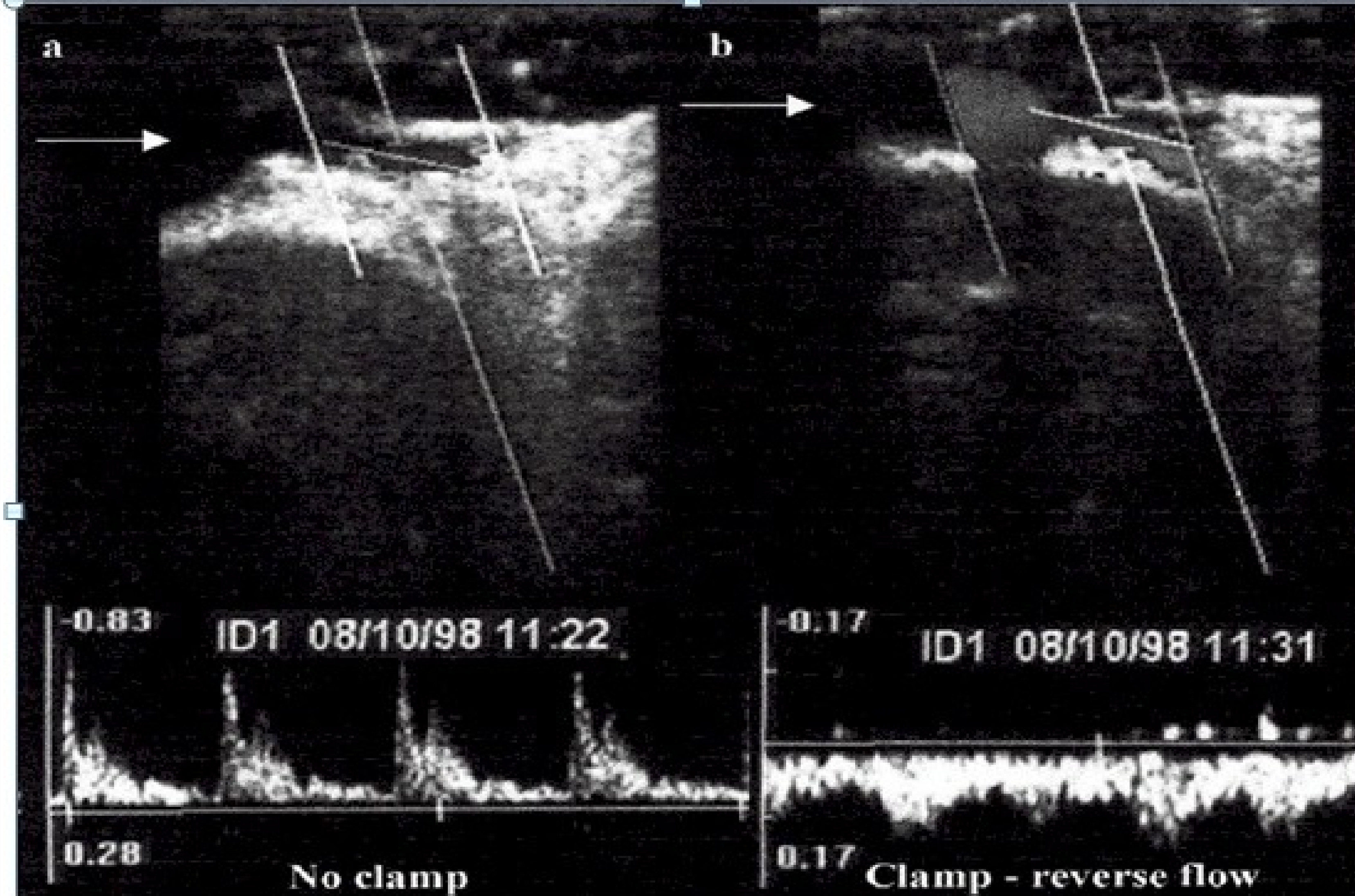
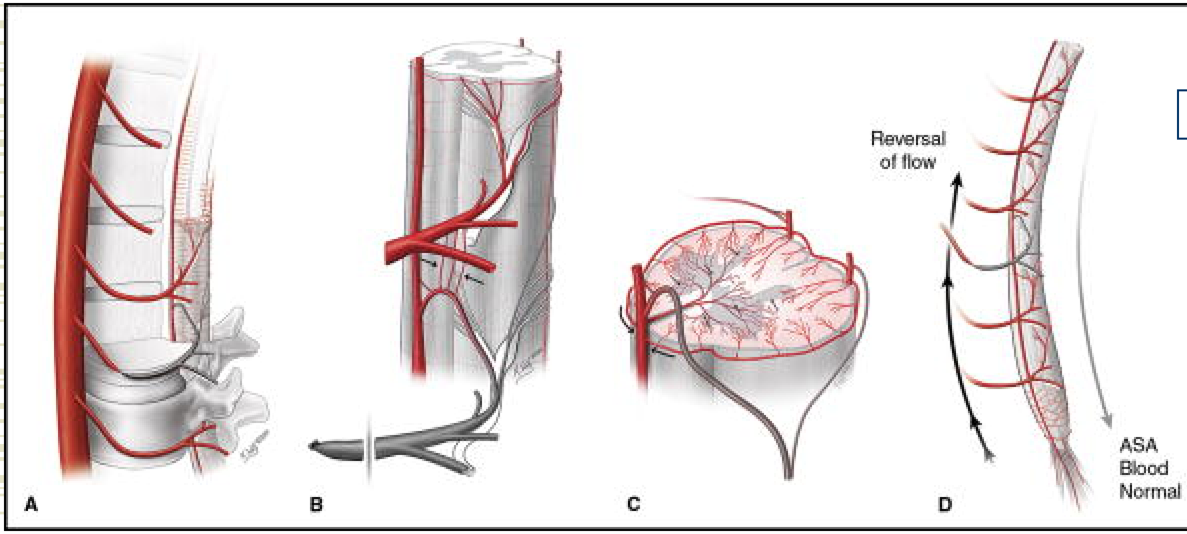


Fig 3. Two-dimensional image and Doppler ultrasonography. *Arrows* indicate aortic lumen and the proximal part of the largest segmental artery close to the celiac trunk. The direction of intercostal blood flow is shown in relation to proximal aortic crossclamping.

