Making sense of the evidence for staging and spinal cord conditioning: myth and reality (including embolization of intercostals)

Christian D. Etz, MD, PhD
Heisenberg Professor for Aortic Surgery

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HERZZENTRUM

Ischemic Spinal Cord Injury

no definite

prevention strategy

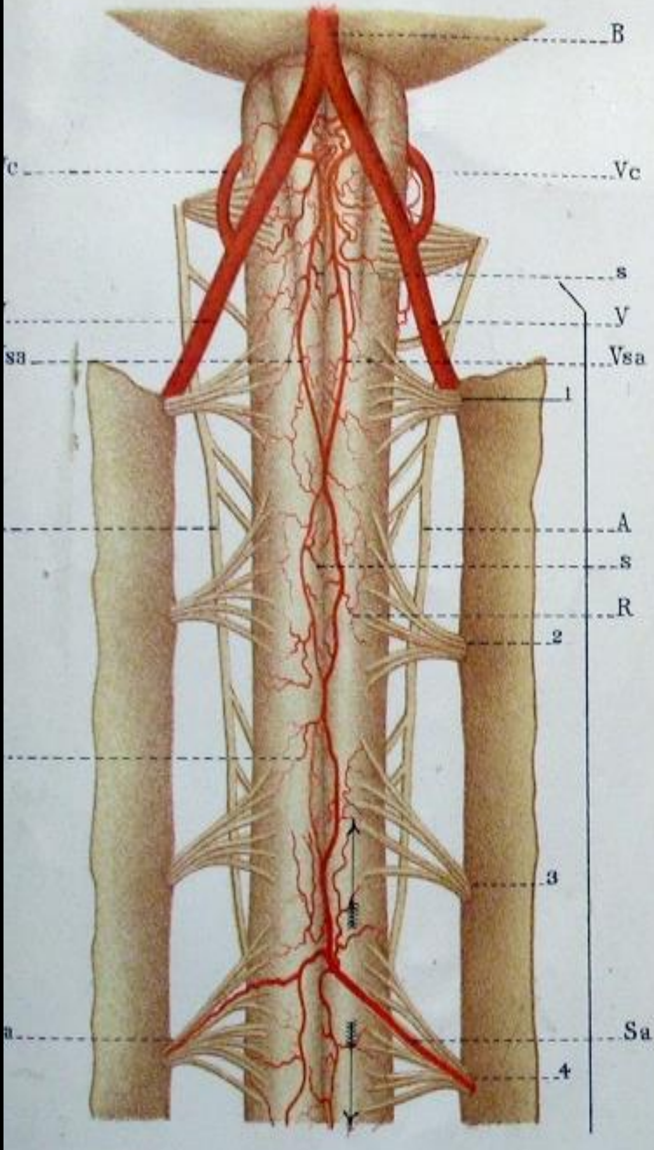
— essential for safe oper d

endovascular repair [1,2]

1 Coselli, LeMaire. Descending and Thoracoabdominal Aortic Aneurysms. In: Lh C, ed. Cardiac Surgery in the Adult. New York: McGraw-Hill; 2008:1277-98.

2 Etz CD et al. Spinal cord perfusion after extensive segmental artery sacrifice: can paraplegia be prevented? Eur J Cardiothorac Surg 2007;31(4):643-8.

‘If the theory does not fit the facts —
too bad for the facts’



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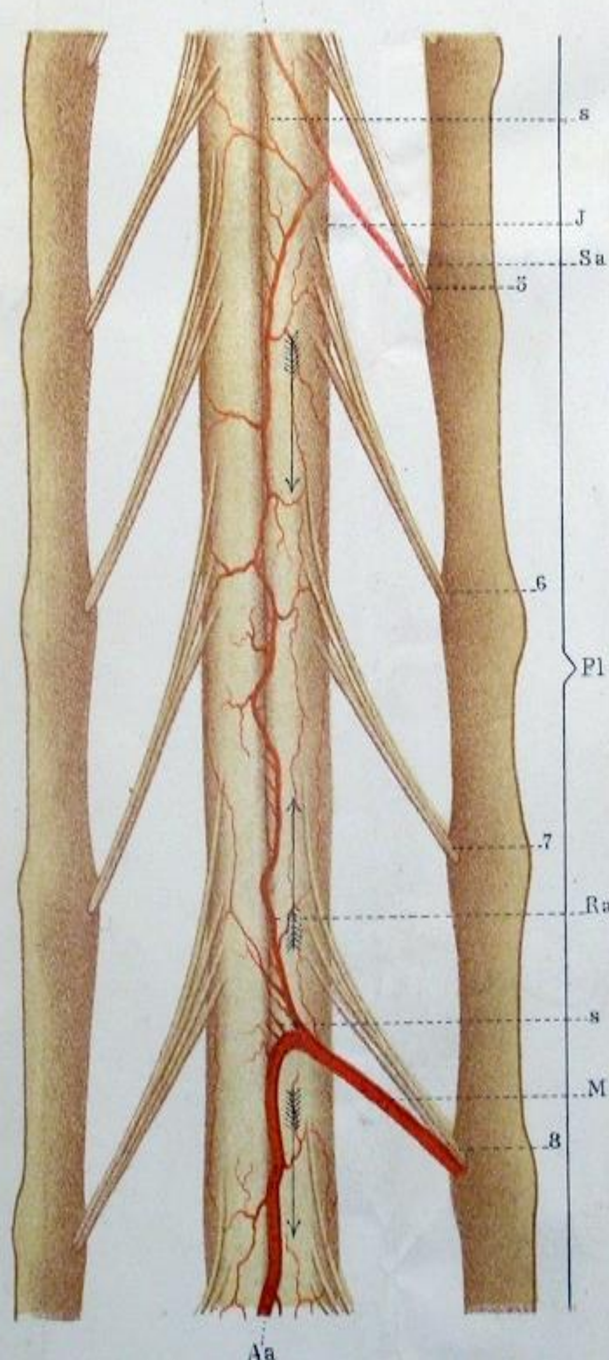

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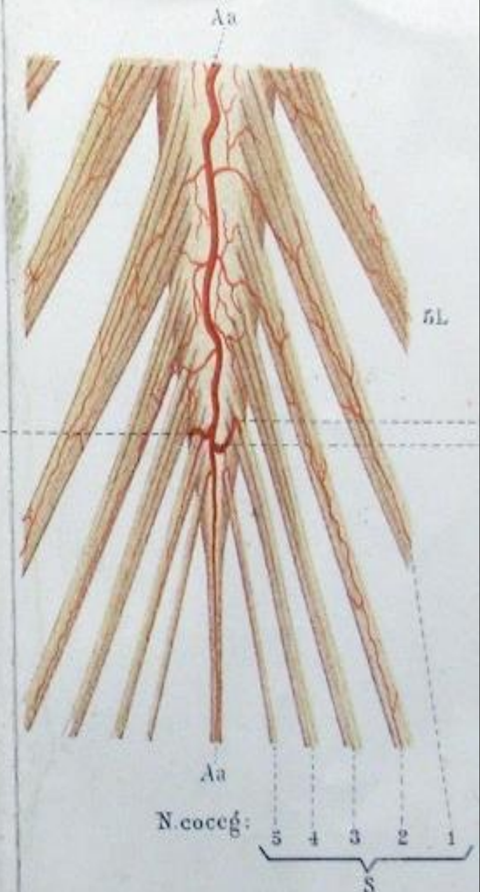

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III.

Die Blutgefässe des menschlichen Rückenmarkes.

I. Theil.

Die Gefässe der Rückenmarkssubstanz.

Von Prof. Dr. **Albert Adamkiewicz.**

(Mit 6 Tafeln.)

(Institut für experimentelle Pathologie der k. k. Universität Krakau.)

(Vorgelegt in der Sitzung am 3. November 1881.)

Thoracic and Thoracoabdominal Aneurysm Repair: Is Reimplantation of Spinal Cord Arteries a Waste of Time?

Christian D. Etz, MD, James C. Halstead, MA (Cantab), MRCS, David Spielvogel, MD, Rohit Shahani, MD, Ricardo Lazala, MD, Tobias M. Homann, MS, Donald J. Weisz, PhD, Konstadinos Plestis, MD, and Randall B. Griepp, MD

Departments of Cardiothoracic Surgery and Neurosurgery, Mount Sinai School of Medicine, New York, New York

(Ann Thorac Surg 2006;82:1670–8)

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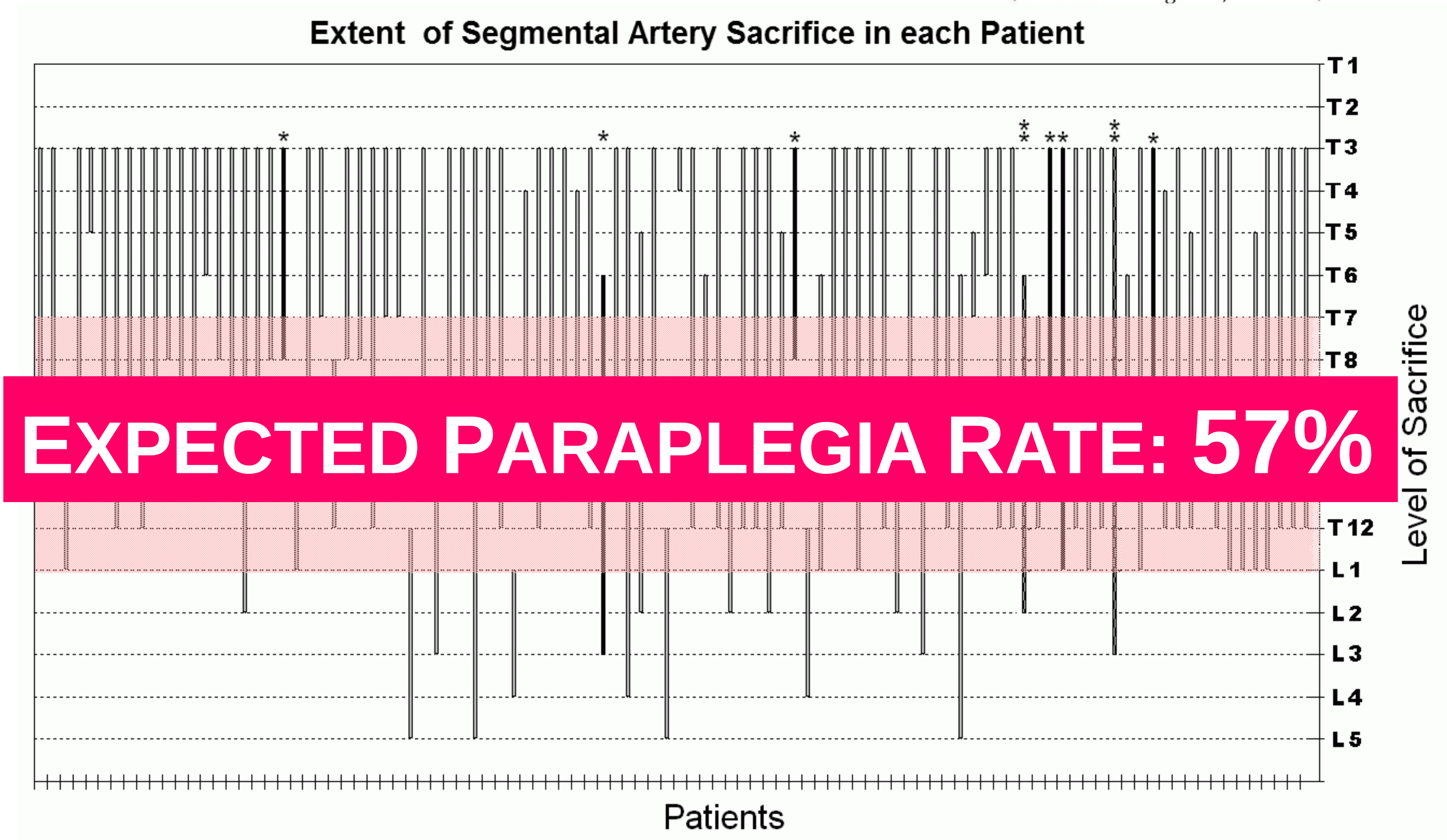
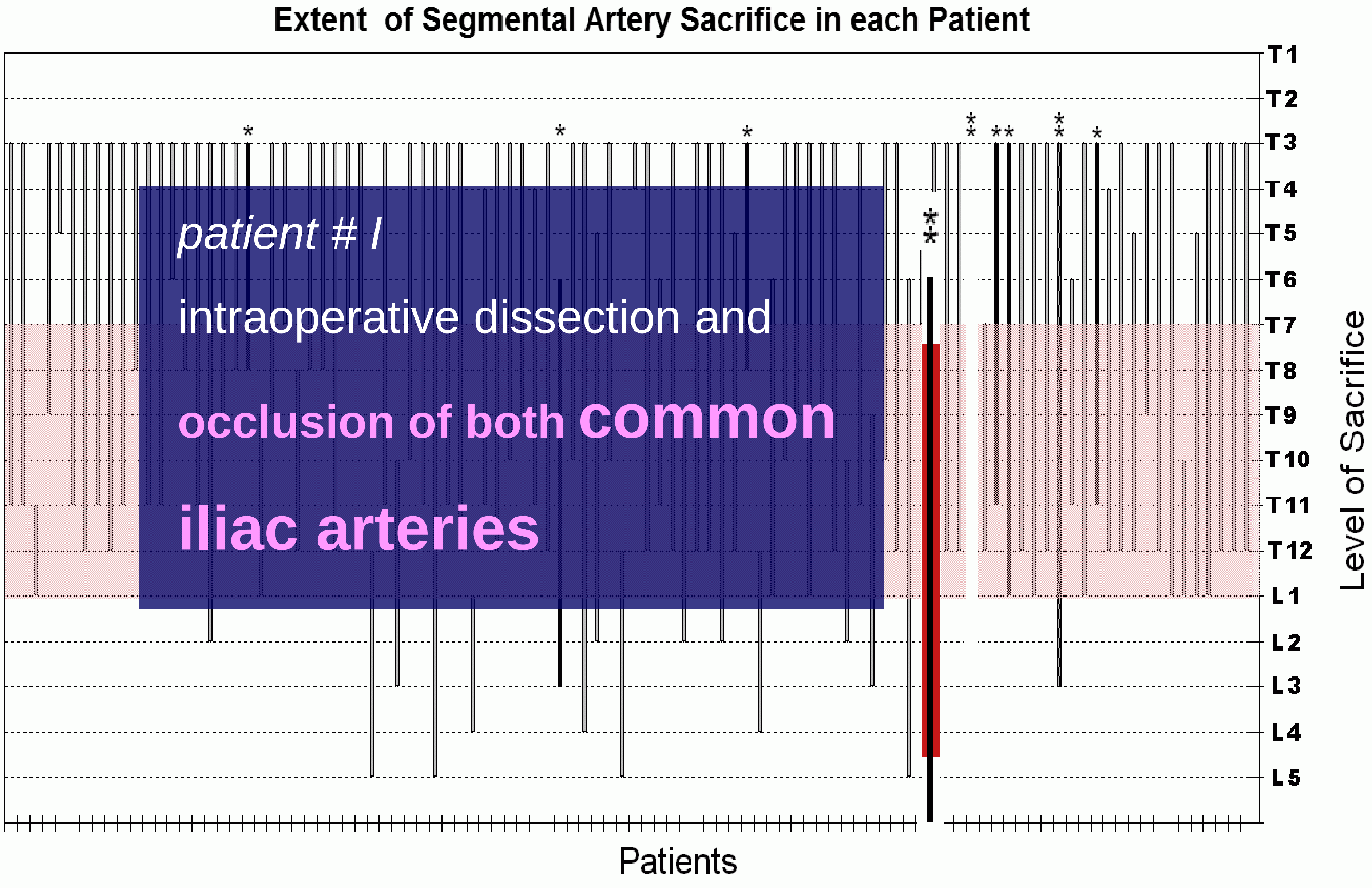
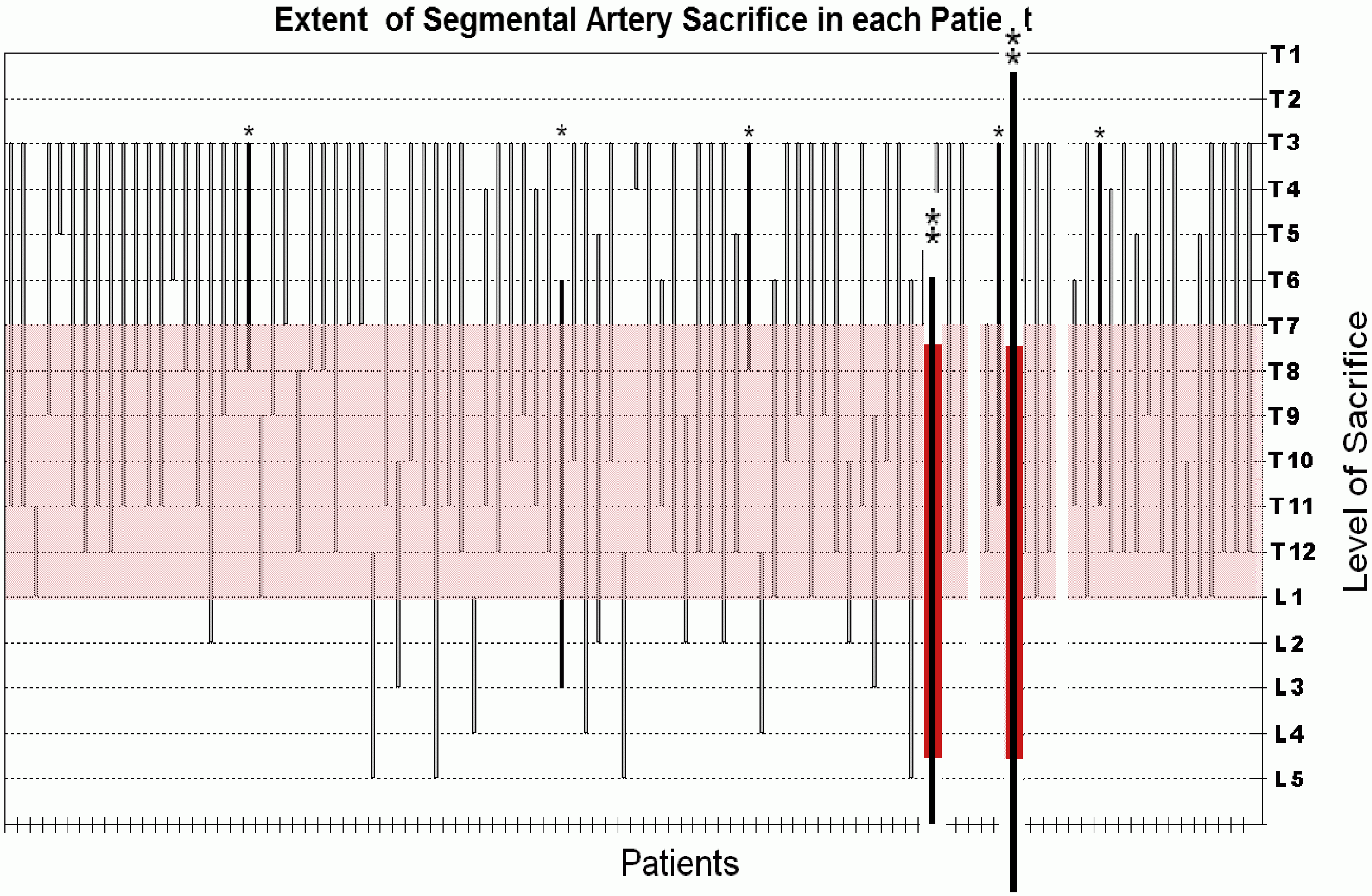


EXPECTED PARAPLEGIA RATE: 57%


Extent of Segmental Artery Sacrifice in each Patient
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
Level of Sacrifice
Patients
patient # I
intraoperative dissection and
occlusion of both common
iliac arteries



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T1
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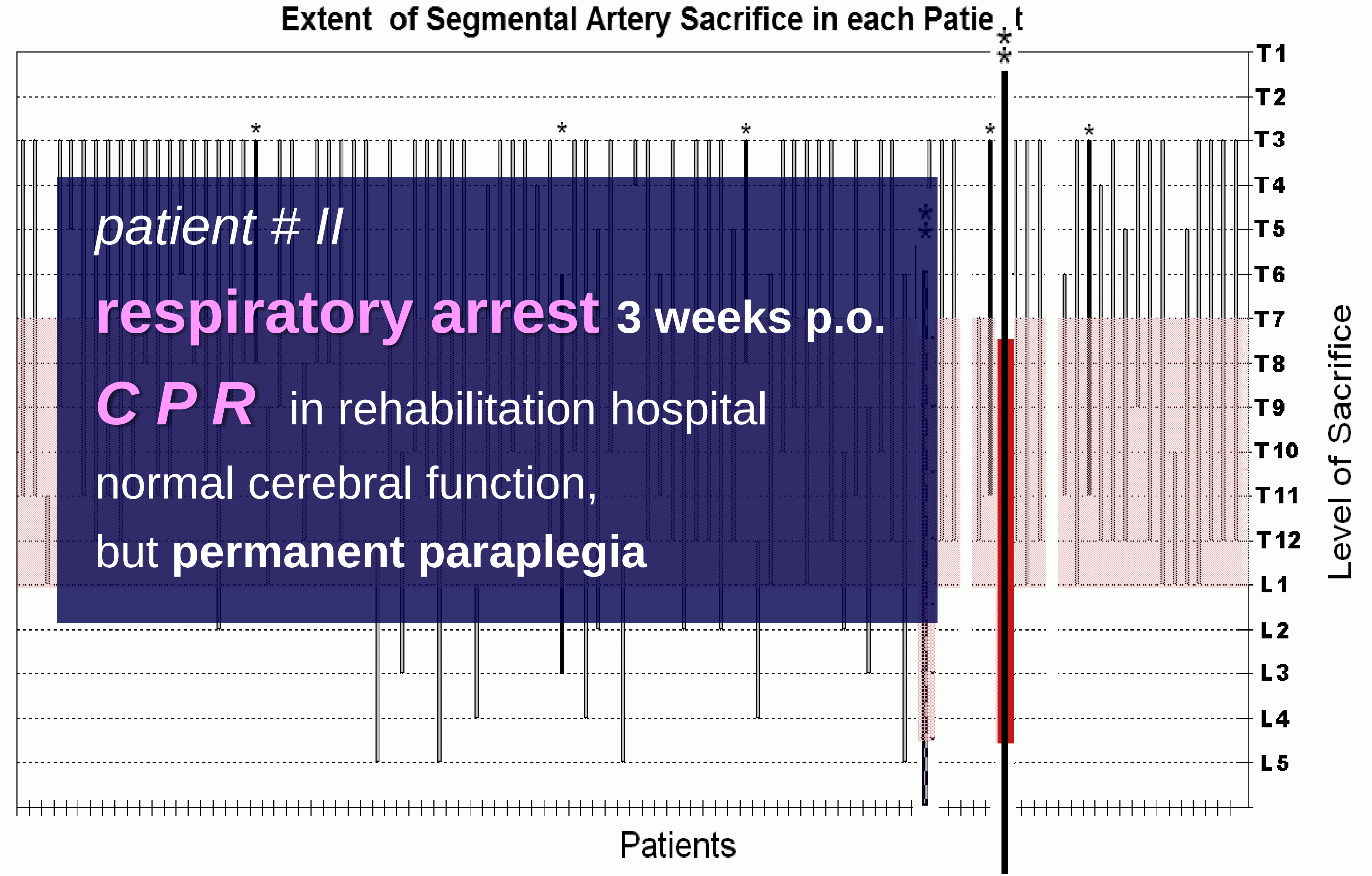
Level of Sacrifice
Patients



Extent of Segmental Artery Sacrifice in each Patie t
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
Level of Sacrifice
Patients
patient # II
respiratory arrest 3 weeks p.o.
C P R in rehabilitation hospital
normal cerebral function,
but permanent paraplegia

Thoracic and Thoracoabdominal Aneurysm Repair: Is Reimplantation of Spinal Cord Arteries a Waste of Time?