Lennart Christianson, MD, PhD (J of thorac Cardiovas Surg 2001 , Vol 121, No 4)



. A through D, Illustration of disrupted spinal cord supply following ligation of a key segmental artery (shown in gray) (A) with three possible compensatory mechanisms for reconstitution of the anterior spinal artery (ASA). Without direct supply to the ASA via the typical flow from the segmental artery to the radiculomedullary artery (RMA), the ASA may be reconstituted by collaterals emanating from an adjacent segment radicular artery (B), communication between the posterior spinal arterial system and the ASA system via the pial plexus and areas of spinal cord parenchymal overlap (C), or compensatory dynamic reversal of flow in the ASA itself using supply from distant RMAs or the anastomotic loop of the conus (D).

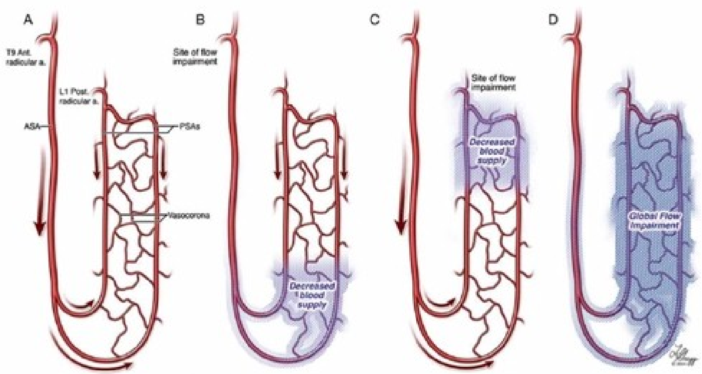


Figure 8 Variability of the dorsal watershed zone. Like any watershed territory, the dorsal watershed zone must be understood as a dynamic concept. From an anatomical standpoint, the location of the zone at risk of early ischemic damage varies with the number, size, and location of the anterior and posterior radiculomedullary contributors (A). From a pathological standpoint, the site of ischemic damage depends on the vessel involved; for example, the stenosis of an anterior spinal contributor will result in more caudal ischemia (B) than stenosis of a posterior spinal contributor (C). The type of flow impairment also plays a role in the extent and location of the ischemic lesion (eg, radiculomedullary stenosis versus occlusion) or global flow impairment (D). ASA, anterior spinal artery; PSAs, posterior spinal arteries.

Gailloud P et al. J NeuroIntervent Surg 2015;7:848-853

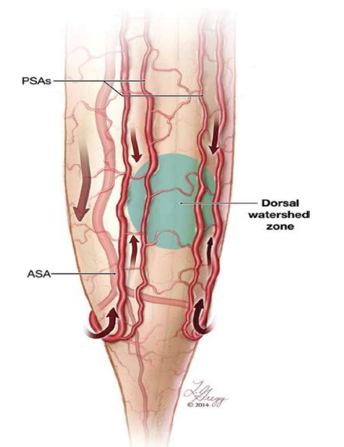


Figure 7 The dorsal watershed zone of the spinal cord. This illustration depicts the circulation patterns within the spinal arteries at the level of the conus medullaris. Note the anterior to posterior flow in the arcuate branches and the ascending flow within the lowest portion of the posterior lateral and posterior medial spinal arteries (PSAs). The dorsal watershed zone (shaded area) corresponds to the portion of the posterior spinal network located at the junction between these ascending and descending flow patterns. ASA, anterior spinal artery.

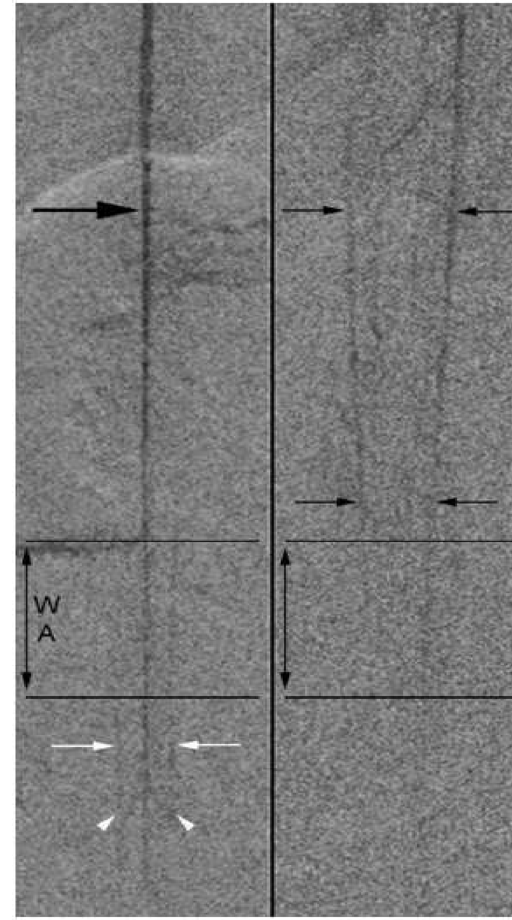


Figure 1 Teenage patient with a spinal epidural arteriovenous fistula. The left and right panels compare magnified posteroanterior views of the vascularization of the conus medullaris documented by selective angiography of the left T9 (left) and left T11 (right) intersegmental arteries. The anterior spinal artery (large black arrow) and the cranial component of the posterior spinal arteries (small black arrows) are flowing in a craniocaudal direction while the caudal part of the posterior spinal arteries (small white arrows), which is supplied by the anterior spinal artery via its arcuate branches (white arrowheads), flows in a caudocranial direction. The horizontal black lines delimit an intermediate territory located along the dorsal surface of the conus medullaris that receives its blood supply from both the cranial and caudal portions of the posterior spinal arteries, hence constituting a watershed area (WA) between these two sources of vascularization.