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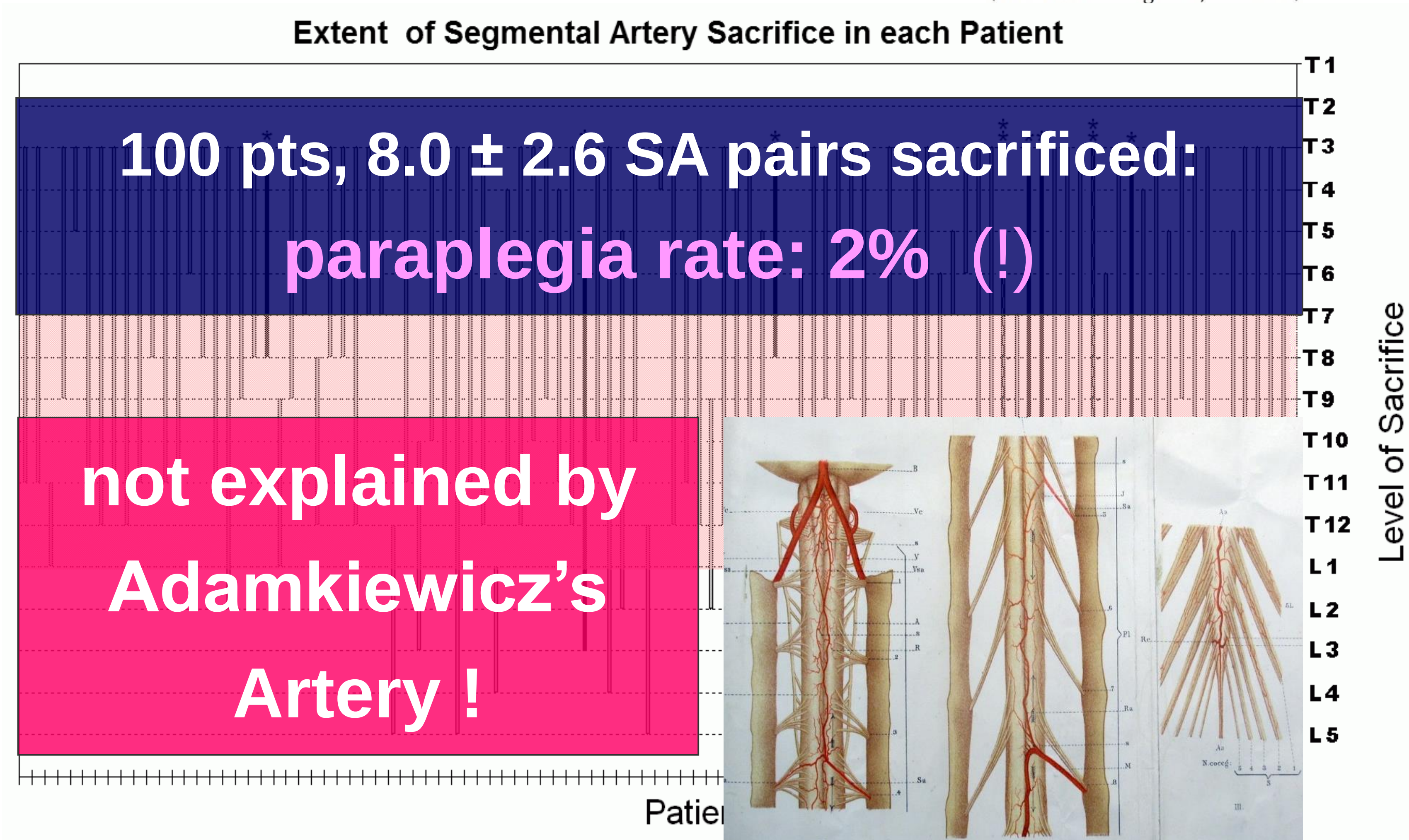
Christian D. Etz, MD, James C. Halstead, MA (Cantab), MRCS, David Spielvogel, MD, Rohit Shahani, MD, Ricardo Lazala, MD, Tobias M. Homann, MS, Donald J. Weisz, PhD, Konstadinos Plestis, MD, and Randall B. Griepp, MD

Departments of Cardiothoracic Surgery and Neurosurgery, Mount Sinai School of Medicine, New York, New York

(Ann Thorac Surg 2006;82:1670–8)



100 pts, 8.0 ± 2.6 SA pairs sacrificed:

paraplegia rate: 2% (!)

not explained by Adamkiewicz's Artery !

Spinal cord blood supply in patients with thoracoabdominal aortic aneurysms

Michael J. Jacobs, MD,[a] Bas A. de Mol, MD,[b] Ted Elenbaas, MD,[c] Werner H. Mess, MD,[d] Cor J. Kalkman, MD,[e] Geert W. Schurink, MD, and Bas Mochtar, MD,[c] *Maastricht, Amsterdam, and Utrecht, The Netherlands*

Objective: In patients with thoracoabdominal aortic aneurysms (TAAAs), the blood supply to the spinal cord is highly variable and unpredictable because of obstructed intercostal and lumbar arteries. This study was performed for the prospective documentation of patent s… tribution to the spinal cord blood su…
Methods: TAAA repair was performed… with type III) according to a protoco… monitoring of motor-evoked potential… cached, selectively grafted, and oversew… of baseline was considered an indicati…
Results: Adequate MEP levels were obt… two patients had delayed paraplegia de… all neurologic deficit of 2.7%. The m… aneurysms was three, five, and five, re… fifth thoracic vertebrae (T5) and the … aortic perfusion. In 18 of 91 type II … these patients, the segment L1 to L5 d… the pelvic circulation provided with th… ies were the lumbar arteries between … arteries. In seven of 25 type III case… cases, no segmental arteries were avail… the combination of the findings of ty… 16% of the cases (19 of 116) and pelvi…
Conclusion: In patients wi… depends on an eminent col… MEPs is a sensitive techniq… critically contribute to spin… rate of neurologic deficit…

Identified and reattached segmental arteries

	Type I aneurysms (n = 68)		*Type II aneurysms (n = 91)*		*Type III aneurysms (n = 25)*		*Type I, II, and III aneurysms*	
	Identified	*Reattached*	*Identified*	*Reattached*	*Identified*	*Reattached*	*Identified*	*Reattached*
T5	10	4	21	16	0	0	31	20
T6	12	4	25	18	2	1	39	23
T7	8	3	19	15	4	2	31	20
T8	25	12	46	31	6	4	77	47
T9	34	19	51	36	14	9	99	64
T10	39	28	59	41	18	12	116	81
T11	42	26	73	58	19	12	134	96
T12	29	19	28	19	20	17	77	55
								49
								36
								20
								25
								21
								566 (69%)

… ’ In patients with TAAA, most intercostal and lumbar arteries are occluded and **spinal cord perfusion depends on an eminent collateral network**.’

Spinal cord ischemia duri… nal aortic aneurysm (TAAA)… most life-destructive complica… torial cause, several strategies… cord integrity have been developed, w… improved clinical outcome.[1-4] These adjunctive procedures include distal aortic perfusion,[1] cerebrospinal fluid (CSF) drainage,[2,3] and systemic or local hypothermia.[4]

From the Department of Surgery,[a] Cardiothoracic Surgery,[c] and Neurophysiology,[d] University Hospital Maastricht, the Department of Cardiothoracic Surgery,[b] Academic Medical Center Amsterdam, and the Department of Anesthesiology,[e] University Academic Medical Center Utrecht.
Competition of interest: nil.
Presented at the Forty-ninth Annual Meeting of The American Association for Vascular Surgery, Baltimore, Md, Jun 12-13, 2001.
Reprint requests: Michael J. Jacobs, MD, University Hospital Maastricht, Department of Surgery, PO Box 5800, 6202 AZ Maastricht, The Netherlands (e-mail: m.jacobs@surgery.azm.nl).

0741-5214/2002/$35.00 + 0 24/6/120041
doi:10.1067/mva.2002.120041

… is illustrated with increased paraplegia rates after prolonged aortic cross-clamp times.[5,6] Permanent cessation is associated with the variable and unpredictable anatomy of the intercostal and lumbar arteries and the extent of the aneurysm. In degenerative thoracoabdominal aneurysms, most segmental arteries are occluded with mural thrombus or atherosclerotic plaques, which suggests that spinal cord perfusion is mainly provided by collateral networks. During the procedure, however, the surgical dilemma of which artery should be reimplanted or ligated is determined with the unknown contribution of the patent segmental vessels to this collateral network and thus spinal cord perfusion.

One of the main limitations of the strategies that aim for the restoration and maintenance of spinal cord blood supply is the inability for the actual assessment of the ade-

30

From the Society for Vascular Surgery

Magnetic resonance angiography of collateral blood supply to spinal cord in thoracic and thoracoabdominal aortic aneurysm patients

Walter H. Backes, PhD,[a] Robbert J. Nijenhuis, MD, PhD,[a,b] Werner H. Mess, MD, PhD,[c]
Freke A. Wilmink, MD,[a] Geert Willem H. Schurink, MD, PhD,[b] and
Michael J. Jacobs, MD, PhD,[b,d] *Maastricht, The Netherlands; and Aachen, Germany*

Objective: Preservation of spinal cord blood supply during descending thoracic (TAA) and thoracoabdominal aortic aneurysm (TAAA) surgery is mandatory to prevent neurologic complications. Although collateral arteries have been identified occasionally and are considered crucial for maintaining spinal cord function in the individual patient, their critical functionality is poorly understood and very little experience exists with visualization. This study investigated whether the preoperative and postoperative presence or absence of collateral arteries detected by magnetic resonance angiography (MRA) is related to spinal cord function during the intraoperative exclusion of the segmental supply to the Adamkiewicz artery.
Methods: Spinal cord MRA was used to localize the Adamkiewicz artery and its segmental supplier in 85 patients scheduled for open elective surgery for TAA or TAAA. The segmental artery to the Adamkiewicz artery was inside the cross-clamped aortic area in 55 patients, and spinal cord supply was consequently dependent on collateral supply. In these 55 patients the presence of collaterals originating from arteries outside the cross-clamped aortic segment was related to changes in the intraoperative motor-evoked potentials (MEPs) that occurred before corrective measures. Twenty-one patients returned for postoperative MRA.
Results: A highly significant ($P < .0015$) relation was found between the presence of collaterals and intraoperative spinal cord function. In 30 of 31 patients (97%) in whom collaterals were identified, MEPs remained stable. The collaterals in most patients originated caudally to the distal clamp (eg, from the pelvic arteries), which were perfused by means of extracorporeal circulation during cross-clamping. The MEPs declined in 9 of 24 patients (38%) in whom no collaterals were preoperatively visualized. Postoperatively, the 21 patients who had MRA, including 10 in whom preoperatively no collaterals were found, displayed a well-developed collateral network.
Conclusion: Collateral arteries supplying the spinal cord can be systematically visualized using MRA. Spinal cord blood supply during open aortic surgery may crucially depend on collateral arteries. Preoperatively identified collateral supply was 97% predictive for stable intraoperative spinal cord function. Patients in whom no collaterals can be depicted preoperatively are at increased risk for spinal cord dysfunction. (J Vasc Surg 2008;48:261-71.)

Collateral arteries are thought to contribute to the blood supply ... aortic aneur... degenerative ... lumbar arter...

spinal cord perfusion is assumed to depend on a collater...

... paraplegia include reattachment of intercostal arteries, cerebrospinal fluid (CSF) drainage, and distal aortic perfusion. However, some experts debate the relevance of time-consuming revascularization procedures because collateral arterial networks may fully substitute for the impaired blood supply.[8,9]

From the Depar... ology,[a] Maas... of Vascular Su...
Correspondence: Michael J. Jacobs, MD, PhD, Maastricht University Hospital, Department of Surgery, PO Box 5800, 6202 AZ Maastricht, The Netherlands (e-mail: m.jacobs@surgery.azm.nl).

Competition of ...
Presented at the ... Surgery, Baltimore, ...
CME article
0741-5214/$34.00

doi:10.1016/j.jvs.2008.03.015

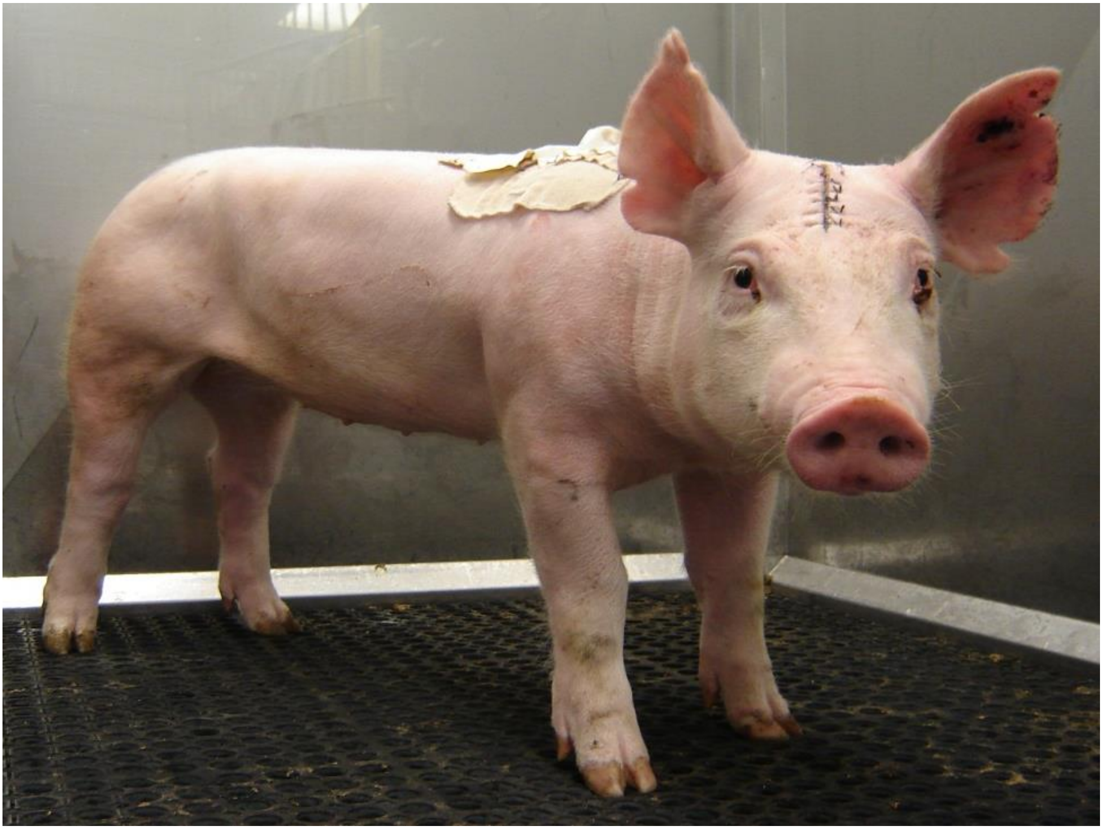
Fig 8. a, Preoperative contrast-enhanced magnetic resonance angiography (MRA) of a 46-year-old man with a type II thoracoabdominal aortic aneurysm. b, The postoperative MRA shows strong development of the remote collateral arterial supply from the pelvic region after aortic repair. Intraoperative motor-evoked potentials remained stable.

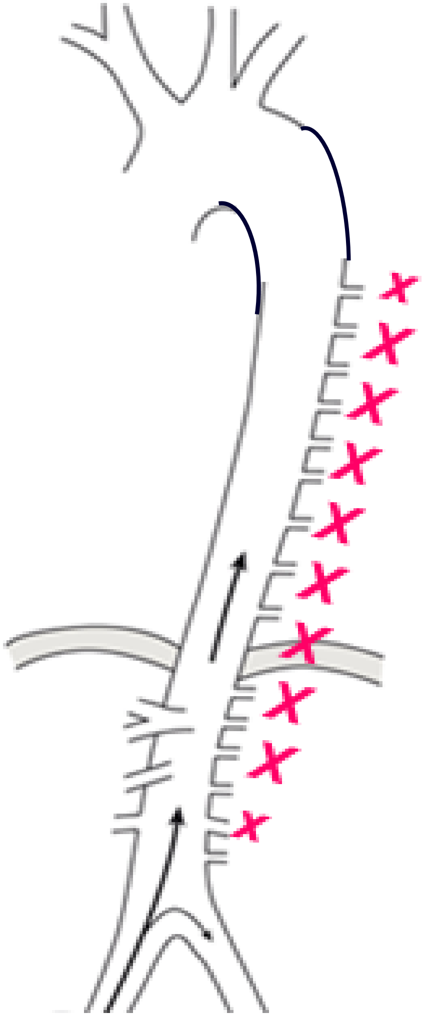
… ’During and after aortic aneurysm repair, the **spinal cord blood supply** may crucially depend on **collateral arteries**.’