The posterior third of the spinal cord is the site of a vascular lesion less frequently than the anterior two-thirds. The reason for this is not clear, but perhaps it may be because of the plexiform character of all arteries on the posterior surface and a greater number of medullary arteries. When there is involvement of

Reversal of blood flow currents in the anterior and posterior spinal arteries may occur in pathological conditions due to hemodynamically active lesions (e.g., arteriovenous malformations in and outside the cord) or due to stenotic or obstructive vascular disease located either in the spinal cord arteries or in the major extraspinal tributaries. Reversals of blood flow direction in the spinal cord arteries may cause steal phenomena with resulting degrees of cord ischemia (Jellinger, 1972).

Jellinger K. 1972. Circulation disorders of the spinal cord. Acta Neurochirurgia 26:327-337.

However, in addition to arterial disorders, disturbances of the venous drainage are important to note. The low pressures that produce circulatory disturbances speak in favor of the view that in the setting of slowly progressing compressive lesions, an impairment of the venous drainage is primarily responsible for the deficient circulation. In a considerable proportion of spinal cord lesions, the pattern suggests an impairment of the venous drainage (Levy and Strauss, 1942; MacNalty and Horsley, 1909; Na et al., 2007).

Levy NA, Strauss HA. 1942. Myelopathy following compression of abdominal aorta for postpartum hemorrhage. Arch Neurol Psych 48:85-91.

Microvasculature of the human spinal cord

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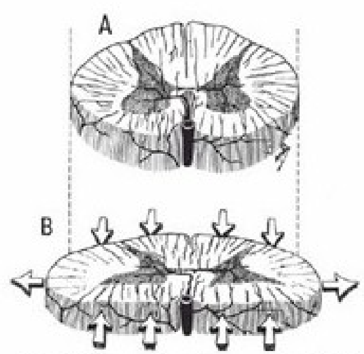


Fig. 5. Cross section of a normal cord (*A*) and a flattened cord (*B*). Flattening of the spinal cord (*B*) elongates and flattens the small arteries and veins of the lateral columns and gray matter, but merely shortens the vessels of the anterior and posterior columns.