‘If the theory does not fit the facts —
change the facts’

A. Einstein

Experimental Serial Segmental Artery Occlusion

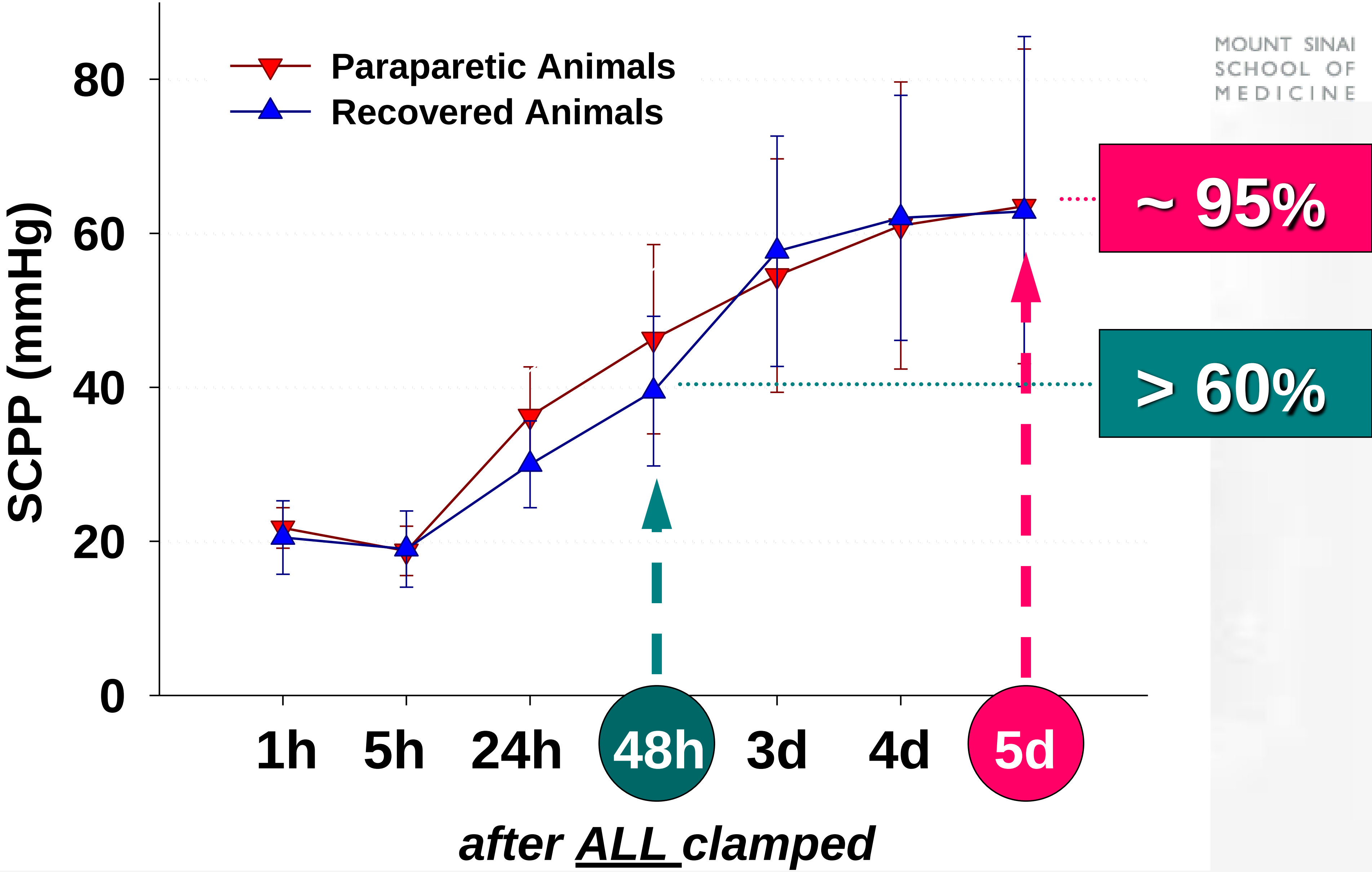




Yorkshire pigs

(*N* = 20)

POSTOPERATIVE SCPP



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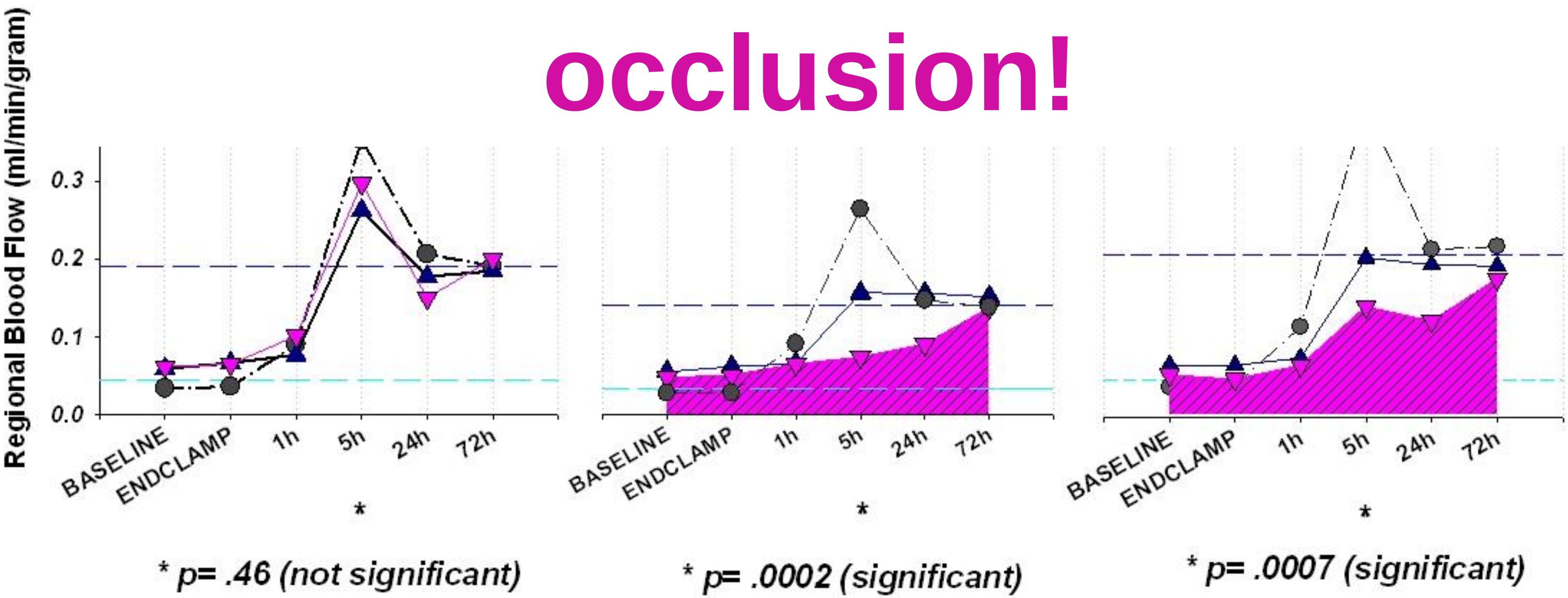
Blood flow recovery starts within hours after SA occlusion!



IDEA:

PRECONDITIONING

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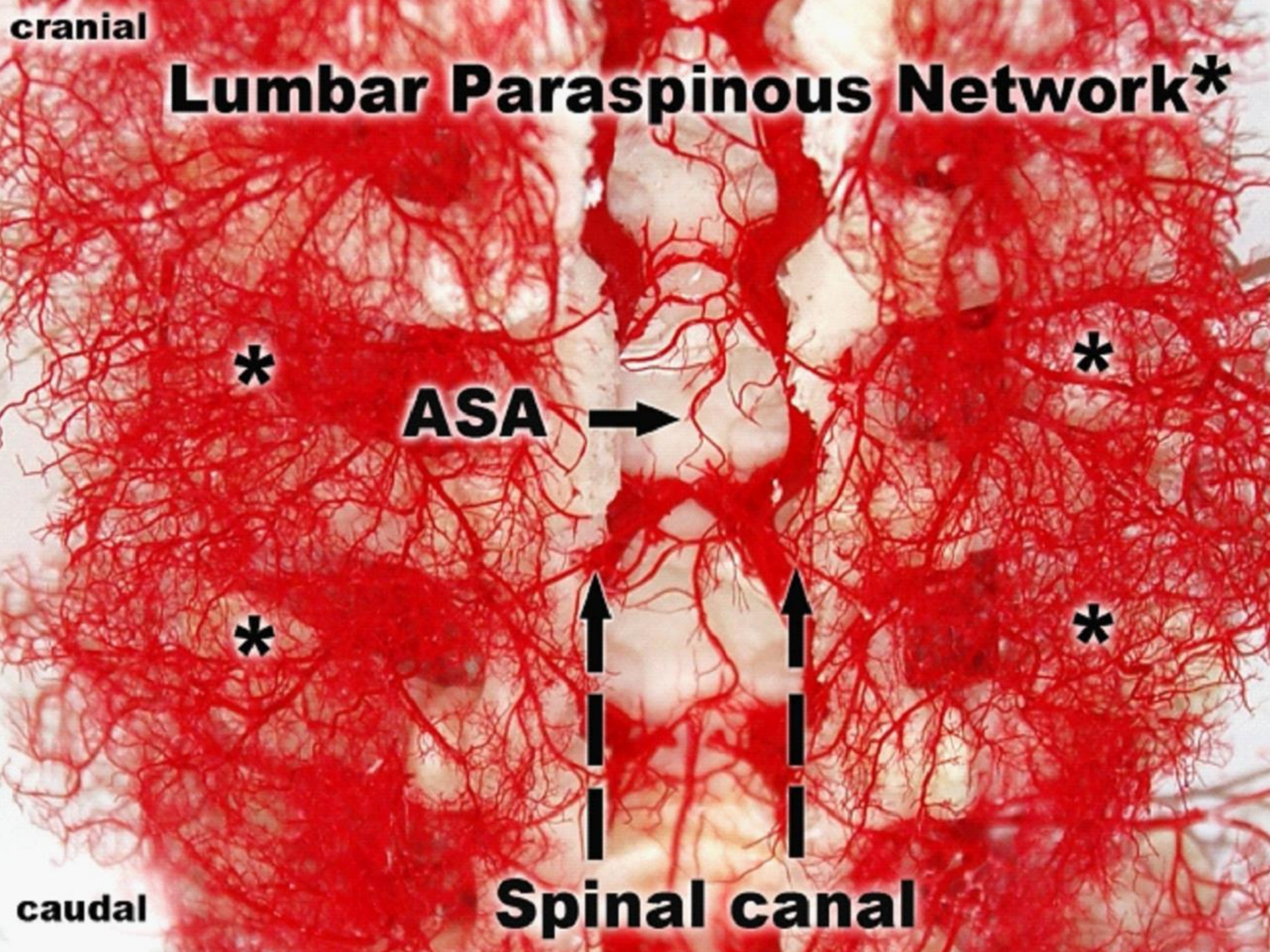
cranial
Lumbar Paraspinous Network*
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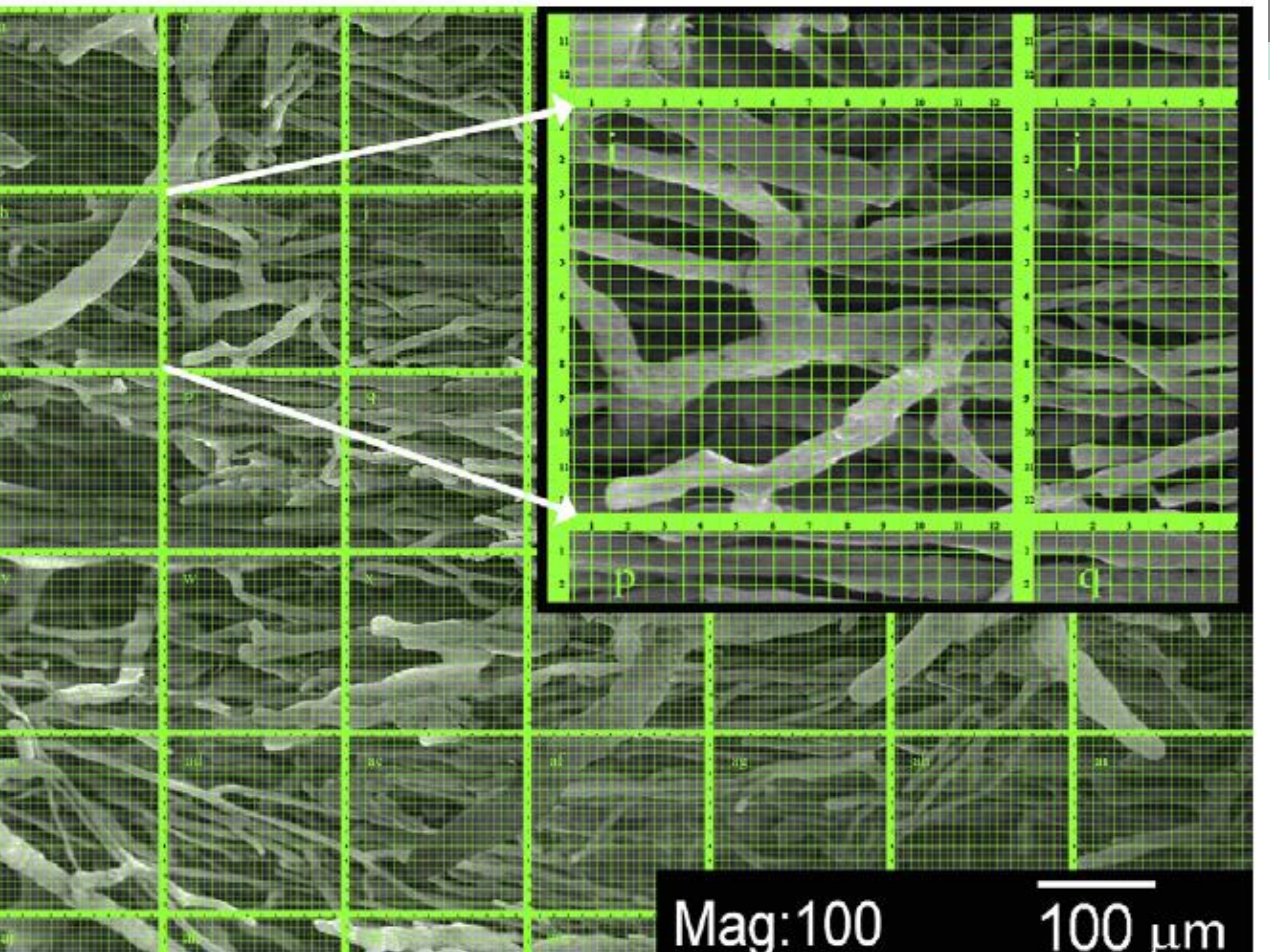
*
ASA
*
*
Spinal canal
caudal



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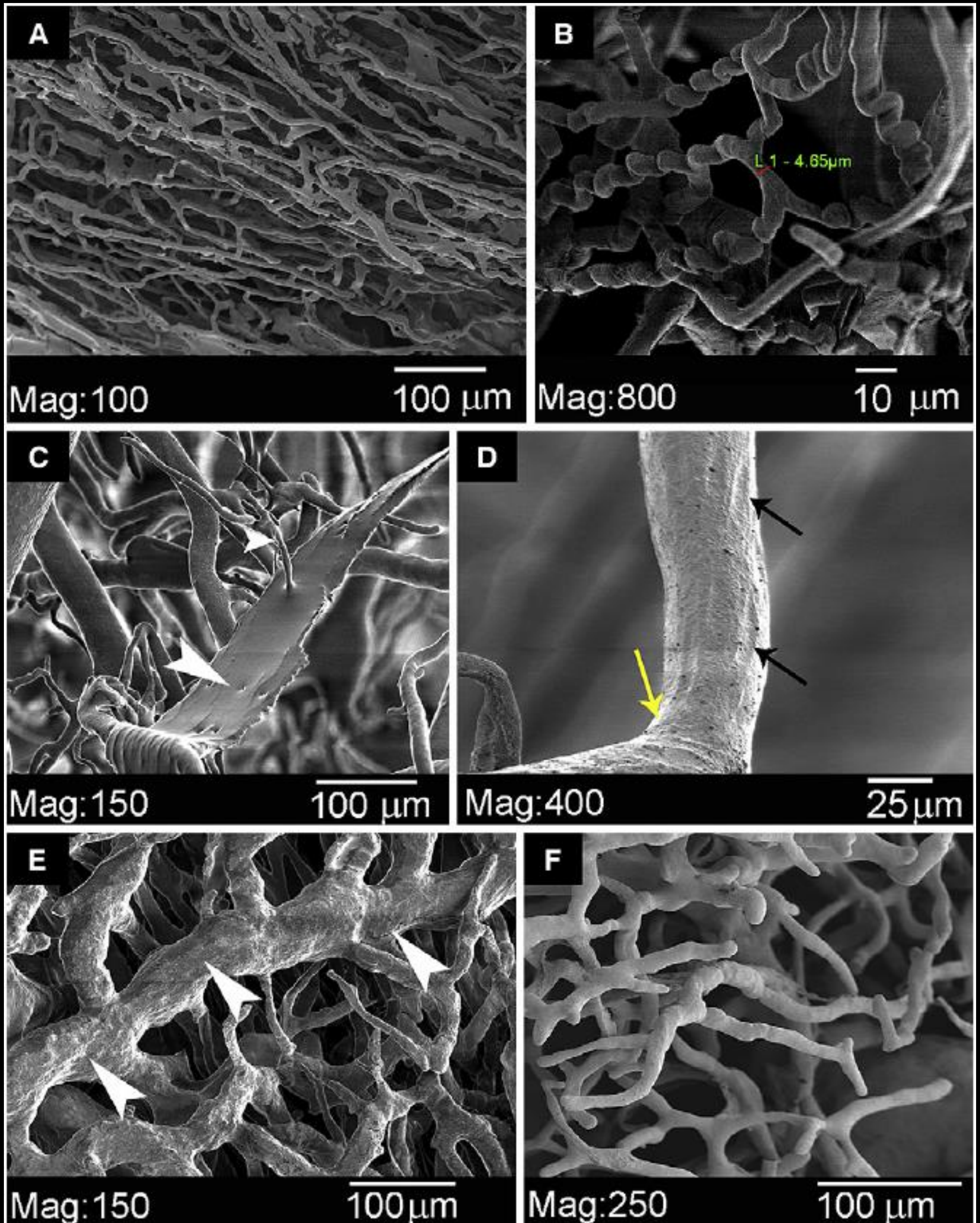
100 μm


A
Mag:100
100 µm
B
L 1 - 4.65µm
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10 µm
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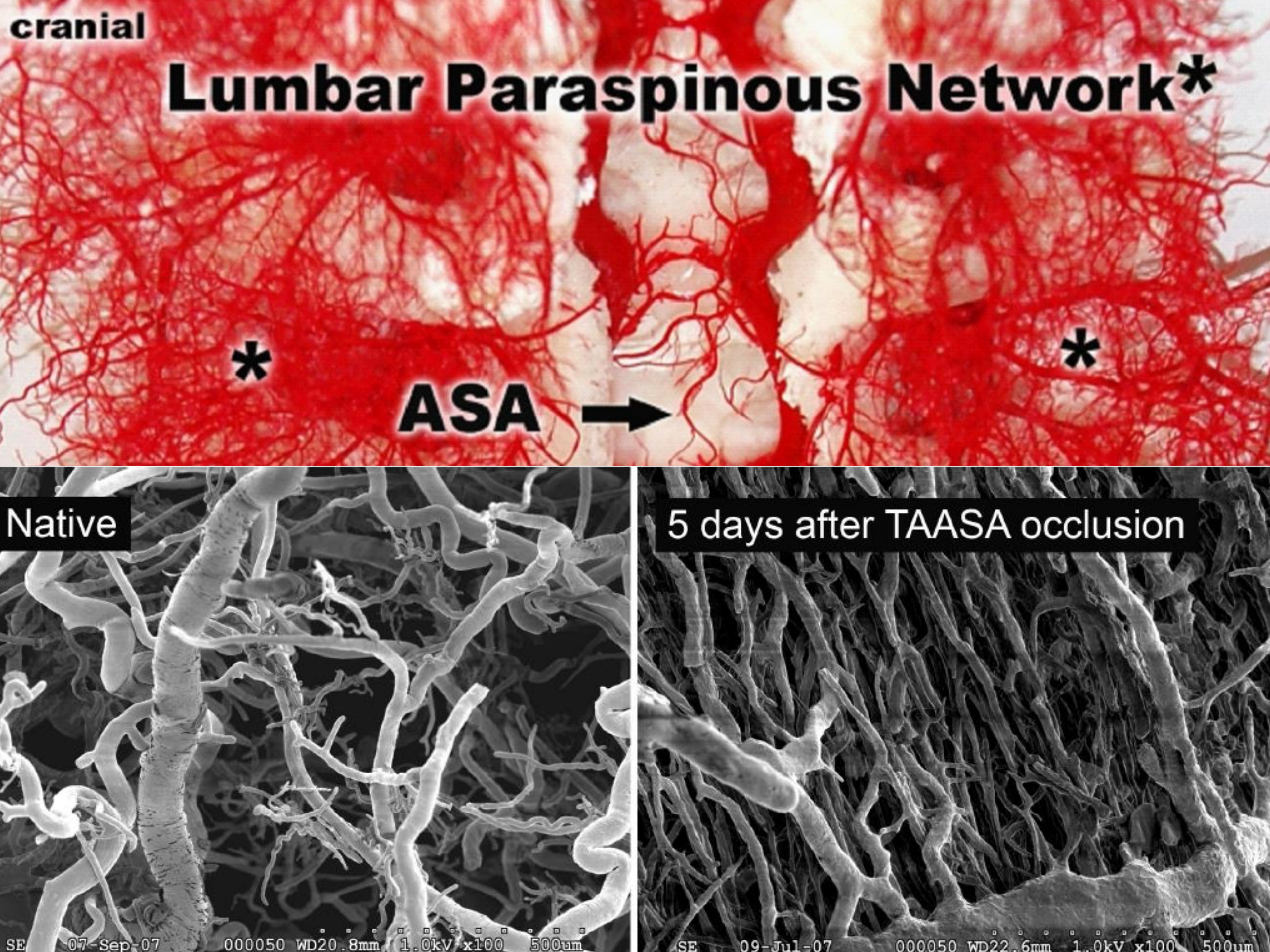
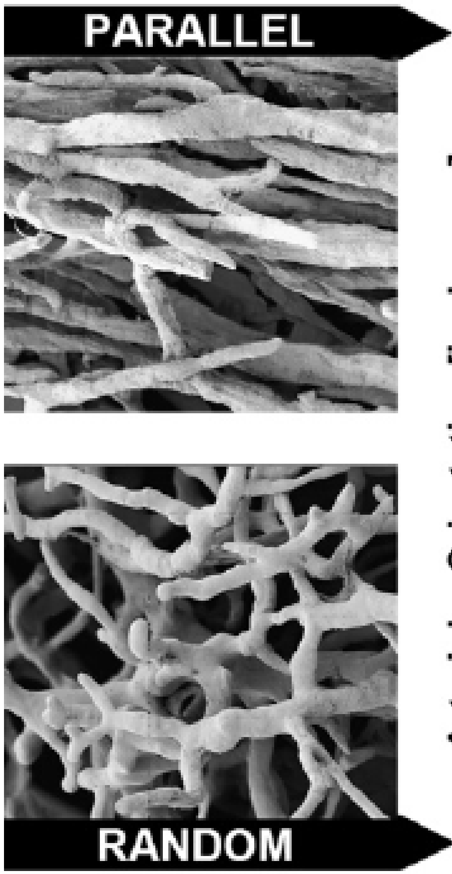
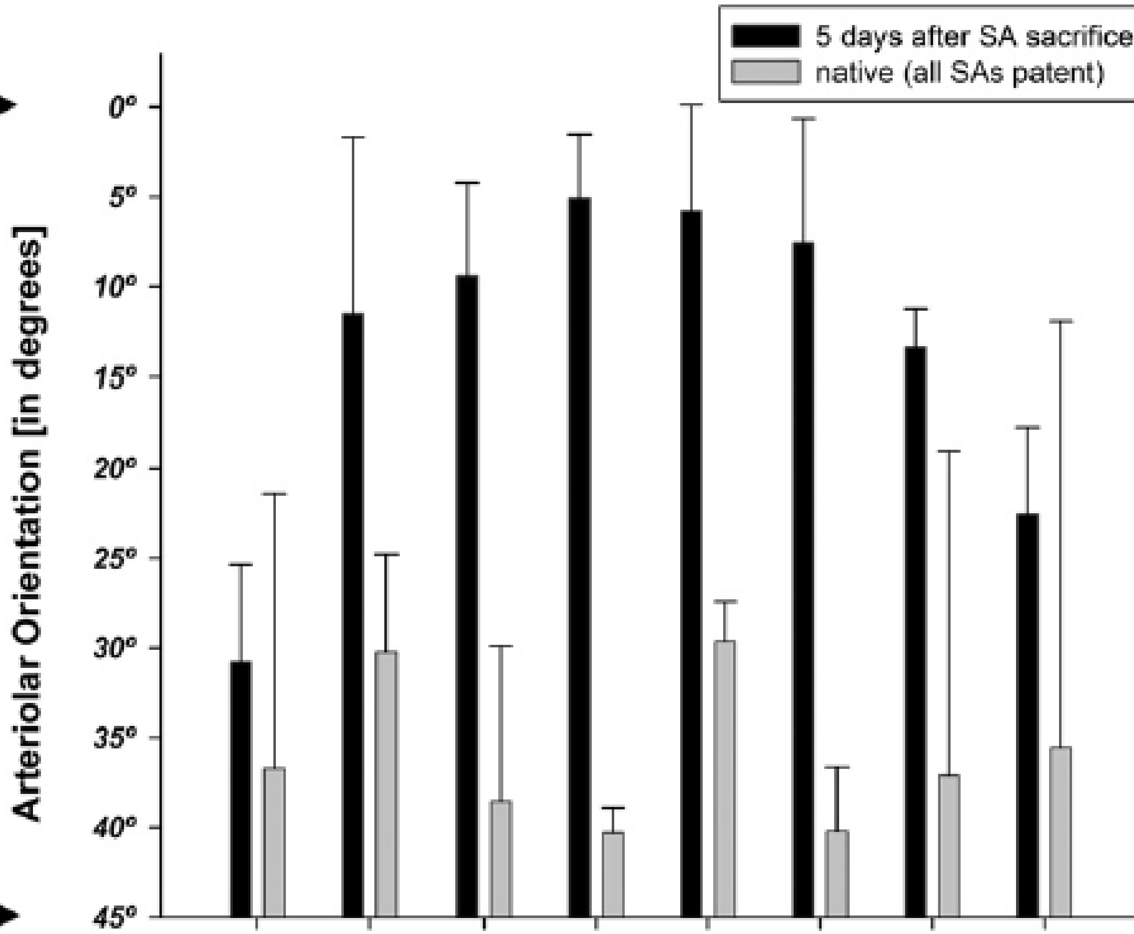
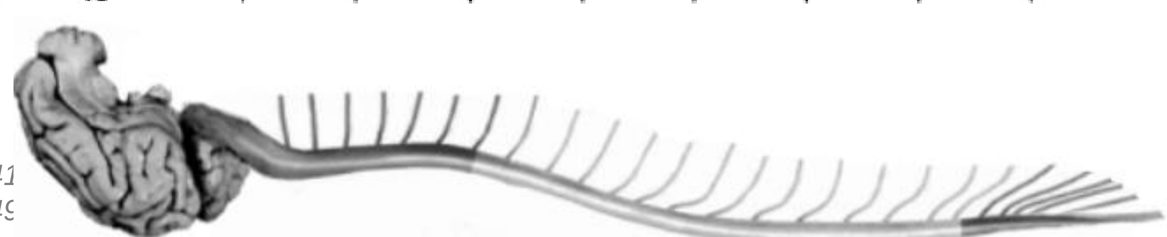
Mag:150
100µm
F
Mag:250
100 µm