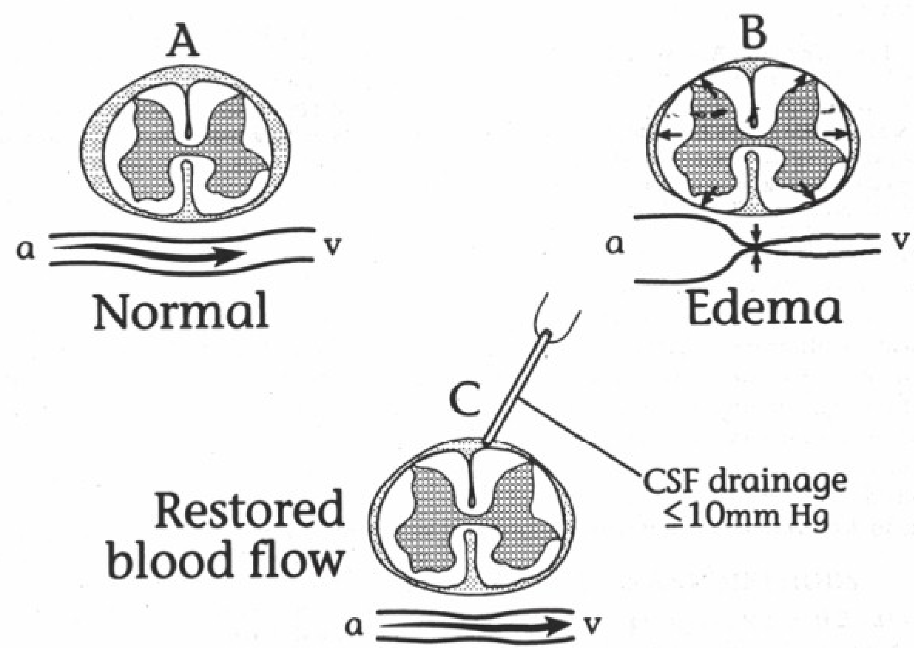
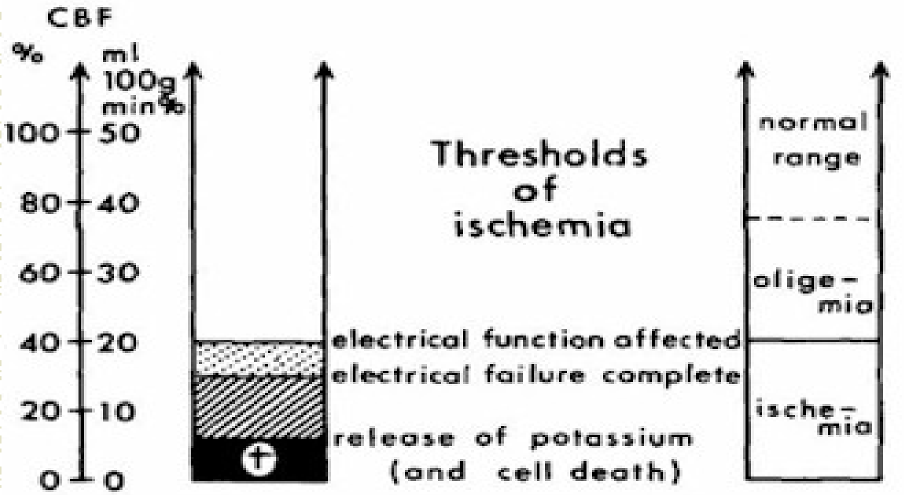
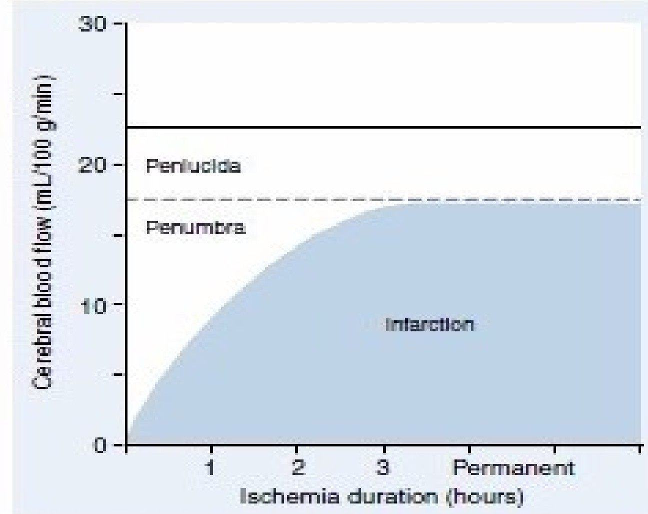
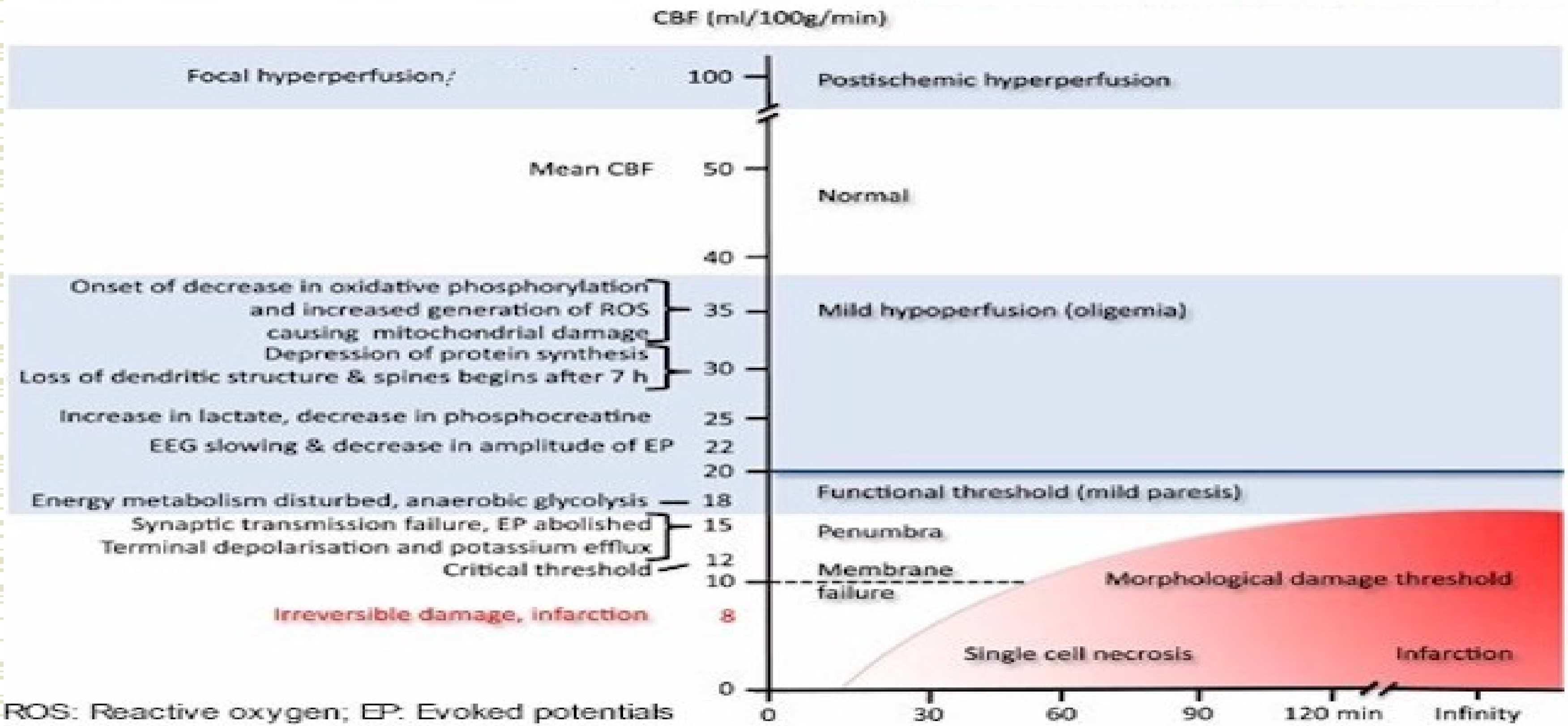


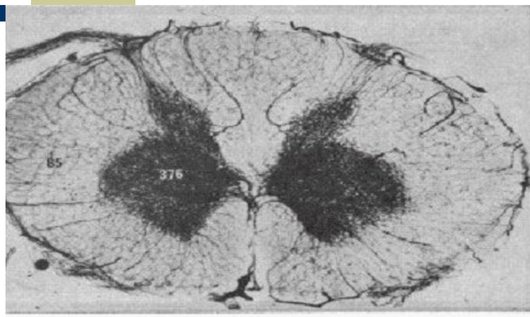
Fig. 8. Speculated mechanism of beneficial effect of cerebrospinal fluid drainage on spinal cord injury (Safi et al., 1997).



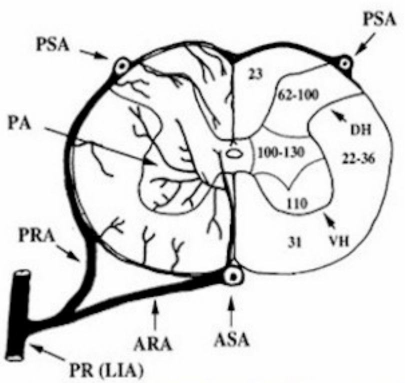


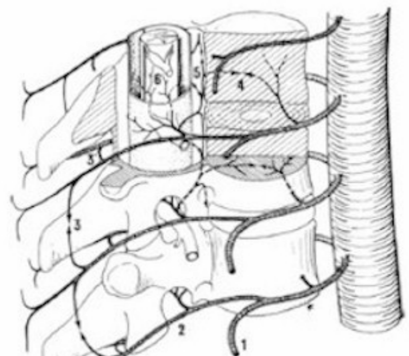


ROS: Reactive oxygen; EP: Evoked potentials

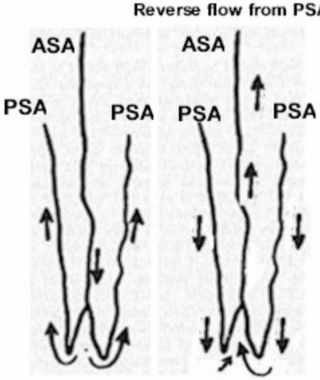


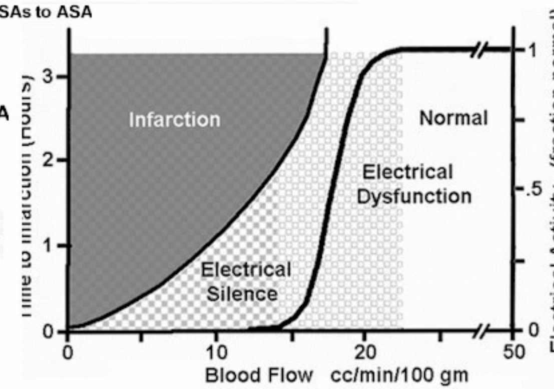
"There exist a very close relationship between the metabolic requirements of the nervous tissue and the final distribution of intraneural vessels in the adult, a relationship which functions in such a way as to provide the nervous system with a blood supply just adequate for its minimal needs (Feeney and Watterson ; The development of the vascular pattern within the walls of the central nervous system of the chick embryo. Journal of Morphology;1946.)."





Reverse flow from PSAs to ASA





1 laminar distribution of SCBF (ml/100g/min) in lumbar spinal cord (*PSA* posterior spinal artery; *PA* penetrating artery; *ASA* anterior spinal artery; *ARA* anterior radicular artery; *PRA* posterior radicular artery; *PR (LIA)* posterior ramus of lumbar intercostal artery); *VH* ventral horn; *DH* dorsal horn

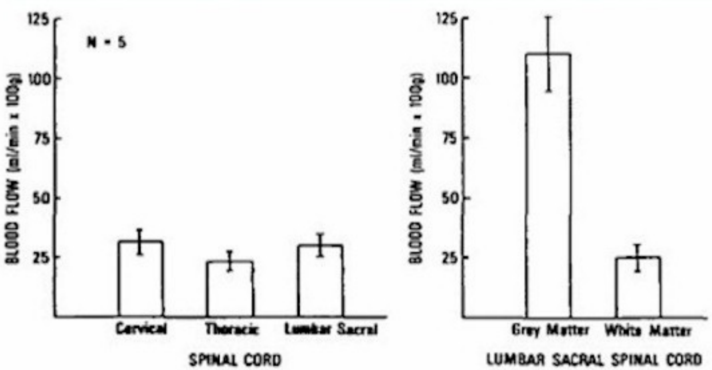


FIGURE 1 *Blood flow to different regions (cervical, thoracic, and lumbosacral) and different tissues (gray and white matter) within the spinal cord of sheep measured under control conditions.*

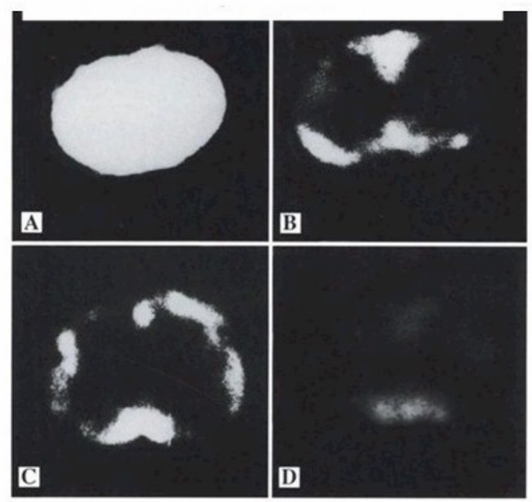


Fig. 7. ATP induced bioluminescence in lumbar transverse spinal cord sections after increasing intervals (control (**A**); 10 min isch. (**B**); 20 min isch. (**C**); and 40 min isch. (**D**)) of aortic occlusion in rabbit. Note the presence of measurable ATP activity in dorsal and ventral white matter even after 20 min of spinal ischemia and complete loss of ATP activity at 40 min after aortic occlusion (adopted from Danielisova *et al.*, 1987)

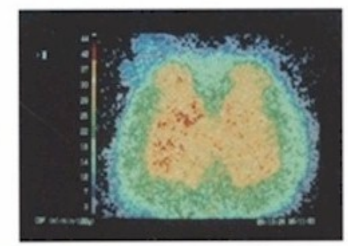


Fig. 2. Spinal cord blood flow (iodo-[14C] antipyrine method) in control animal (L4 spinal segment), (Ishikawa and Marsala in preparation)

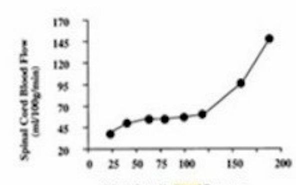


Fig. 3. Spinal cord blood flow autoregulation in the rat spinal cord. As indicated, SCBF is maintained constant in the range of 50–120 mm Hg of mean arterial blood pressure. (Adopted from Hicket *et al.*, 1986; Rubinstein and Arbit, 1990)

- The blood flow and metabolic rate of the spinal gray matter be 3-5 time greater than white matter.
- The fact that when SSEPs changes suggesting the white matter would be in the ischemic penlucida or penumbra while the gray matter would have reached the stage of irreversible lesions, thereby explaining why paraplegia may occur despite SSEPs recovered.
- Aggressive intervention before treatable spinal cord ischemia evolves into irreversible neuronal ischemia.