cranial
Lumbar Paraspinous Network*
*
*
ASA
Native
SE 07-Sep-07 000050 WD20.8mm 1.0kV x100 500um
5 days after TAASA occlusion
SE 09-Jul-07 000050 WD22.6mm 1.0kV x100 500um

Orientation of the *Paraspinous* Collateral Network Arterioles *prior to* and *after* complete SA sacrifice







Etz et al., J Thorac Cardiovasc Surg. **2011** Apr;141
Etz et al., J Thorac Cardiovasc Surg. **2015** Apr;149

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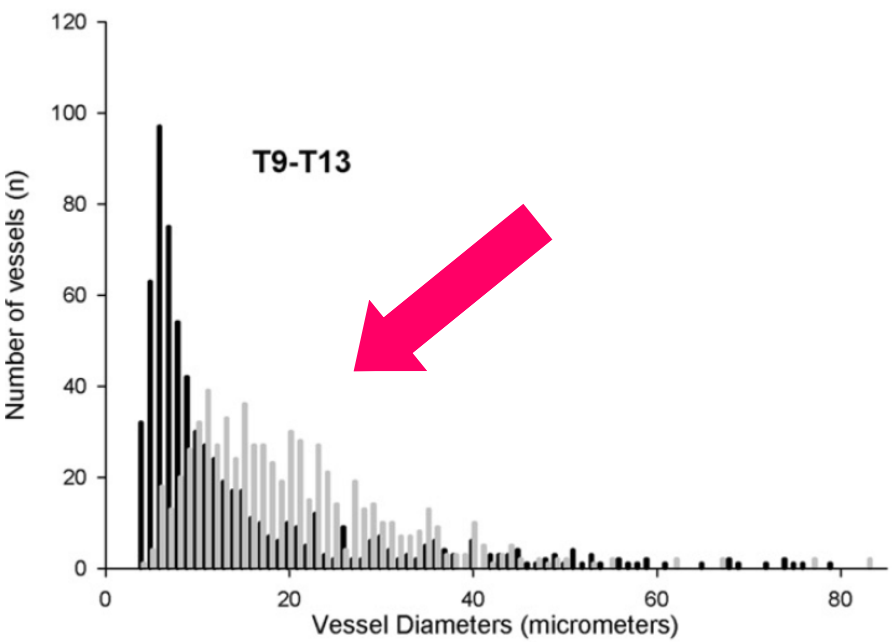
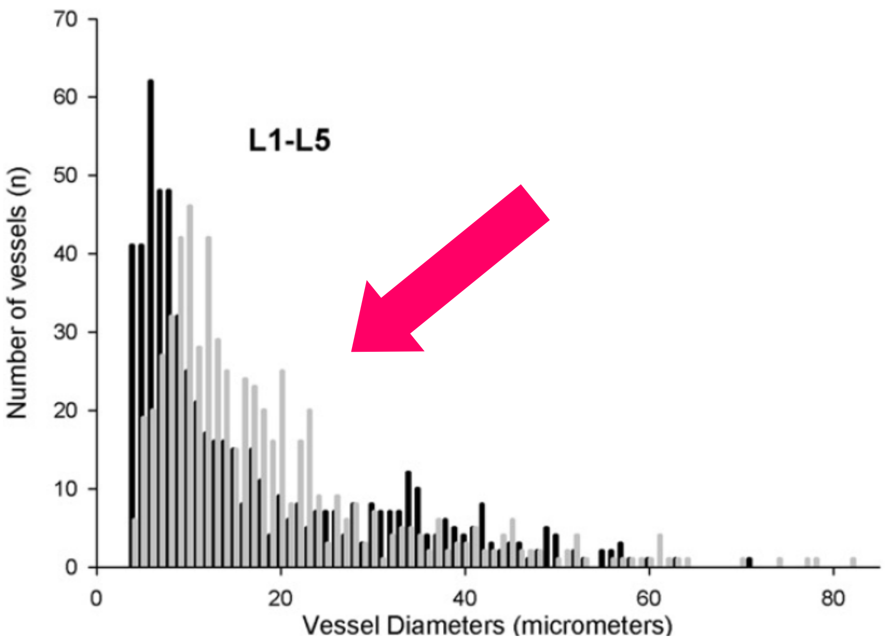
Significant Enlargement of lower thoracic and lumbar collaterals





IMPLICATION:

THE STAGED REPAIR

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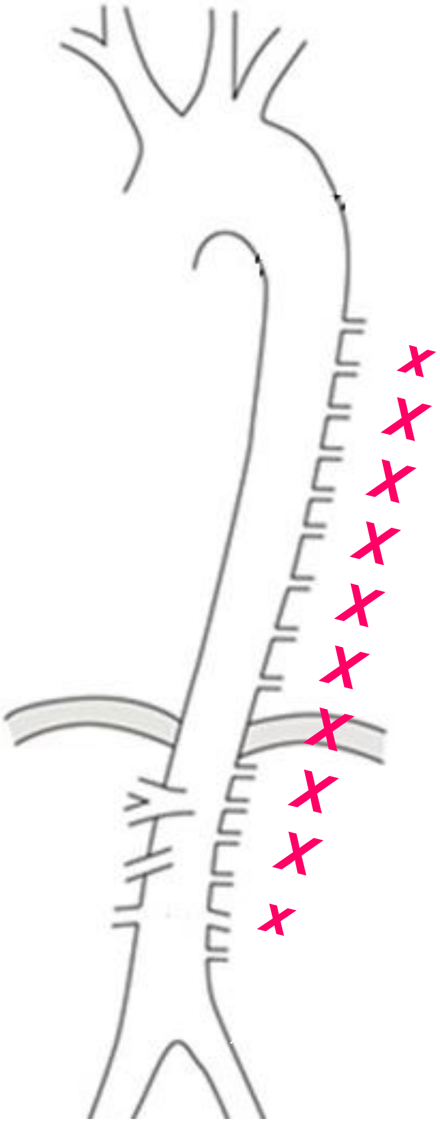
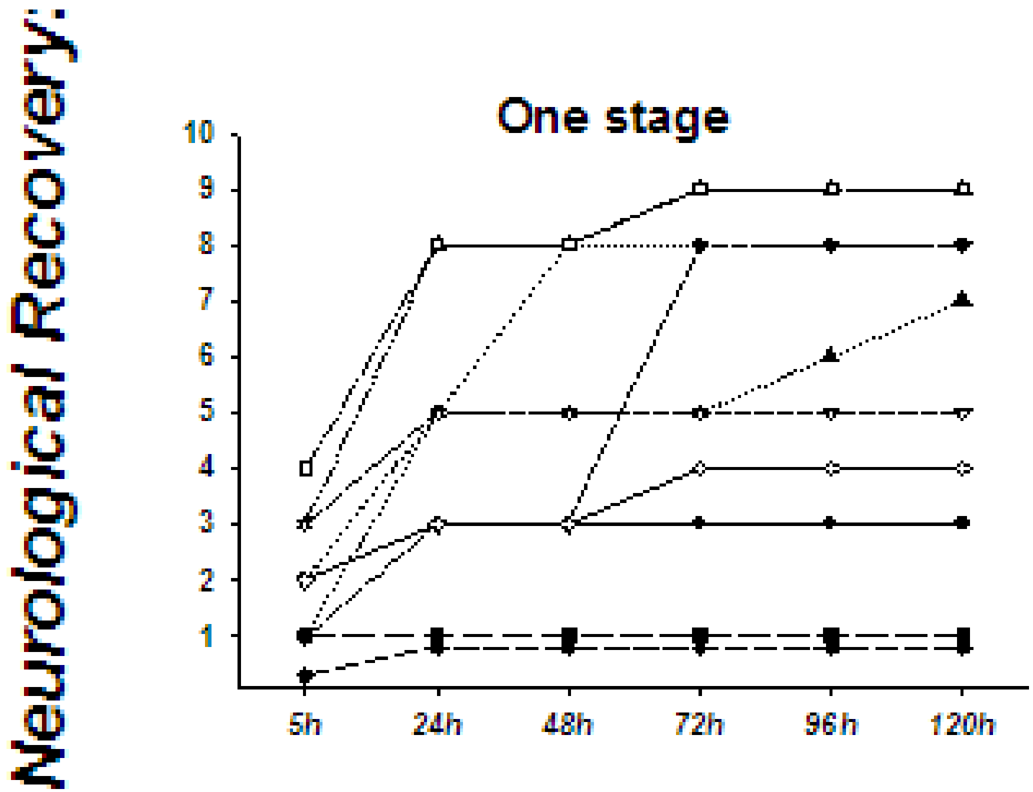
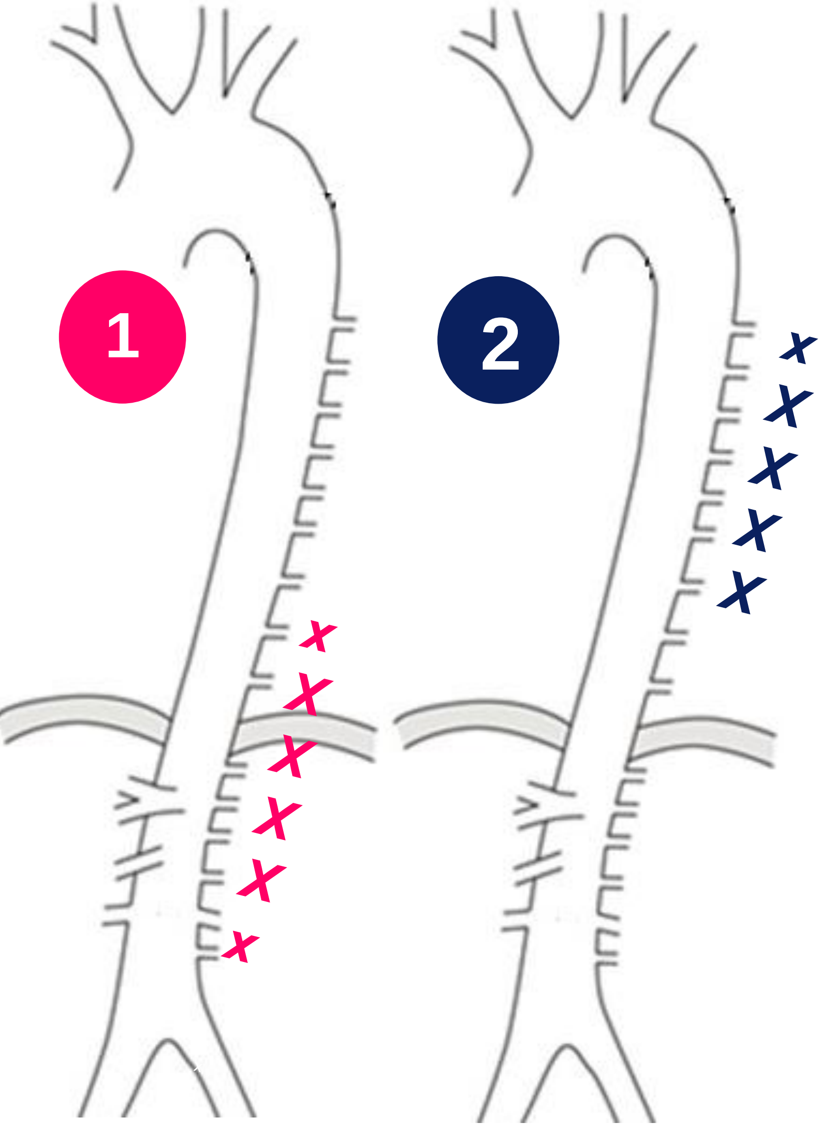
conventional approach



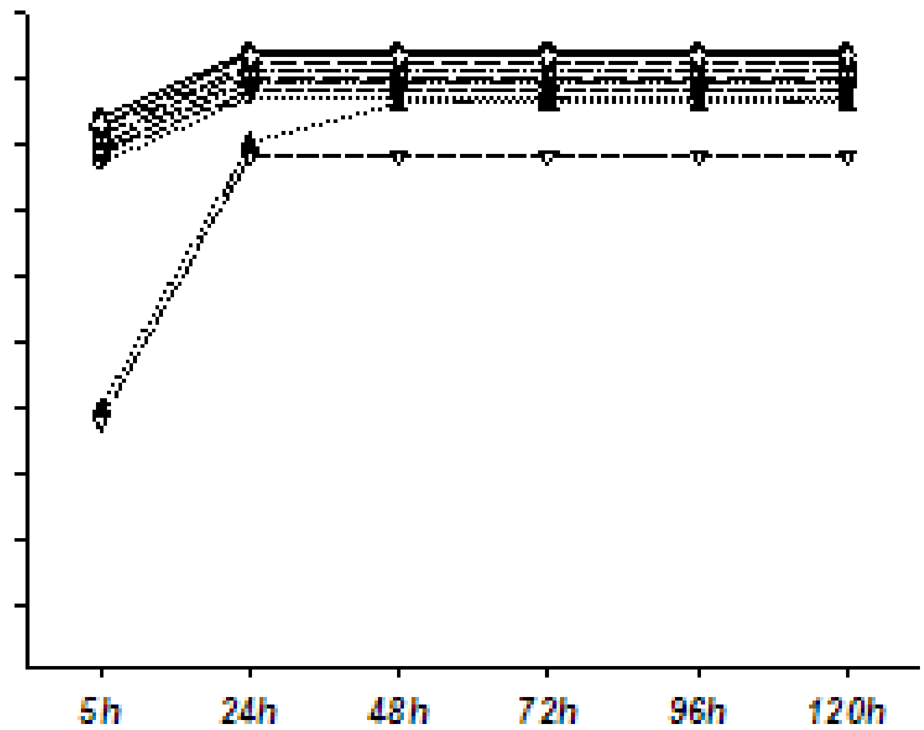


paraplegia rate: 20-30%

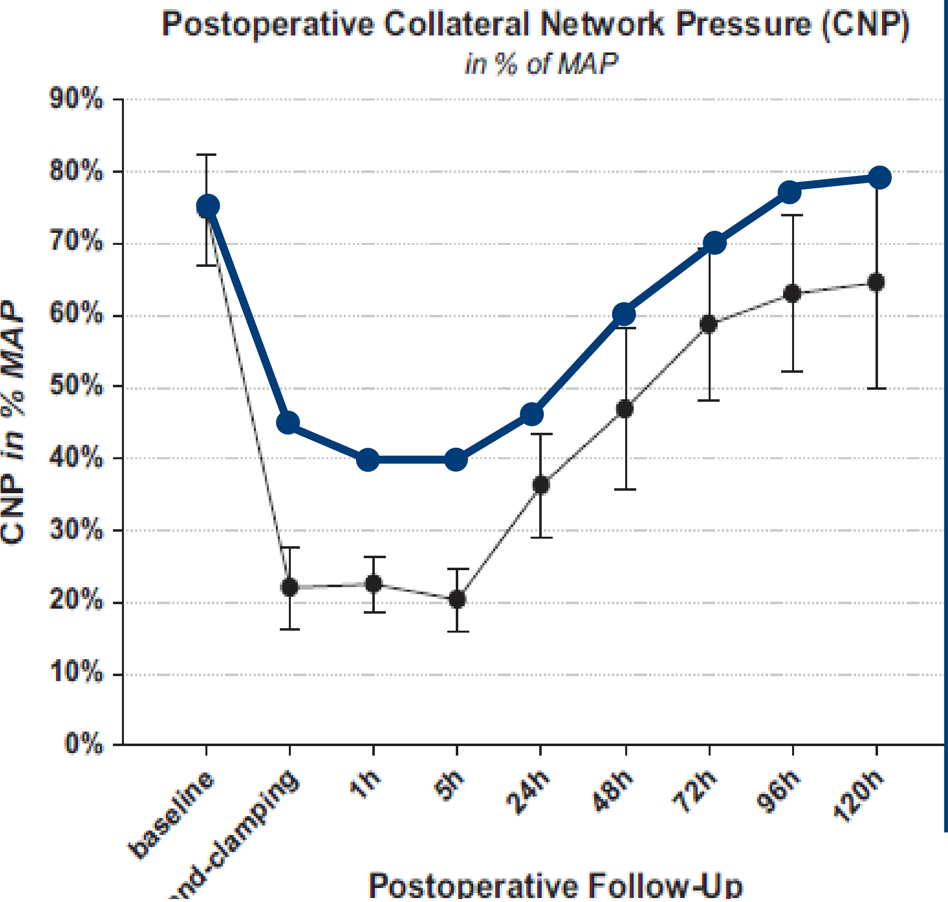
The staged repair

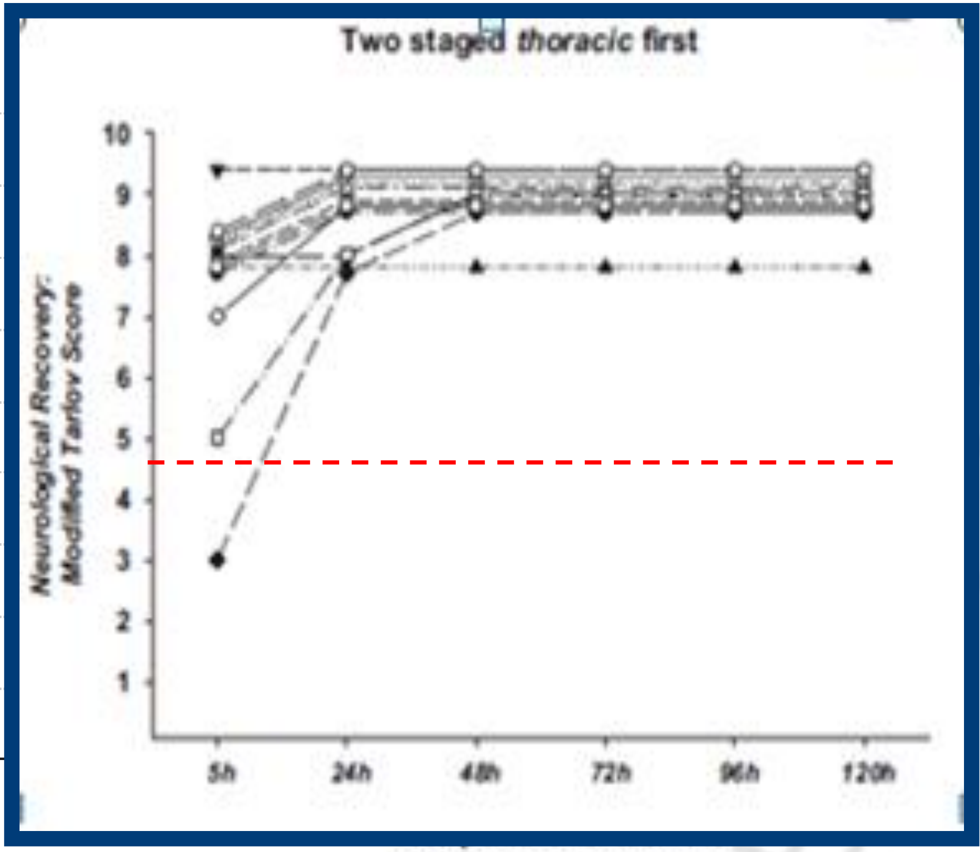


100% recovery!



After total SA Occlusion: regeneration of arterial perfusion in 5 days —





Etz et al. J Thorac Cardiovasc Surg. 2010 Dec;140(6 Suppl):S125-30

Eur J Vasc Endovasc Surg (2015) 49, 248–254

Editor's Choice – The Impact of Early Pelvic and Lower Limb Reperfusion and Attentive Peri-operative Management on the Incidence of Spinal Cord Ischemia During Thoracoabdominal Aortic Aneurysm Endovascular Repair

Staged and adjunctive procedures to preserve spinal cord flow in group 2

Following the demonstration of the potentially beneficial effects of a staged repair to encourage spinal cord pre-conditioning during extensive TAAA repair,[11] the thoracic endovascular component was implanted during the first procedure in all cases in which the anatomy was suitable (i.e., when a distal sealing zone with a maximum diameter <42 mm was present). Every effort was made to maintain the perfusion of at least one internal iliac artery (IIA); if required, iliac branched devices were employed. When left subclavian artery (LSA) coverage was deemed necessary for proximal seal, carotid subclavian transposition or bypass was performed as an initial procedure. These "first stage" procedures were performed 6–10 weeks before definitive TAAA repair.

management significantly reduces SCI following type I–III TAAA endovascular repair. With the use of these modified protocols, extensive TAAA endovascular repairs are associated with low rates of SCI.

Article history: Received 24 August 2014, Accepted 25 November 2014, Available online 6 January 2015
Keywords: Endovascular repair, Peri-operative management, Spinal cord ischemia, Thoracoabdominal aortic aneurysm

group 1
conventional endo

14.0% SCI

group 2
+ lower limb perfusion
+ post op maintanance of high blood pressure
+ staged procedure

1.2% SCI

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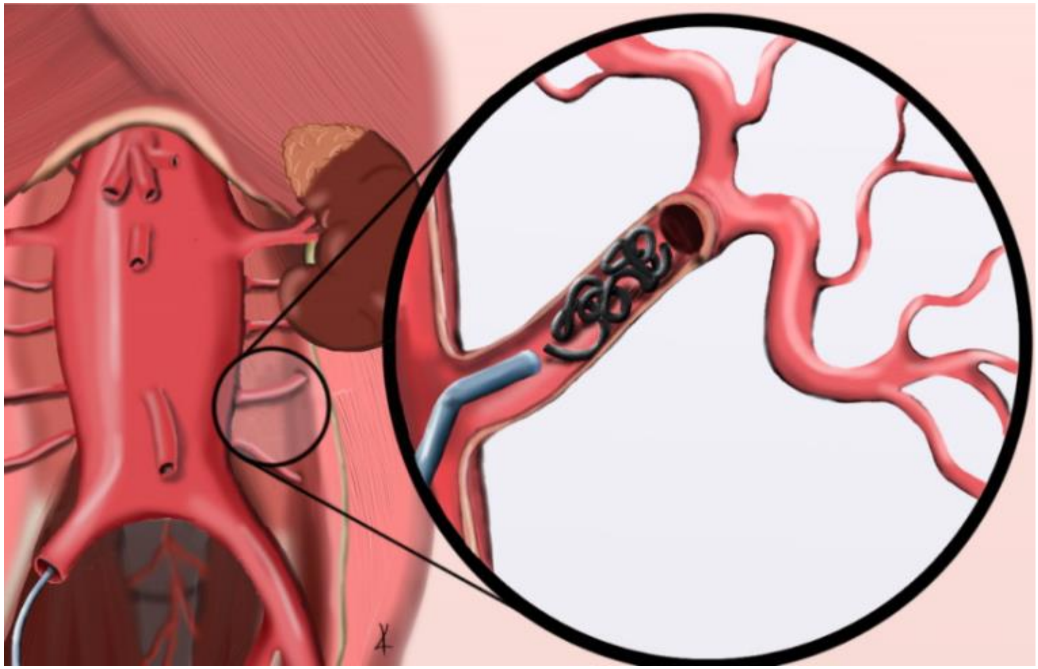
Minimally invasive
Segmental artery coil embolization



Minimally invasive coil deployment - schematically

Coil-occluded (right) / patent SA (left)

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Hypothesis: Preemptive Conditionig with Minimally Invasive Segmental Artery Coilembolisation (MISACE) may help to prevent SCI

J Thorac Cardiovasc Surg. 2014 January ; 147(1): 220–226. doi:10.1016/j.jtcvs.2013.09.022.

Endovascular Coil Embolization of Segmental Arteries Prevents Paraplegia After Subsequent TAAA Repair – An Experimental Model

S Geisbüsch, MD[1], A Stefanovic[1], JS Koruth, MD[2], HM Lin, ScD[3], S Morgello, MD[4], DJ Weisz, MD[5], RB Griepp, MD[1],

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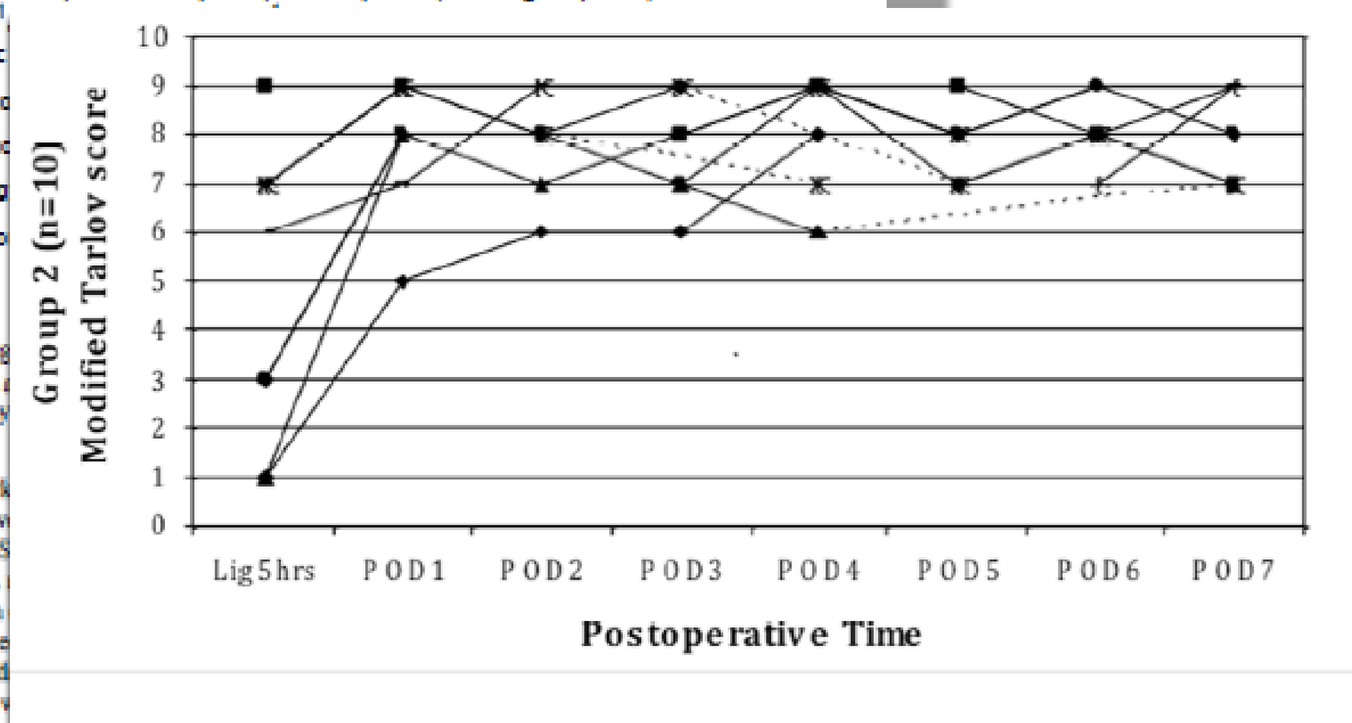
[2]Department of Cardiology, Mo

[3]Department of Health Evidenc

[4]Department of Neuropatholog

[5]Department of Neurology, Mo



Abstract

Objective—To test a strateg extensive thoracoabdominal a arteries (SAs) endovascularly model.

Methods—30 juvenile York —intercostal and lumbar—w and occlusion of intercostal S before this simulated TAAA occluded using embolization (T11-L3). No SAs were coile daily videotapes using a mod each segment of spinal cord w 0=normal, 8=complete necrosis.

Results—Hind limb function remained normal after coil embolization. After simulated TAAA repair, paraplegia occurred in 6/10 control pigs, but only 2/10 pigs in Group 1: no pigs in Group 2 had SCI. Tarlov scores were significantly better in Group 2 (Control vs 1 p=0.06; Control vs 2 p=

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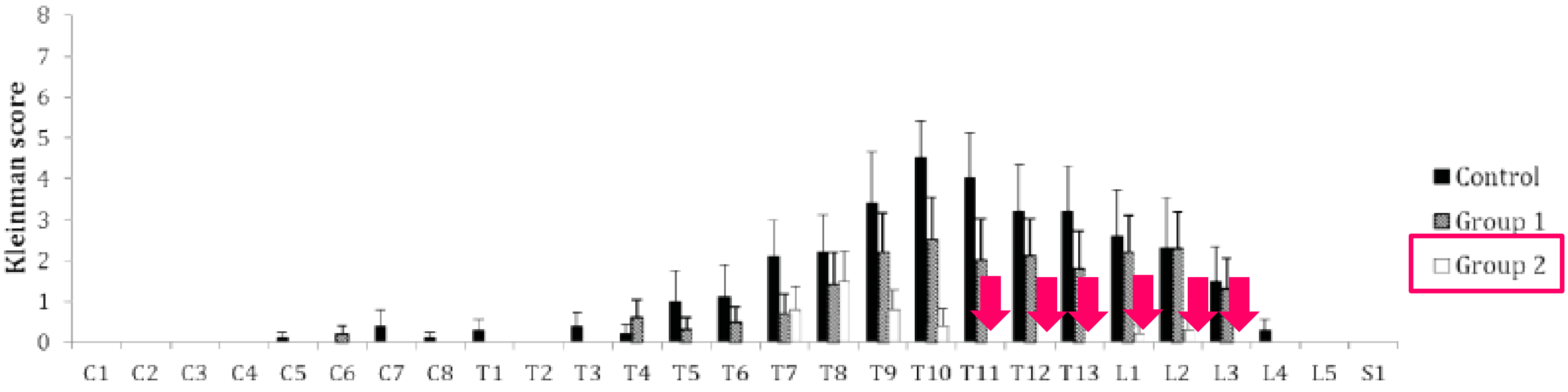
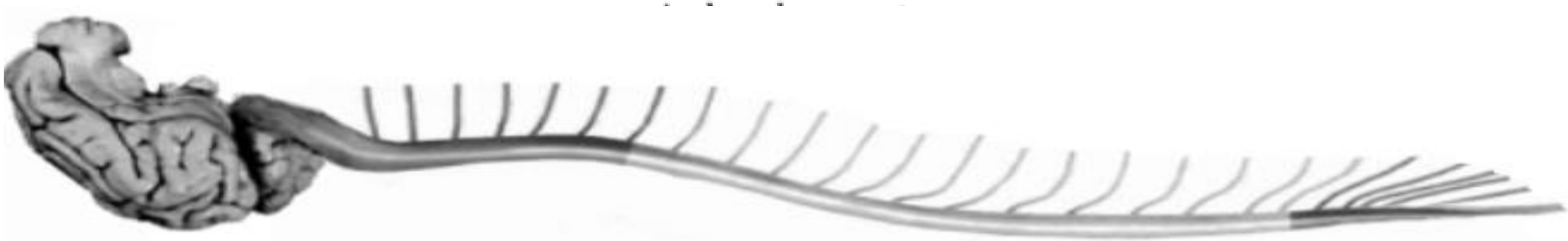
MISACE: safety

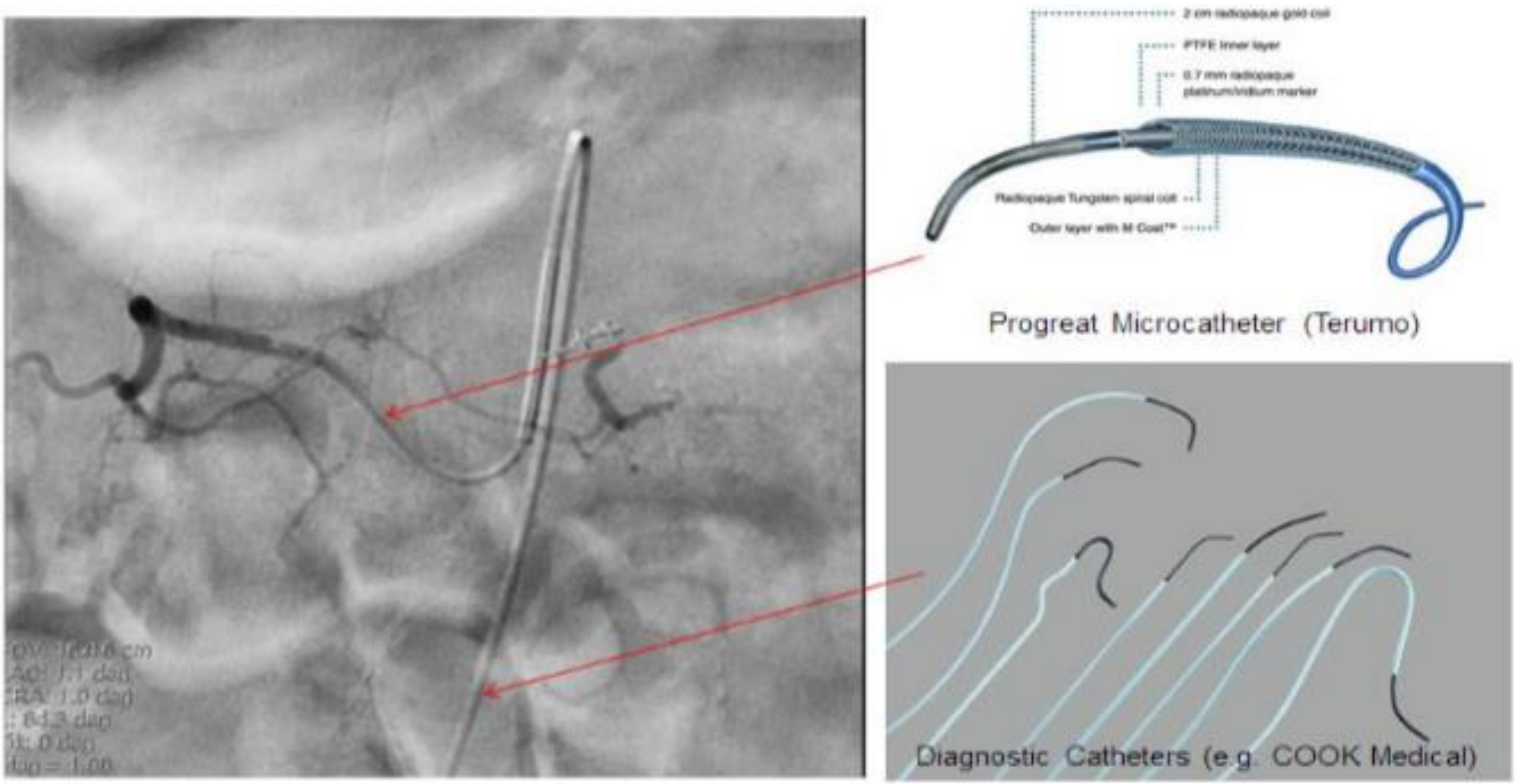




Spinal cord damage was most prominent in the T9–T13 region. Almost no necrosis is seen in the coiled region (T11-L3) for Group 2.

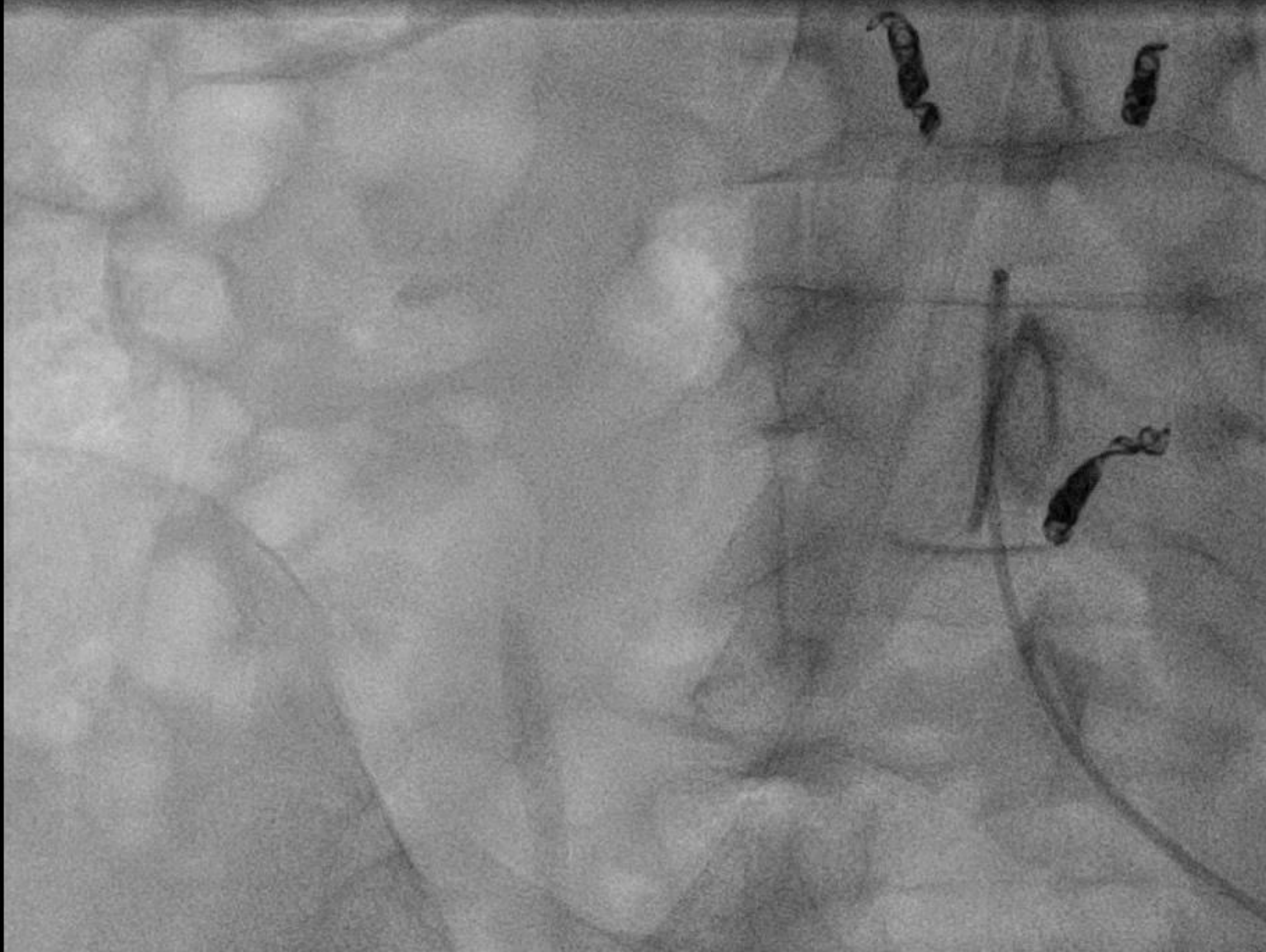
Geisbüsch et al.

no histologic damage in coiled areas !