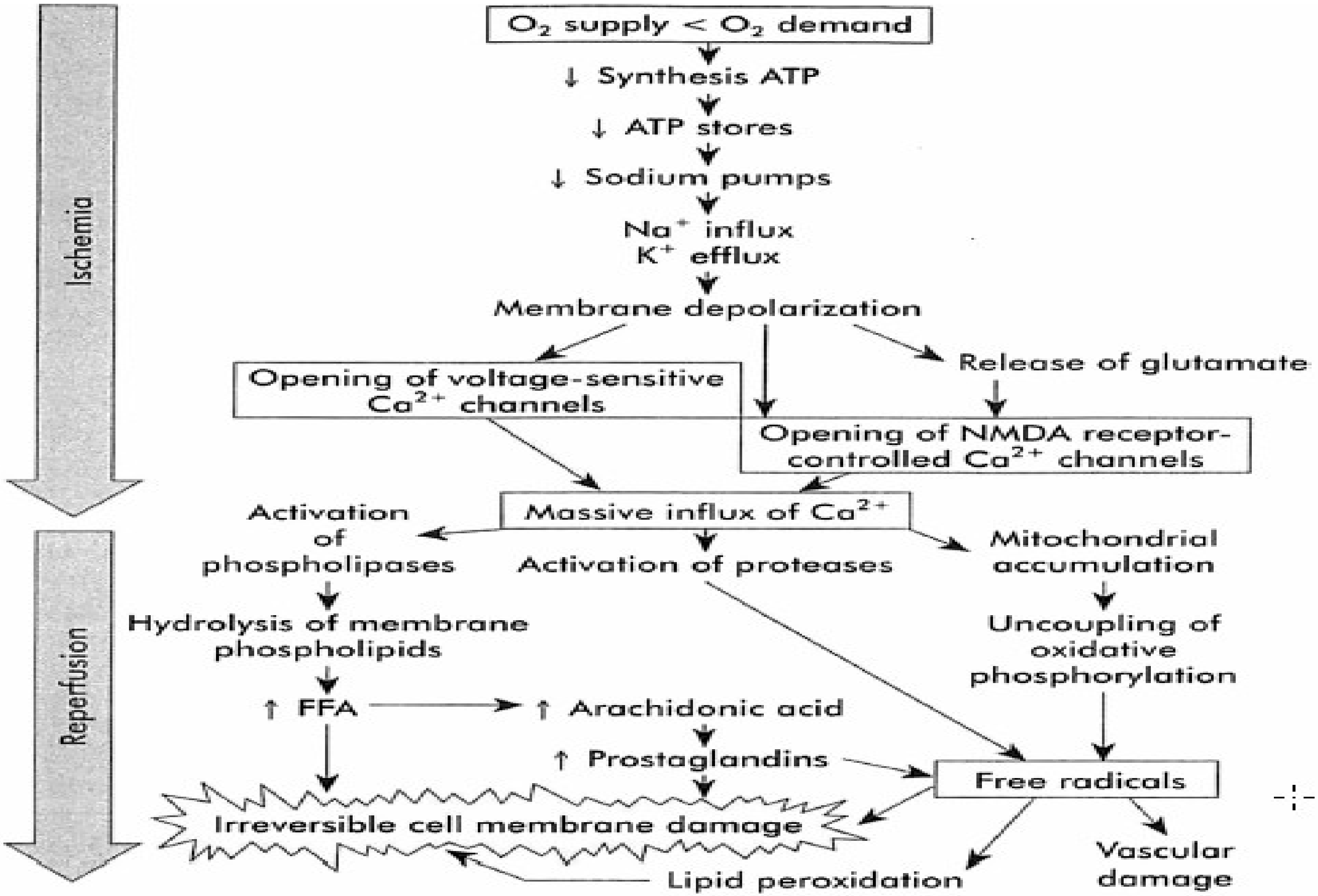
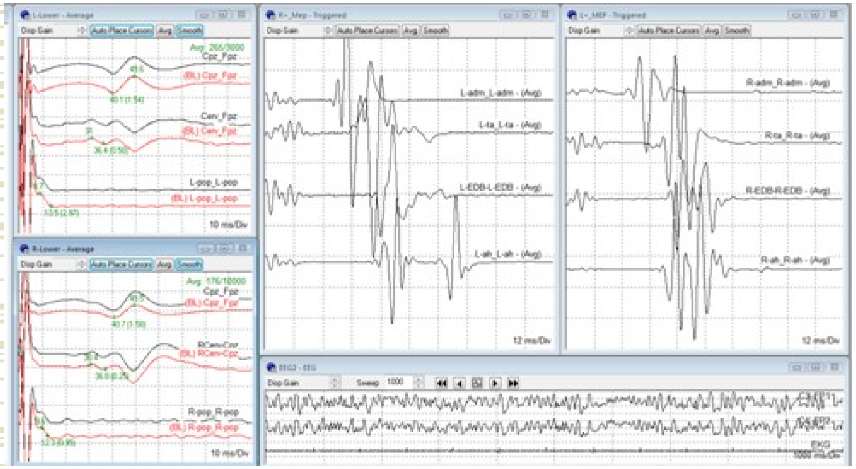