MISACE technique

MISACE proof of concept – ‚**FIRST-IN-MAN**‘

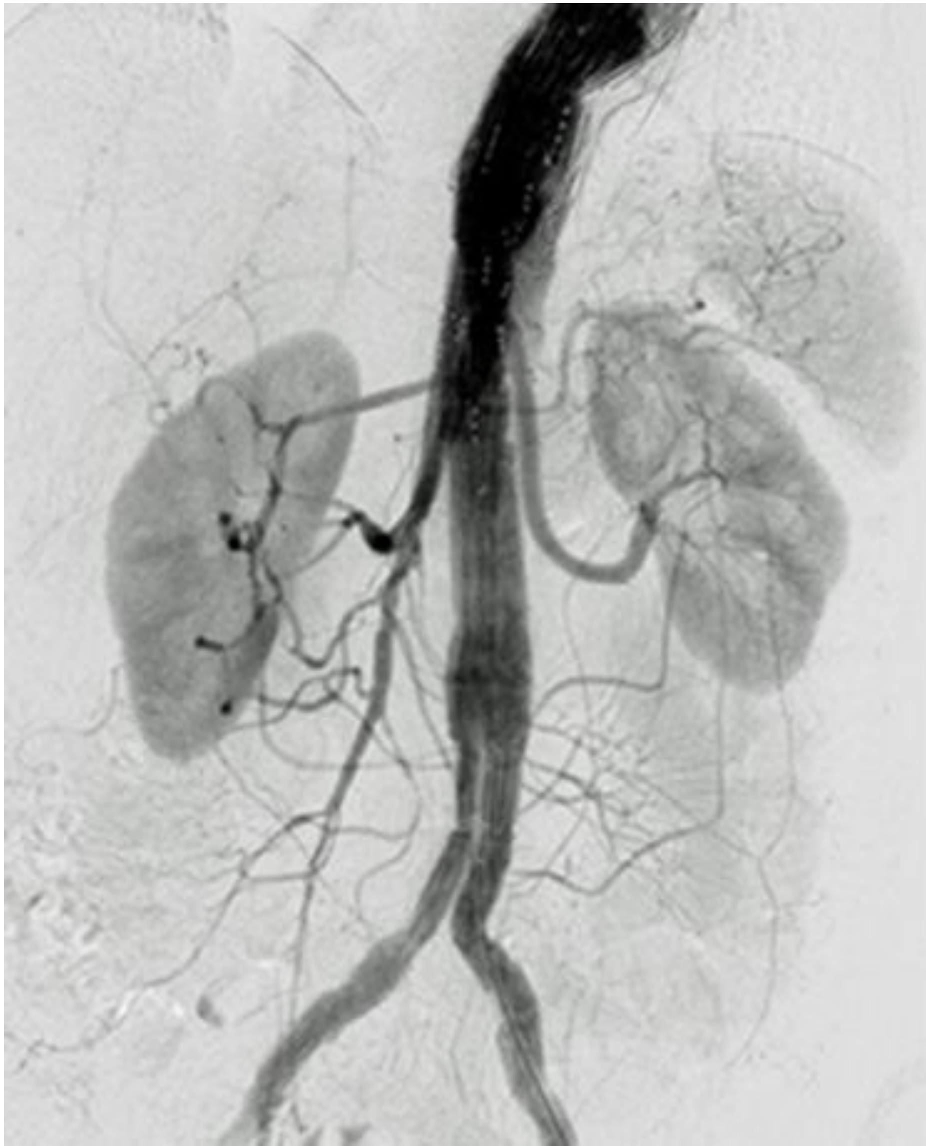


MISACE

Endovascular repair
2nd-stage

- **8 week interval**
- **Endo repair** with a **four-branched stent-graft** (T-branch, CE-marked, Cook Medical, Bjaeverskov, Denmark) in general anesthesia with adjunctive CSF-drainage
- all remaining open SAs between the T7 and the infrarenal aorta occluded **w/o endoleakage**

discharged home w/o neurologic deficit on POD #8



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1. staged preconditioning — now clinically available
2. staging with only 1-2 sessions in the cath lab
3. reduced steal / clean OR field / shorter OR times
4. reduction of type II endoleakage after endo repair

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ACD

EDITORIAL COMMENTARY

Setting the stage: Thoracoabdominal aortic aneurysm repair in 2 acts

Grayson H. Wheatley III, MD

See related art

Ischemic spinal cord injury

cord ischemia. Perioperative adjuncts such as intraoperative monitoring of spinal cord function with motor- and

The third breakthrough represented by the MISACE technique is that an interval is needed between coil-embolizing

‚There are several important breakthroughs relating to managing and preventing spinal cord injury that have been simultaneously brought together with the MISACE technique.‘

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Philadelphia, Pa.
Disclosures: Author has nothing to di
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available ahead of print Feb 4, 201
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(E-mail: grayson.wheatley@tuhs.t
J Thorac Cardiovasc Surg 2015;149:1
0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2014

ACD

technique is the capacity to selectively coil-embolize segmental arteries. Although this can be done with percutaneous techniques using local anesthesia, the ability to selectively cannulate a segmental artery is very intricate and not simple. This is especially the case in patients undergoing TAAA with tortuous anatomy and thrombus in the aneurysm sac. The authors note that in 1 of their patients, the tortuous iliac artery anatomy prevented them from coil-embolizing a unilateral segmental artery. Moreover, once the vessel is selectively cannulated, it is important to preserve as much of the collateral network as possible by only occluding the ostium of the segmental artery. These techniques are not within the realm of most aortic surgeons and frequently multidisciplinary collaboration is required.

vascular, needs to be in the minds of aortic surgeons and interventionalists. Etz and colleagues[3] have exposed a new frontier in managing and helping prevent spinal cord injury associated with TAAA repair.

References

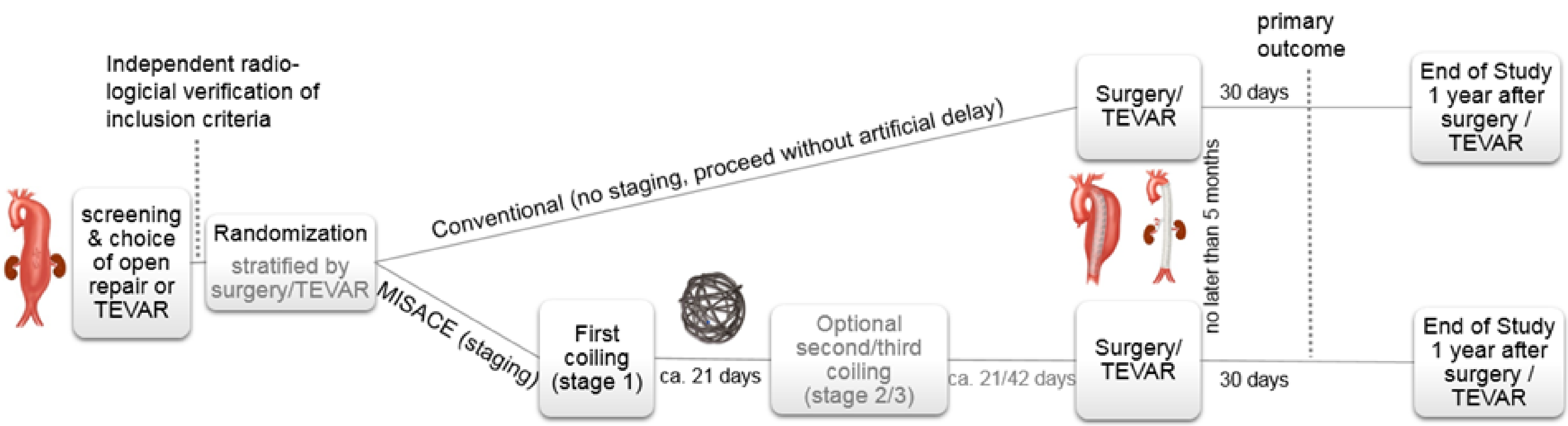
1. Griepp RB, Griepp EB. Spinal cord perfusion and protection during descending thoracic and thoracoabdominal aortic surgery: the collateral network concept. *Ann Thorac Surg*. 2007;83(Suppl):S865-9; discussion S890-2.
2. Etz CD, Kari FA, Mueller CS, Brenner RM, Lin HM, Griepp RB. The collateral network concept: remodeling of the arterial collateral network after experimental segmental artery sacrifice. *J Thorac Cardiovasc Surg*. 2011;141:1029-36.
3. Etz CD, Debus ES, Mohr WF, Kobel T. First in man endovascular pre-conditioning of the paraspinal collateral network by segmental artery coil-embolization to prevent ischemic spinal cord injury. *J Thorac Cardiovasc Surg*. 2015;149:1074-9.

multicentre, open label, randomized controlled clinical trial

PAPA_ARTiS

Paraplegia Prevention in Aortic Aneurysm Repair by Thoracoabdominal Staging with 'Minimally-Invasive Segmental Artery Coil-Embolization (MISACE)':

A multicentre randomized controlled trial (PAPA_ARTiS)



Trial duration	First patient in to last patient out (months): 40 Duration of the entire trial (months): 46 Recruitment period (months): 24

Sample size	To be assessed for eligibility: n = 450 To be assigned to the trial: n = 306 To be analysed: n = 160 (interim 1), 220 (interim 2), 275 (final)

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PAPA_ARTiS
GERMANY

1: Aachen
2: Bern
3: Essen
4: Freiburg
5: Hamburg (UKE)
6: Hanover (MHH)
7: Heidelberg
8: Innsbruck
9: Leipzig
10: Munich
11: Münster
12: Nuremberg
13: Vienna

PAPA_ARTiS **EUROPE** (Horizon 2020)

1. CH: Bern
2. DE: Freiburg
3. DE: Hamburg
4. DE: Leipzig
5. FR: Bordeaux
6. FR: Lille
7. IT: Bologna
8. IT: Milan
9. NL: Maastricht
10. PL: Zabrze
11. SE: Malmö
12. SE: Örebro
13. UK: Liverpool
14. US: Houston
15. US: Philadelphia

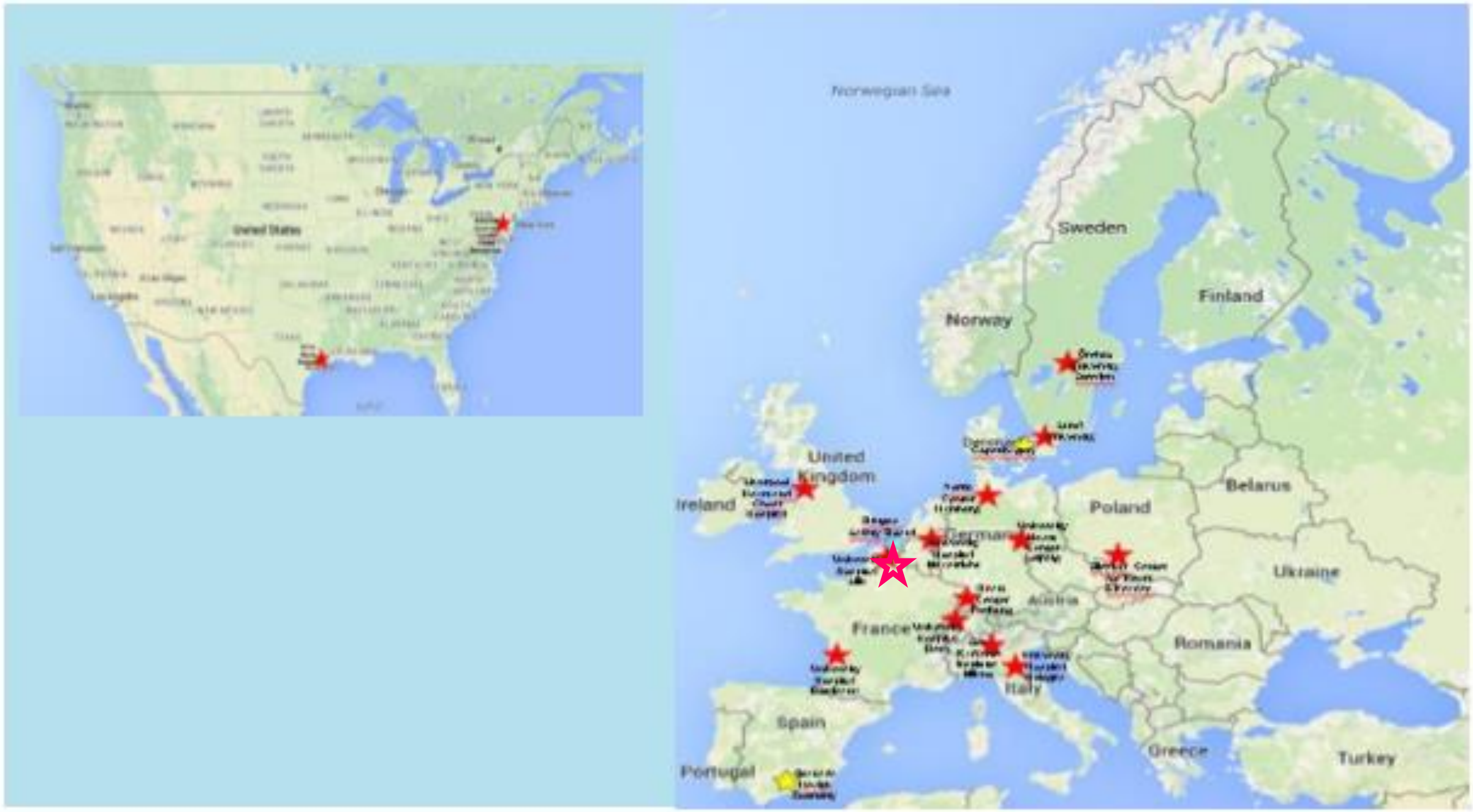

Figure 10 - Participating centres PAPA-ARTiS (EU, Switzerland and the US). Red stars represent recruitment centres and the yellow stars represent the radiology core lab (Copenhagen, WP6) and the health economics group (Grenada, WP3).

HERZZENTRU

F

Paraplegia Prevention in Aortic Aneurysm Repair by Thoracoabdominal Stag
with 'Minimally-Invasive Segmental Artery Coil-Embolization (MISACE)':
A multicentre randomized controlled trial (PAPA_ARTiS)

Independent radio-logical verification of inclusion criteria

artificial delay)

Surgery/ TEVAR

30 days

primary outcome

End of 1 yea surg

***Ultimate goal: Translation of the ‚staged repair' concept** into*

***clinical practice** to achieve*

ZERO PARAPLEGIA in

open and endo TAA/A repair

Recruitment period (months): 24

Sample size	To be assessed for eligibility: n = 450 To be assigned to the trial: n = 306 To be analysed: n = 160 (interim 1), 220 (interim 2), 275 (final)

DISCUSSION

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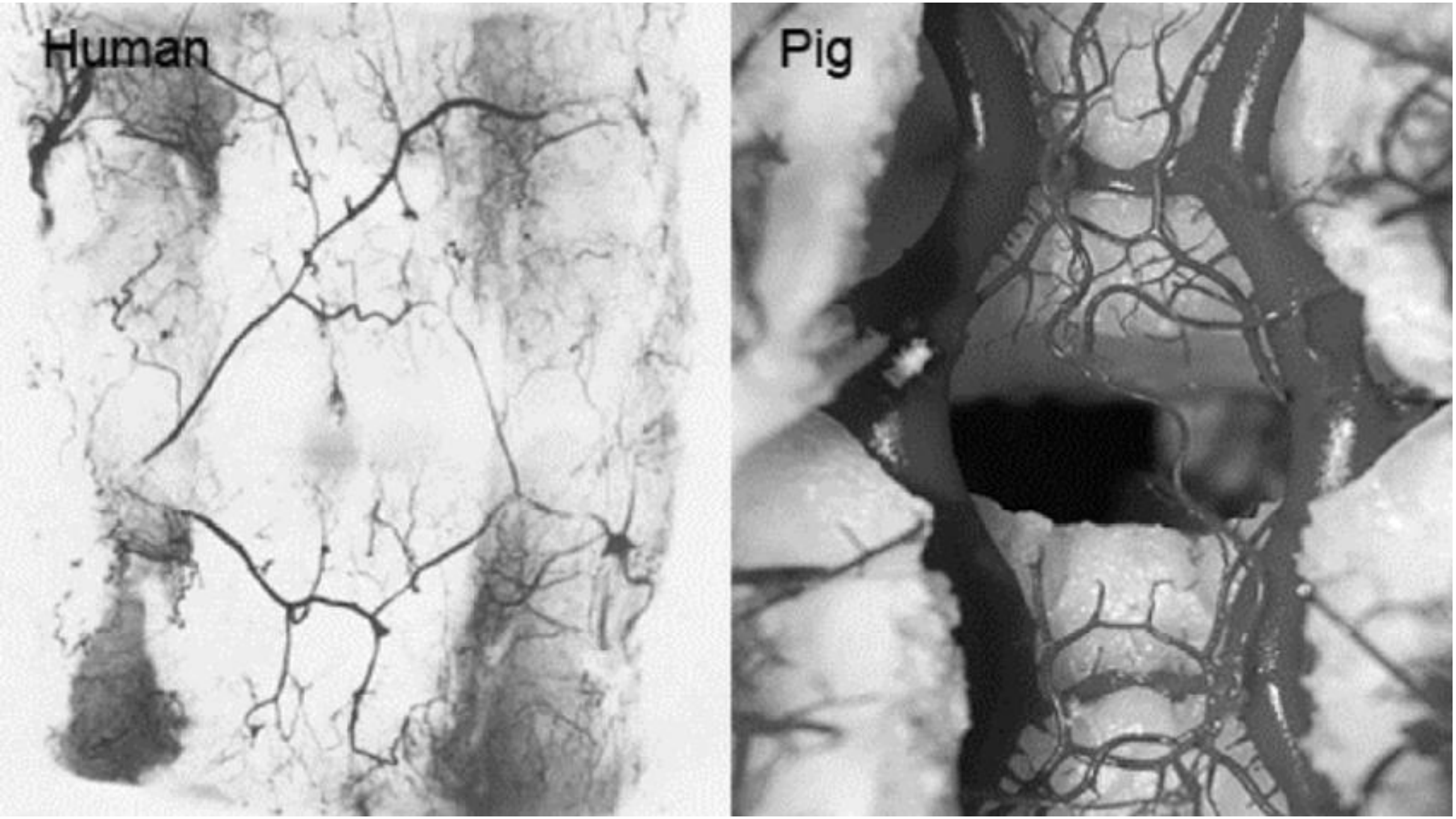
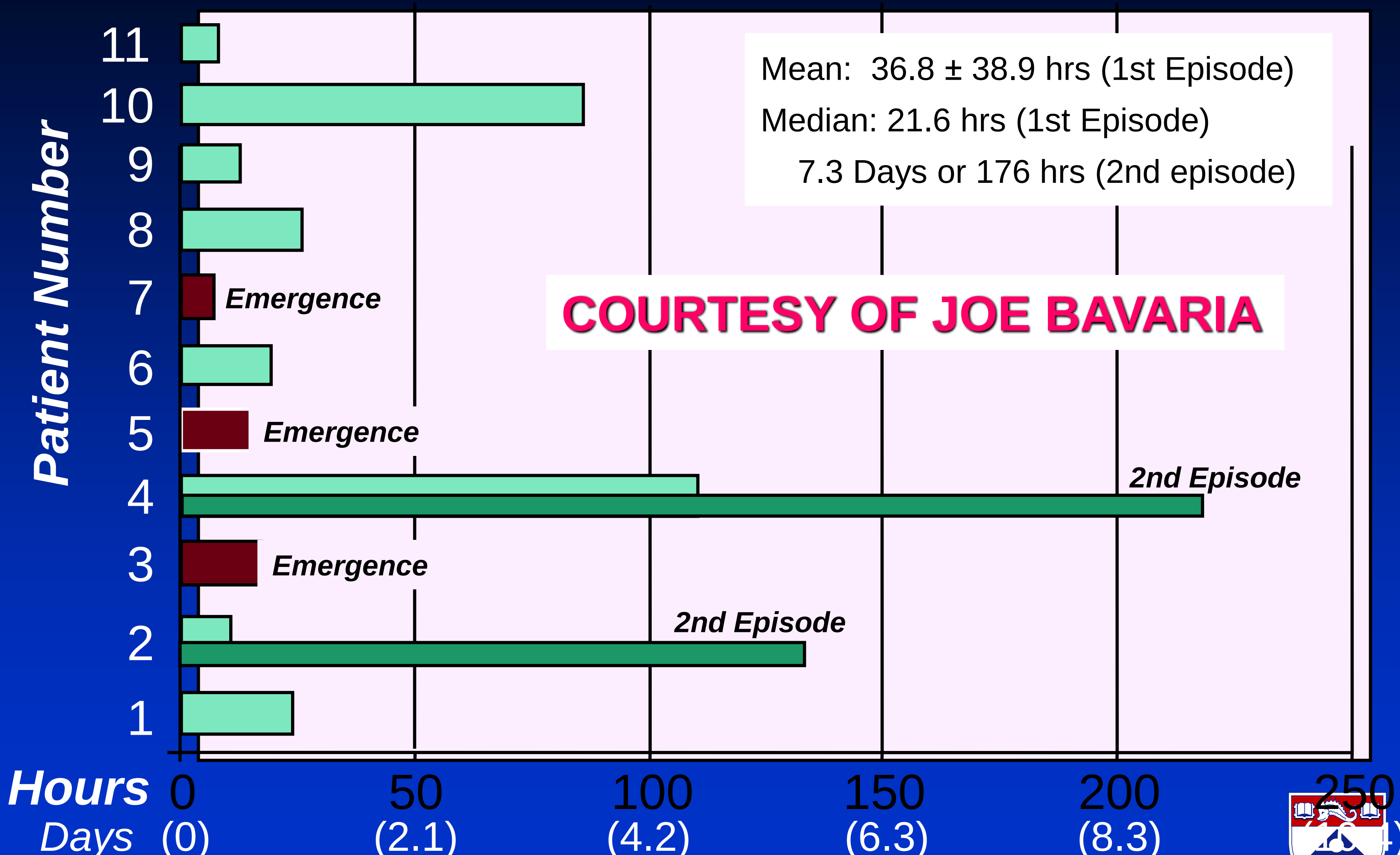


Immediate spinal cord blood flow backup (Kari et al.)