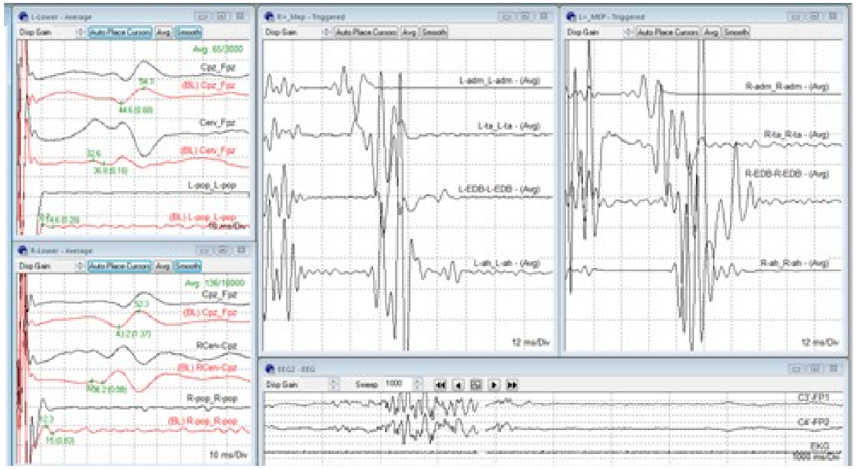
Fig. 5. Ischemic/reperfusion injury. Two components of tissue injury contribute to the ultimate neurologic damage. The ischemic component includes the processes of tissue damage occurring during ischemia. Cell death caused by the ischemic component alone depends on the severity and duration of ischemia. The secondary consequences of ischemia include the biochemical changes that take place at the time of reperfusion and reoxygenation after ischemia. The duration of these secondary processes and the extent to which they contribute to ultimate neurologic damage determine the therapeutic window during which treatment administered after ischemia may be effective. ATP, adenosine triphosphate; FFA, free fatty acids; NMDA, *N*-methyl-D-aspartic acid. (*From* Cottrell J, Smith D. Anesthesia and neurosurgery. 3rd edition. Philadelphia: Mosby; 1994; with permission.)