ONSET TIME OF POSTOPERATIVE PARAPLEGIA

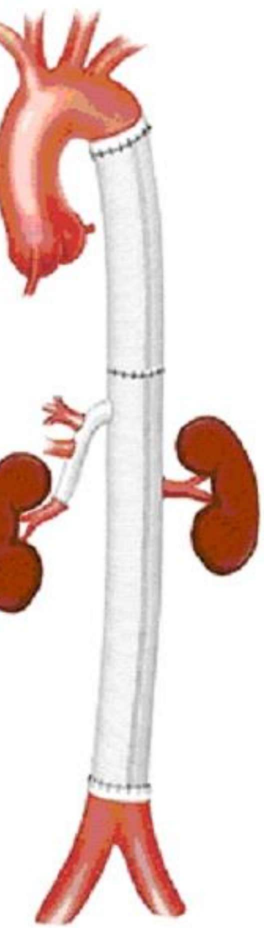
Concept: Delayed Paraplegia, timing of delayed paraplegia, and clinical support of the "Griepp/Etz Observation"



Department of Surgery, University of Pennsylvania Health System

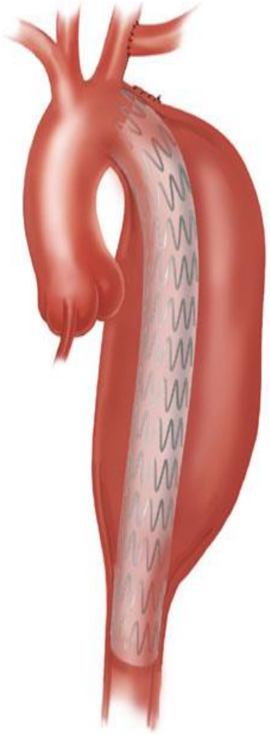
INCIDENCE

Inzidenz der Paraplegie offene Chirurgie



Open Surgery	year	N	DTA	**Type I**	**Type II**	**Type III**	**Type IV**
Greenberg et al	2008	372	1%	14%	**22%**	10%	2%
Conrad et al	2008	471	7%	24%	**20%**	13%	2%
Fehrenbacher	2010	343	1%	4.3%	**5.4%**	3.1%	0%
Coselli et al.	2007	2286	#	3.3%	**6.3%**	2.6%	1.4%
Bavaria et al	2007	94	14%	#	#	#	#
Zoli et al	2010	609	2.3%	2.5%	11.5%	3.9%	2.2%
Sundt et al	2011	99	3%	0%	0%	0%	0%
Schepens et al	2009	571		Paraplegia 5.3%, paraparesis 3%			

Inzidenz der Paraplegie Endo / Stentgraft



endo	Year	N	DTA	Type I	Type II	Type III	Type IV
Greenberg et al.[3] **	2008	352	1%	10%	**19%**	5%	3%
Gravereaux et al.[4]	2001	53	5.7%	#	#	#	#
Conrad et al.	2008	105	7%	#	#	#	#
Bavaria et al.[5]	2007	140	3%	#	#	#	#

** "***The severity of the SCI*** *(paraplegia versus paraparesis) and the potential for recovery did not differ between treatment modalities … **SCI was more commonly noted immediately after OPEN REPAIR** (29% versus 13%) **and in a delayed presentation** (up to 6 days) **after ER**"*

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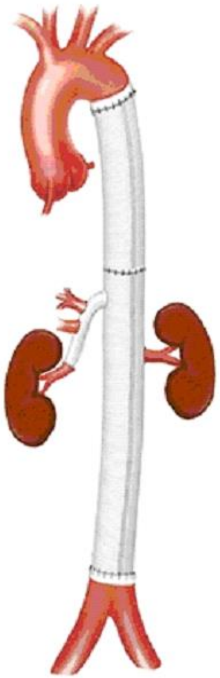

open repair

year	N	DTA	Type I	Type II	Type III	Type IV
2008	372	1%	**14%**	**22%**	10%	2%
2008	471	7%	**24%**	**20%**	13%	[illegible]
2010	343	1%	**4.3%**	**5.4%**	3.1%	[illegible]
2007	2286	#	**3.3%**	**6.3%**	2.6%	1.4%
2007	94	14% $$	#	#	#	#
2010	609	2.3%	2.5%	11.5%	3.9%	2.2%
2011	99	3% ##	0%	0%	0%	0%
2009	571	#	Paraplegia 5.3%, paraparesis 3%			

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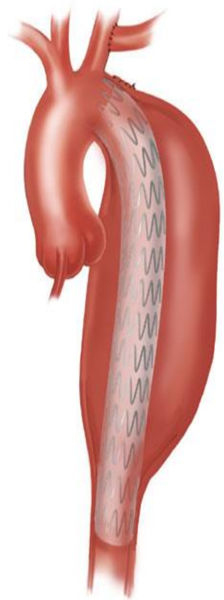


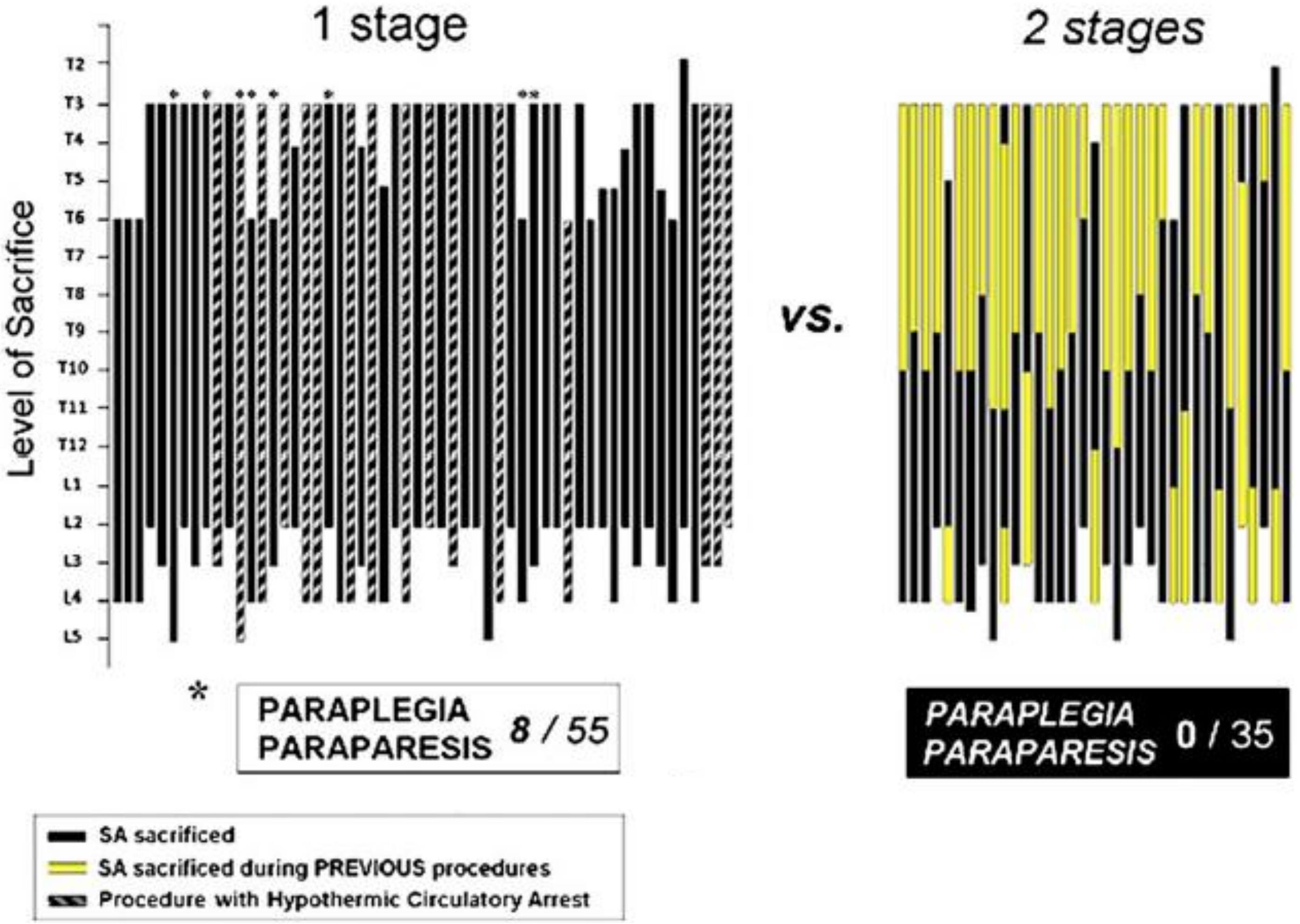
endovascular

Year	N	DTA	Type I	Type II	Type III	Type IV
2008	352	1%	10%	**19%**	5%	3%
2001	53	5.7%	#	#	#	#
2008	105	7%	#	#	[illegible]	#
2007	140	3%	#	#	#	#

!

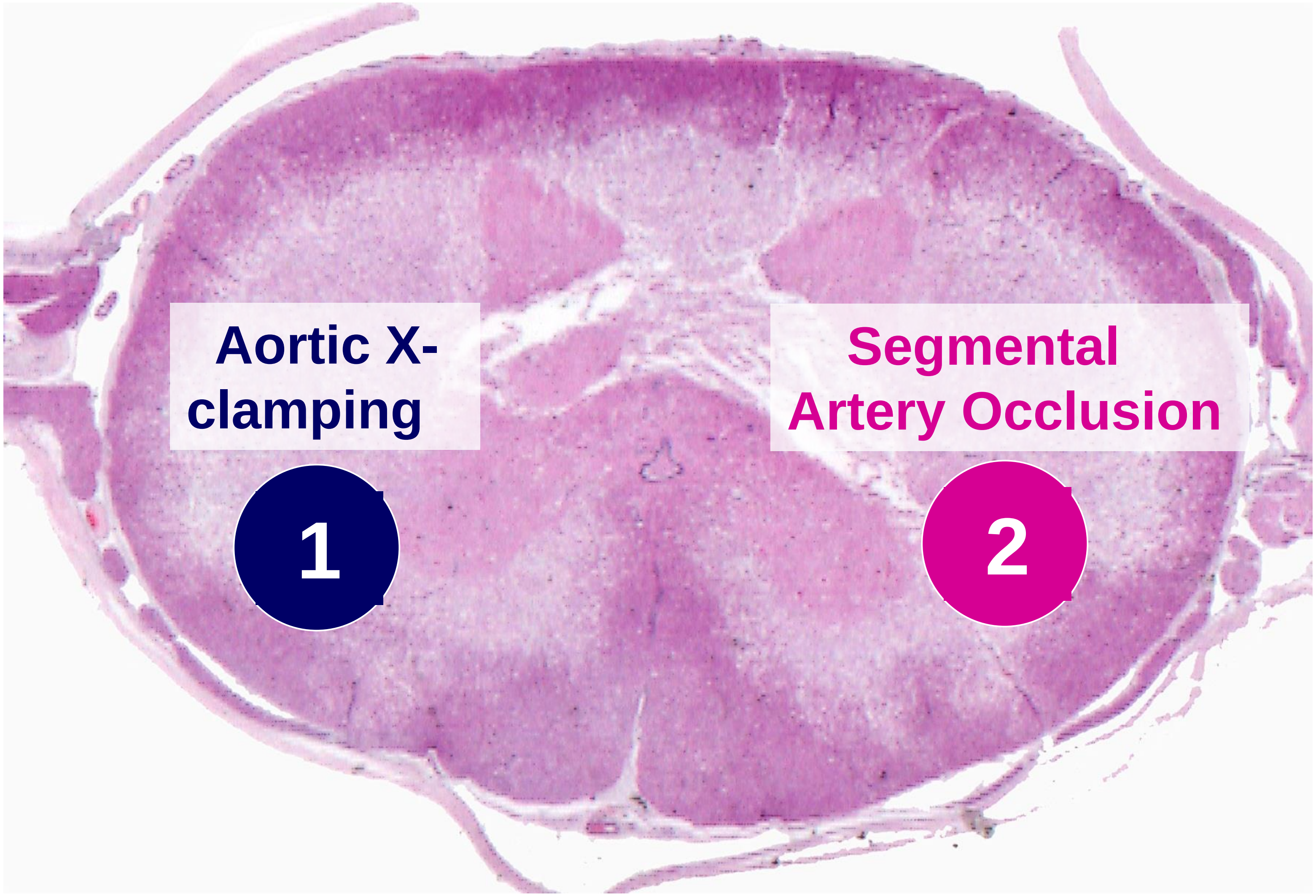
Aortic X-clamping vs. Segmental Artery Occlusion

Retrospective clinical data: significant lower incidence of SCI wit ‘staged repair’ (= staged occlusion of SAs)



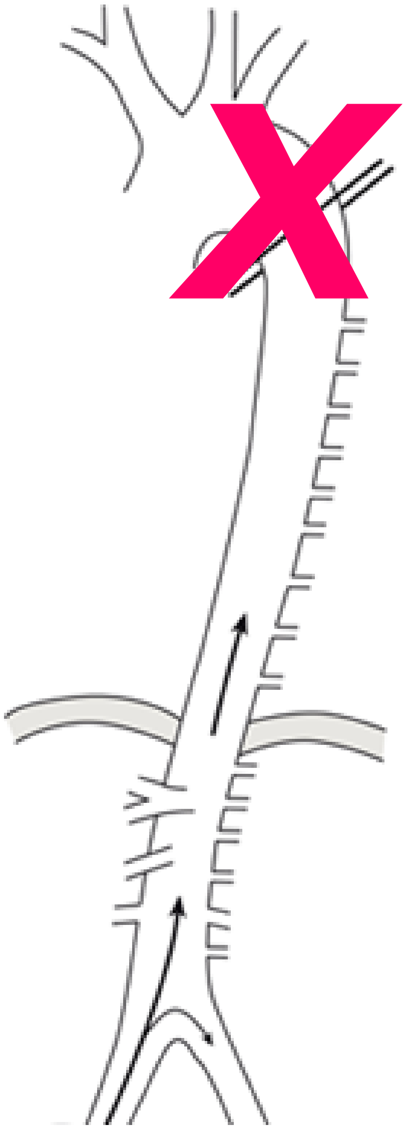
X-clamping

ischemic Spinal Cord Injury



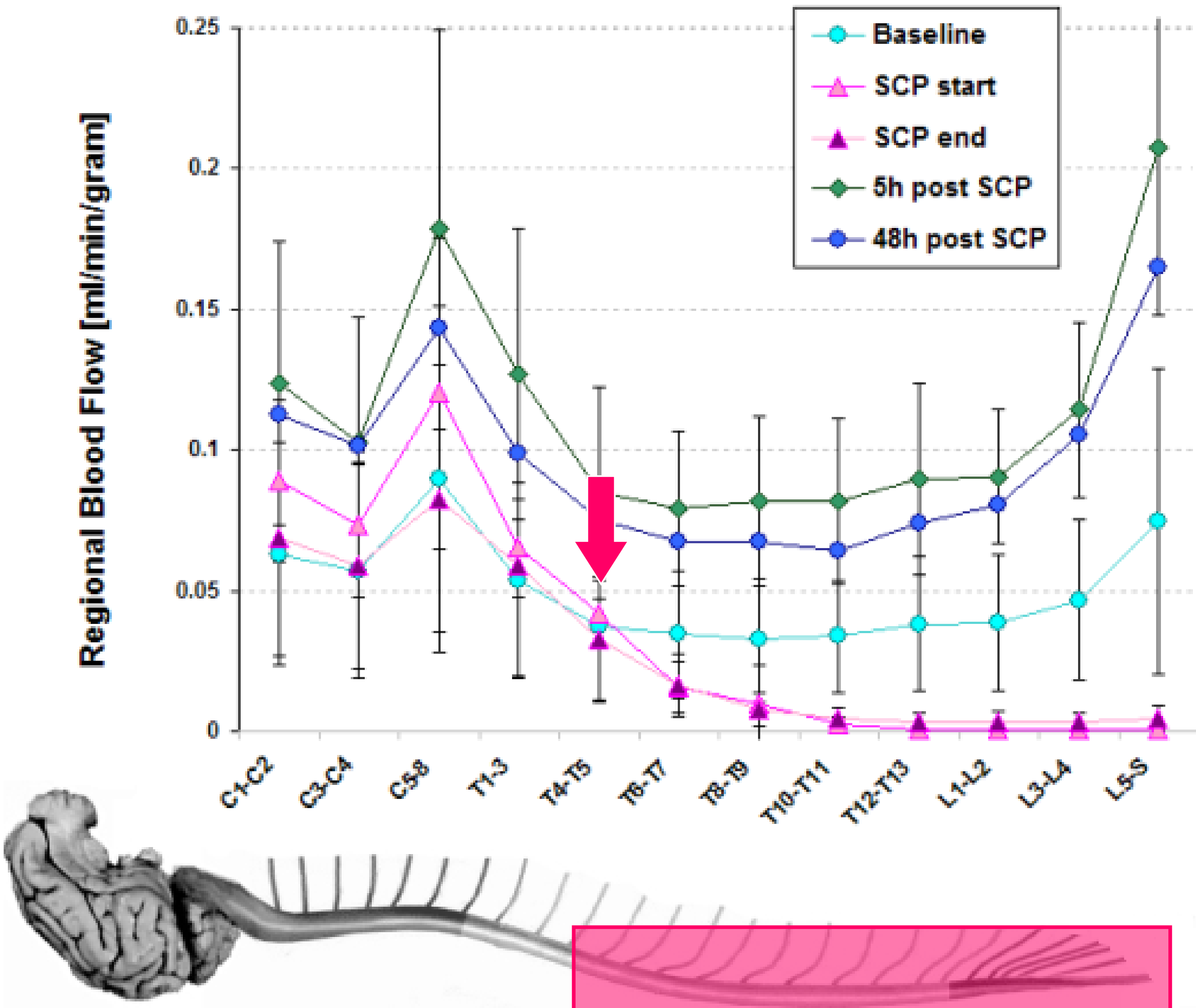
Aortic X-clamping

→ open TAA/A repair



SPINAL CORD BLOOD FLOW

prior to, *during* and after SCP @ 28ºC



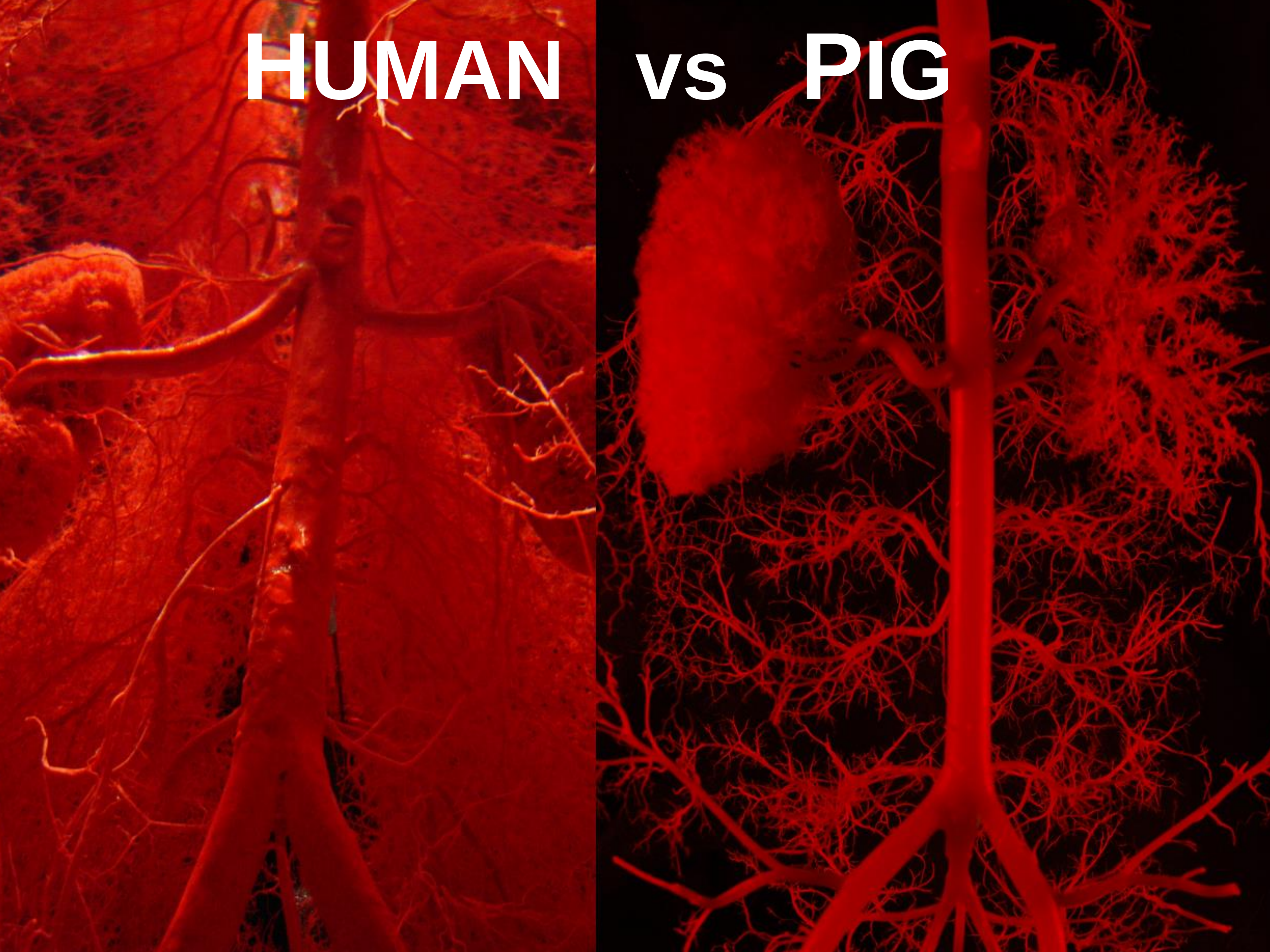
baseline flow

desc X-clamp:

NO flow

below T_8

Human vs. pig


HUMAN vs PIG

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UNKNOWN

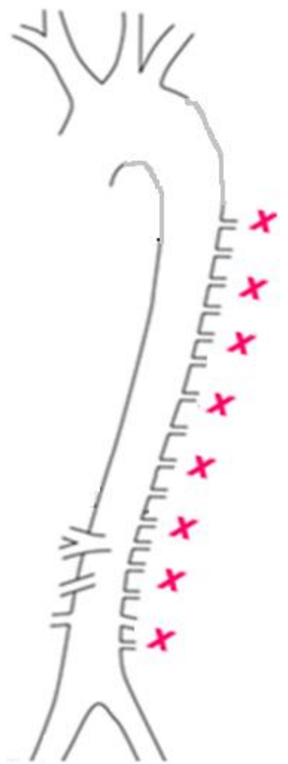
open questions to be clarified

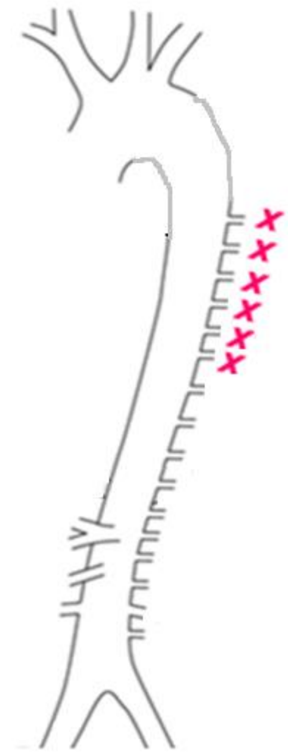
2 Bestimmung des optimalen Okklusionsmusters

Hypothese: alternierend schnellere Arteriogenese (besser als regional)