Loss MEPs / TEVAR

Baseline

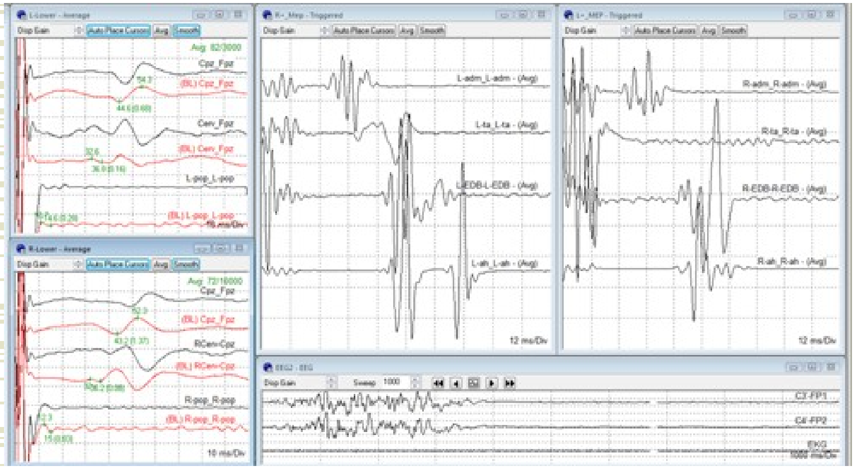


BP 135/70



Loss MEPs / TEVAR

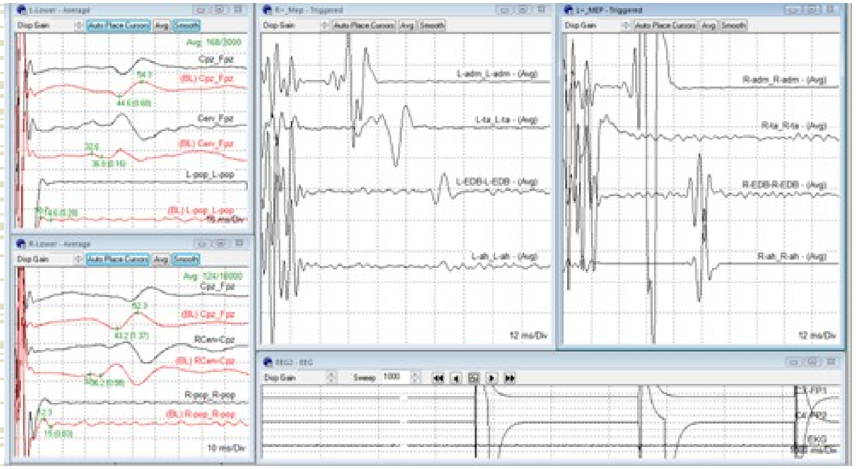
2nd stent deployed, T9 artery



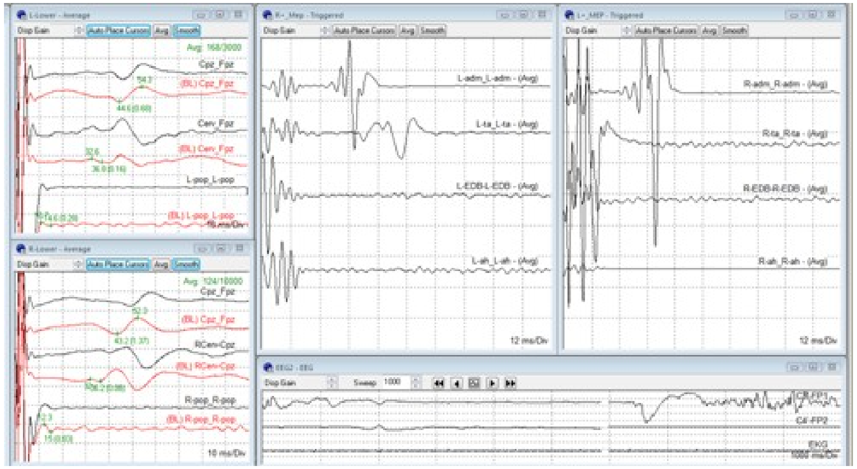
2nd stent deployed: 2 minutes

Loss MEPs / TEVAR

2nd stent deployed : 3 minutes

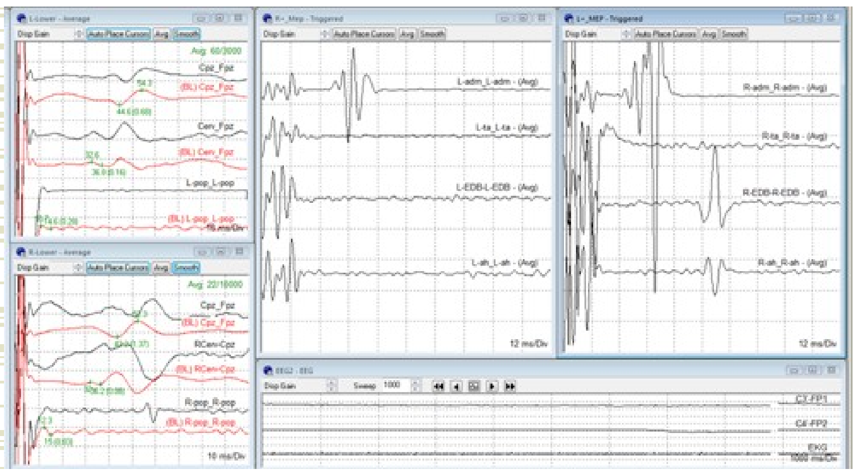


2nd stent deployed: 5 minutes

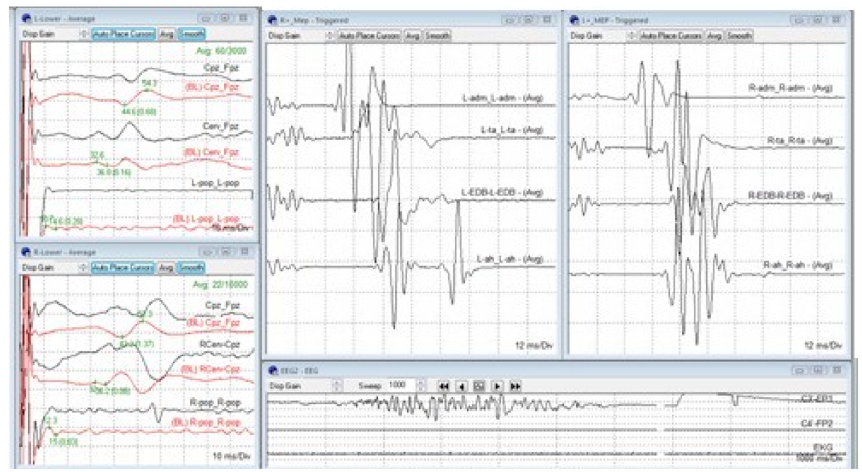


Loss MEPs / TEVAR

Induced HTN, SBP : 146 mmHg

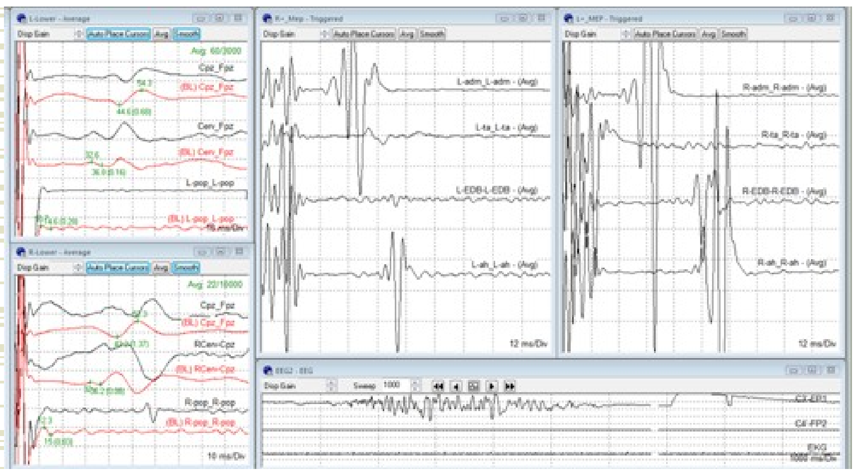


SBP : 187 mmHg



Loss MEPs / TEVAR

SBP: 145 mmHg



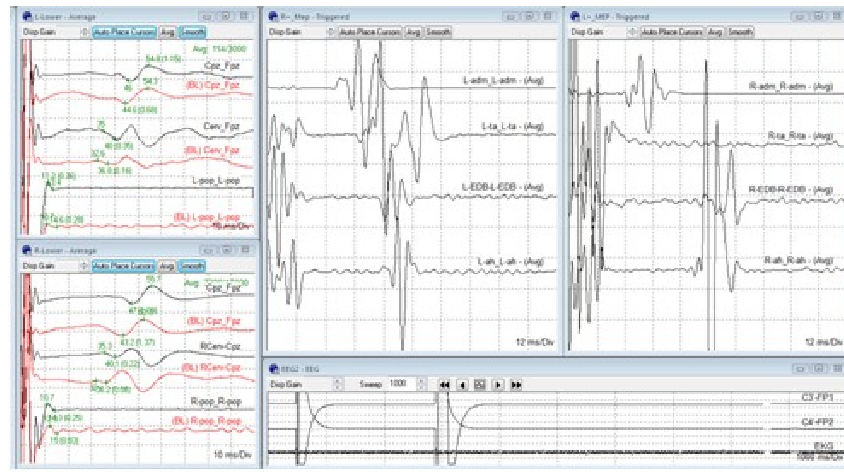
SBP: 120 mmHg

Loss MEPs / TEVAR

SBP: 150 mmHg

Threshold restored MEP,

SBP: 160 mmHg



Thank you for your attention ！

TOLERABLE ISCHEMIC TIMES

KIDNEYS	30 MINUTES
GUTS	> 120 MINUTES
LOWER LEGS	> 200 MINUTES
SPINAL CORD	?? COLLATERAL CIRCULATION 30 MINUTES ?
BRAIN	3 MINUTES
HEART	?? COLLATERAL CIRCULATION Max 4 hours