Okklusion

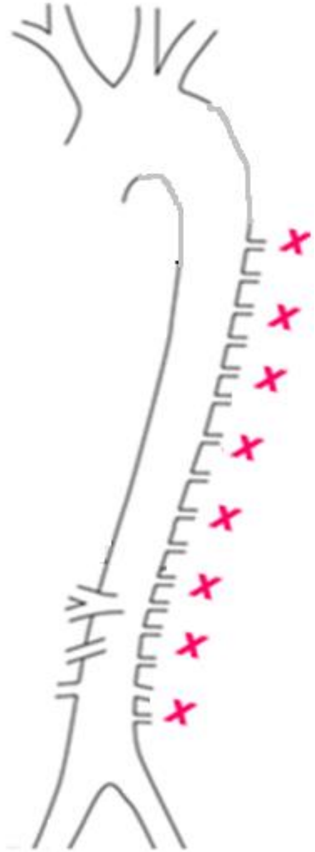
alternierend (N=10) vs. regional (N=10)





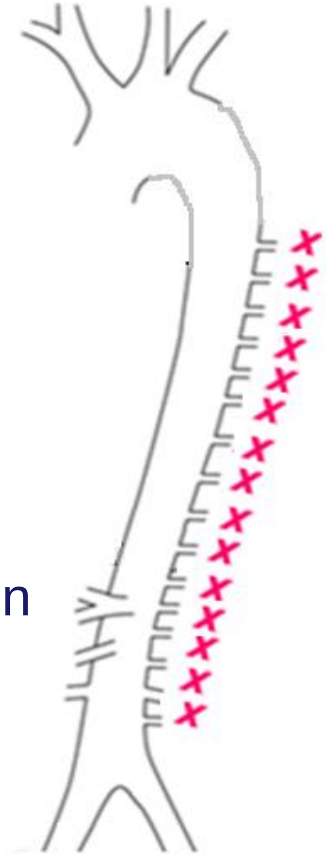
Perfusionsdruck – Blutfluß – Ultrastruktur im Verlauf

3 Optimales Timing / Intervall ?



2. Stufe nach

5, 10 oder 20 Tagen

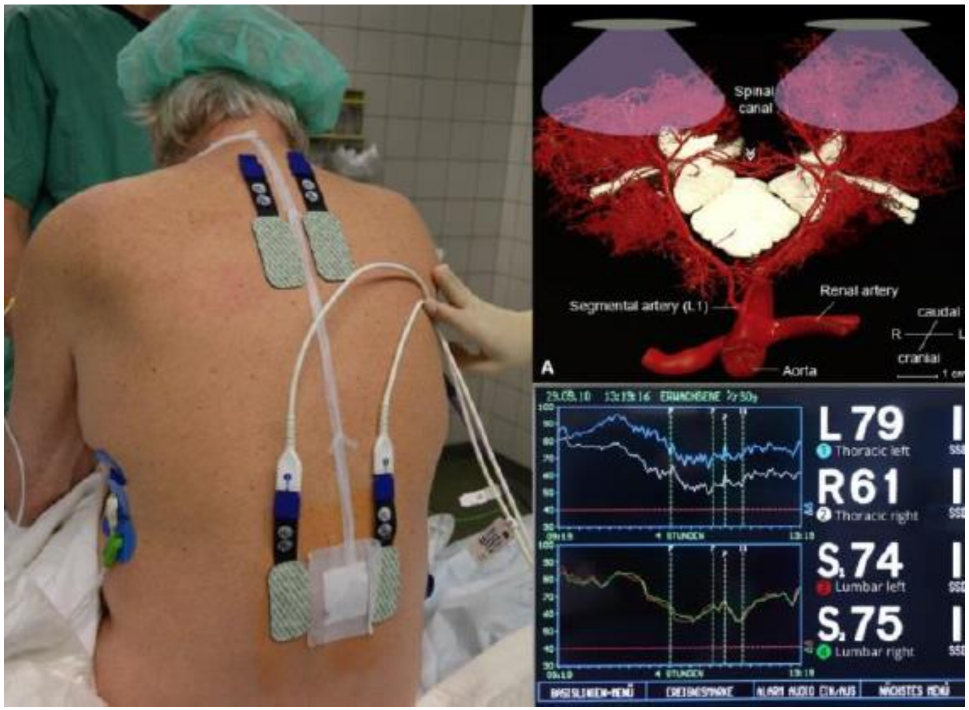


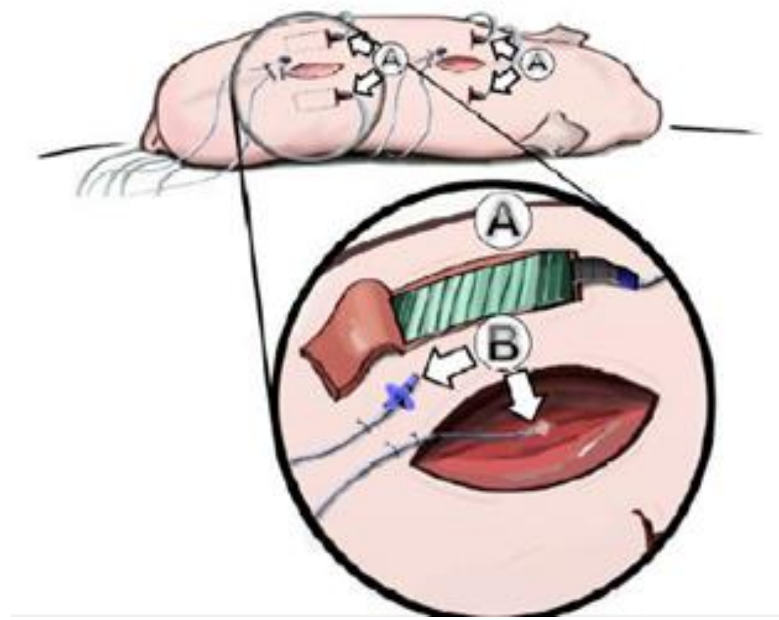
(je N=10)

Etz *et al. J Thorac Cardiovasc Surg.* ***2008*** *Feb;135(2):324-30*
Etz *et al., J Thorac Cardiovasc Surg.* ***2011*** *Apr;141(4):1029-36*
Etz *et al., J Thorac Cardiovasc Surg.* ***2015*** *Apr;149(4):1074-9*

4 Optimales Monitoringverfahren / Validierung Tiermodell

Hypothese: Regionale Nahinfrarot Spektroskopie (NIRS) korreliert mit Kollateral Perfusion / spinaler Oxigenierung *in Echtzeit*





Etz *et al., Eur J Vasc Endovasc Surg.* ***2013*** *Dec;46(6):651-6*
Etz *et al., Eur J Cardiothorac Surg.* ***2015*** *Jun;47(6):943-57*

DIRECT SCPP MONITORING

Direct Spinal Cord Perfusion Pressure Monitoring in Extensive Distal Aortic Aneurysm Repair

Christian D. Etz, MD, PhD, Gabriele Di Luozzo, MD, Stefano Zoli, MD, Ricardo Lazala, MD, Konstadinos A. Plestis, MD, Carol A. Bodian, DrPH, and Randall B. Griepp, MD

Departments of Cardiothoracic Surgery and Anesthesiology, Mount Sinai School of Medicine, New York, New York

Background. Although maintenance of adequate spinal cord perfusion pressure (SCPP) by the paraspinal collateral network is critical to the success of surgical and endovascular repair of descending thoracic and thoracoabdominal aortic aneurysms, direct monitoring of SCPP has not previously been described.

Methods. A catheter was inserted into the distal end of a ligated thoracic segmental artery (SA) (T6 to L1) in 13 patients, 7 of whom underwent descending thoracic and thoracoabdominal aortic aneurysm repair using deep hypothermic circulatory arrest. Spinal cord perfusion pressure was recorded from this catheter before, during, and after serial SA sacrifice, in pairs, from T3 through L4, at 32°C. Somatosensory and motor evoked potentials were also monitored during SA sacrifice and until 1 hour after cardiopulmonary bypass. Target mean arterial pressure was 90 mm Hg during SA sacrifice and after nonpulsatile cardiopulmonary bypass, and 60 mm Hg during cardiopulmonary bypass.

Results. A mean of 9.8 ± 2.6 SAs were sacrificed without somatosensory and motor evoked potential loss. Spinal cord perfusion pressure fell from 62 ± 12 mm Hg (76% ± 11% of mean arterial pressure) before SA sacrifice to 53 ± 13 mm Hg (58% ± 15% of mean arterial pressure) after SA clamping. The most significant drop occurred with initiation of nonpulsatile cardiopulmonary bypass, reaching 29 ± 11 mm Hg (46% ± 18% of mean arterial pressure) before deep hypothermic circulatory arrest. Spinal cord perfusion pressure recovered during rewarming to 40 ± 14 mm Hg (51% ± 20% of mean arterial pressure), and further within the first hour of reestablished pulsatile flow. Somatosensory and motor evoked potentials returned in all patients intraoperatively. Recovery of SCPP began intraoperatively, and in 5 patients with prolonged monitoring, continued during the first 24 hours postoperatively. All but 1 patient, who had remarkably low postoperative SCPPs and experienced paraparesis, regained normal spinal cord function.

Conclusions. This study supports experimental data showing that SCPP drops markedly but then recovers gradually during the first several hours after extensive SA sacrifice. Direct monitoring may help prevent a fall of SCPP below levels critical for spinal cord recovery after surgery and endovascular repair of descending thoracic and thoracoabdominal aortic aneurysms.

(Ann Thorac Surg 2009;87:1764–74)

Paraplegia remains the most devastating complication after repair of extensive descending thoracic (DTA) and thoracoabdominal aortic aneurysms (TAAA). The maintenance of adequate spinal cord perfusion pressure (SCPP) is critical to the success of open and endovascular repair of DTAs and TAAAs to prevent spinal cord ischemia when blood flow to the segmental arteries (SAs) is interrupted.

Monitoring of spinal cord function using motor (MEP) or somatosensory evoked potentials (SSEP) is widely accepted in the assessment of intraoperative spinal cord viability during aortic procedures, but is an indirect measurement of the adequacy of spinal cord perfusion [1–6]. If MEPs or SSEPs diminish, the response usually involves anesthetic and hemodynamic maneuvers to improve spinal cord perfusion—chiefly by increasing mean arterial pressure (MAP) and improving cerebrospinal fluid (CSF) drainage—but the assessment of the efficacy of these measures is likewise indirect. It is possible that inadequate spinal cord perfusion may occur even when MEP and SSEP monitoring shows no cause for alarm, and that a more direct, sensitive way of monitoring spinal cord perfusion could be helpful intraoperatively, although the presence of intact MEP and SSEP already provides considerable reassurance of adequate intraoperative spinal cord perfusion.

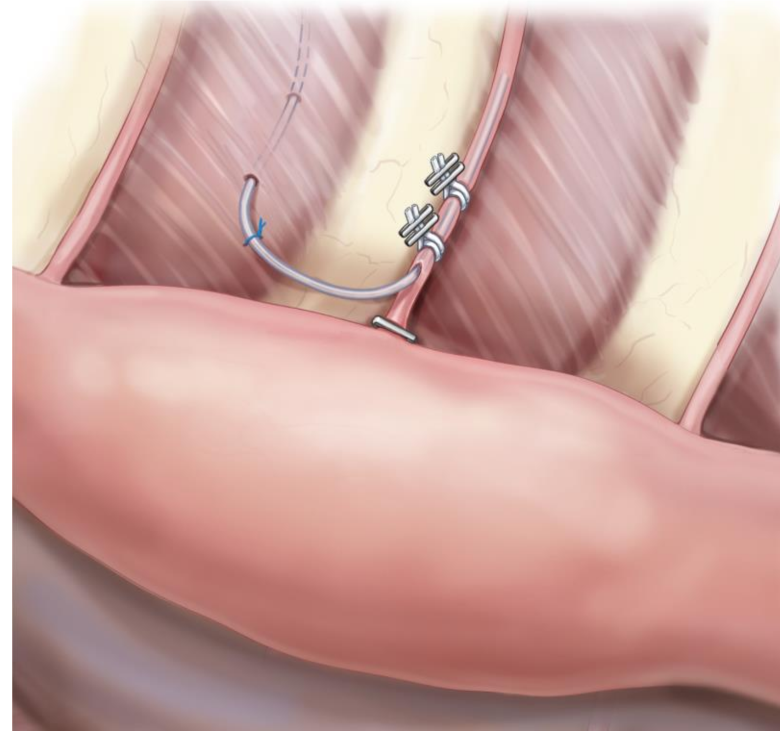
A recent retrospective study of our clinical cases has suggested, however, that spinal cord vulnerability to inadequate perfusion is likely to be highest not during operation, but in the early postoperative period, and that inadequate perfusion resulting in spinal cord injury may occur with systemic pressures below the individual patient's usual blood pressure even though those systemic pressures fall within limits usually regarded as normal

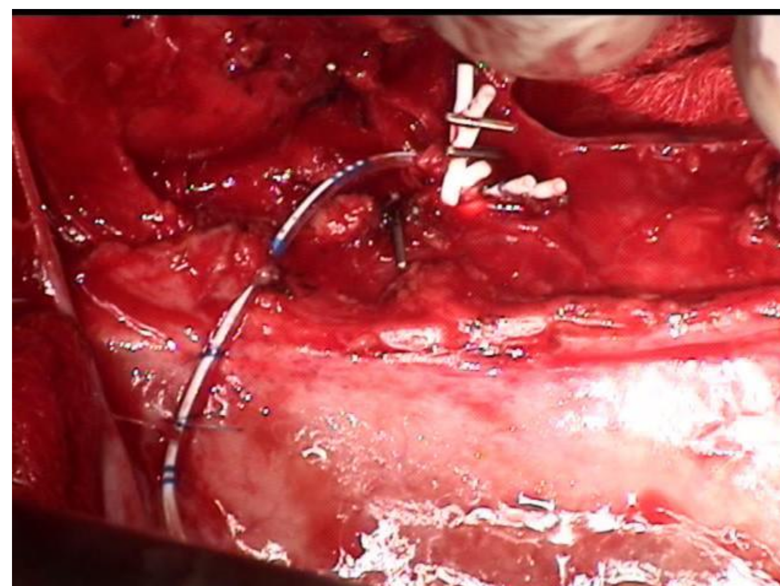
Accepted for publication Feb 24, 2009.

Presented at the Fifty-fifth Annual Meeting of the Southern Thoracic Surgical Association, Austin, TX, Nov 5–8, 2008.

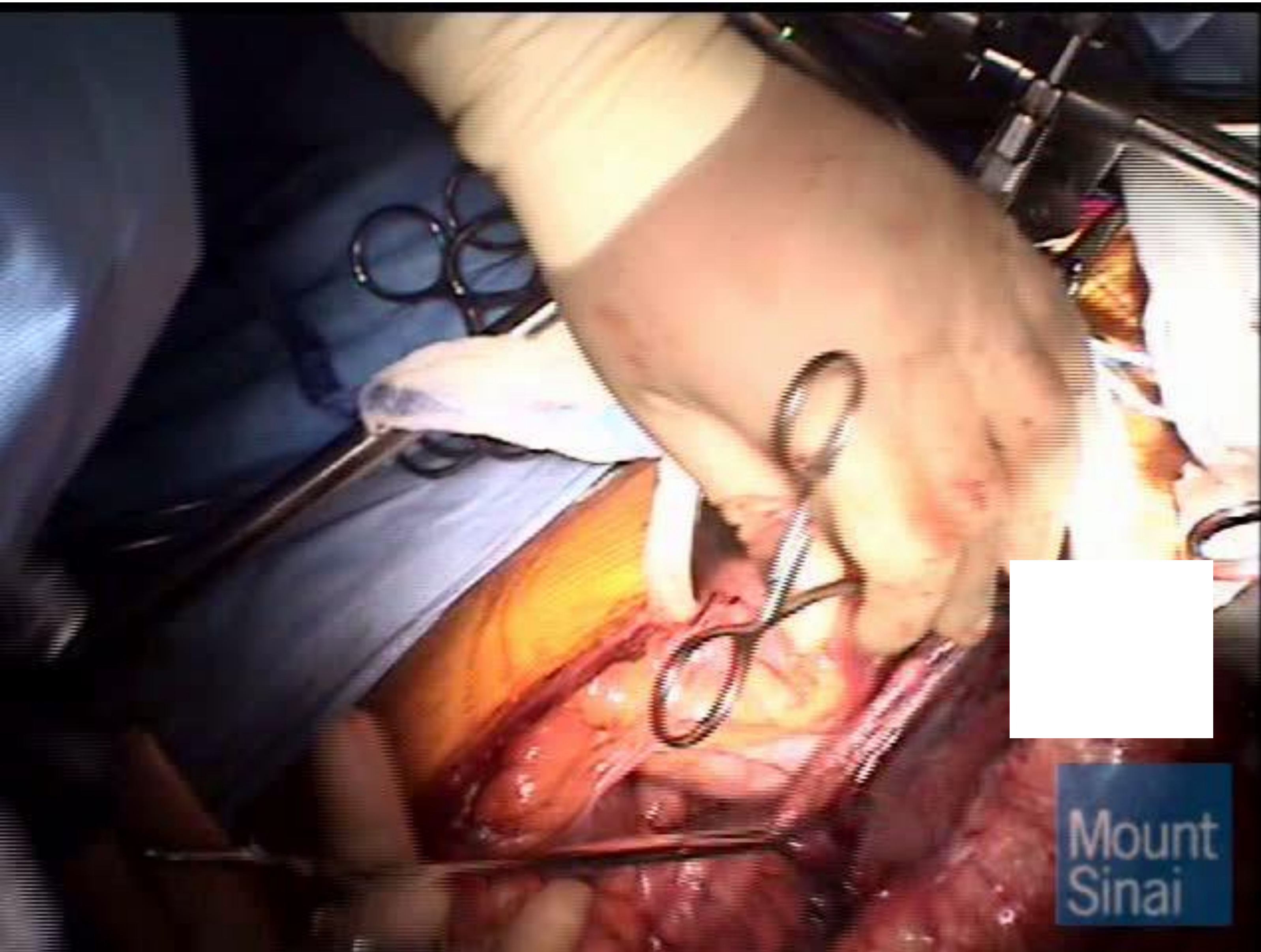
Address correspondence to Dr Etz, Department of Cardiothoracic Surgery, Mount Sinai School of Medicine, One Gustave L. Levy Place, New York, NY 10029; e-mail: christian.etz@mountsinai.org.

0003-4975/09/$36.00
doi:10.1016/j.athoracsur.2009.02.101

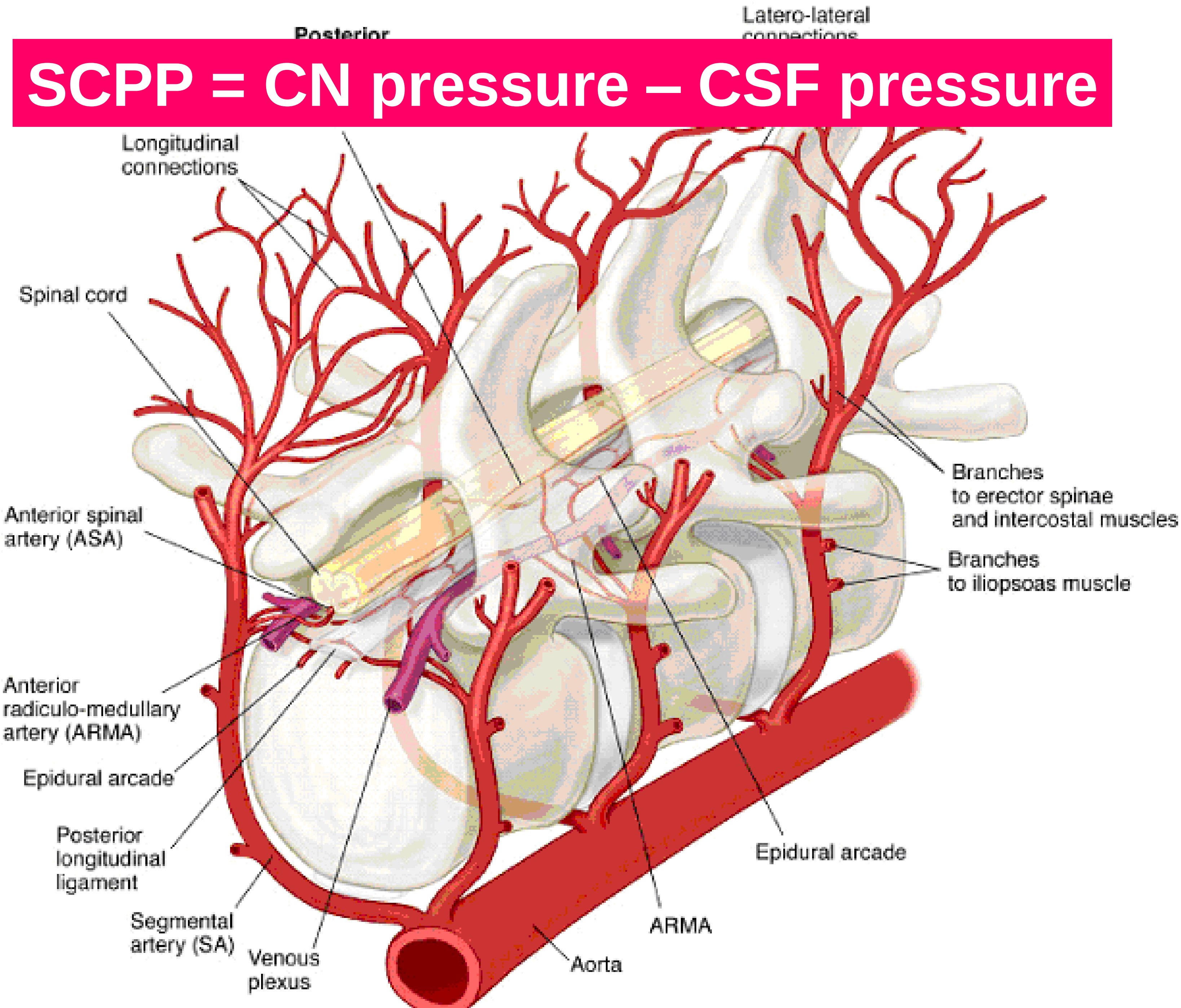




SCPP-CATH PLACEMENT

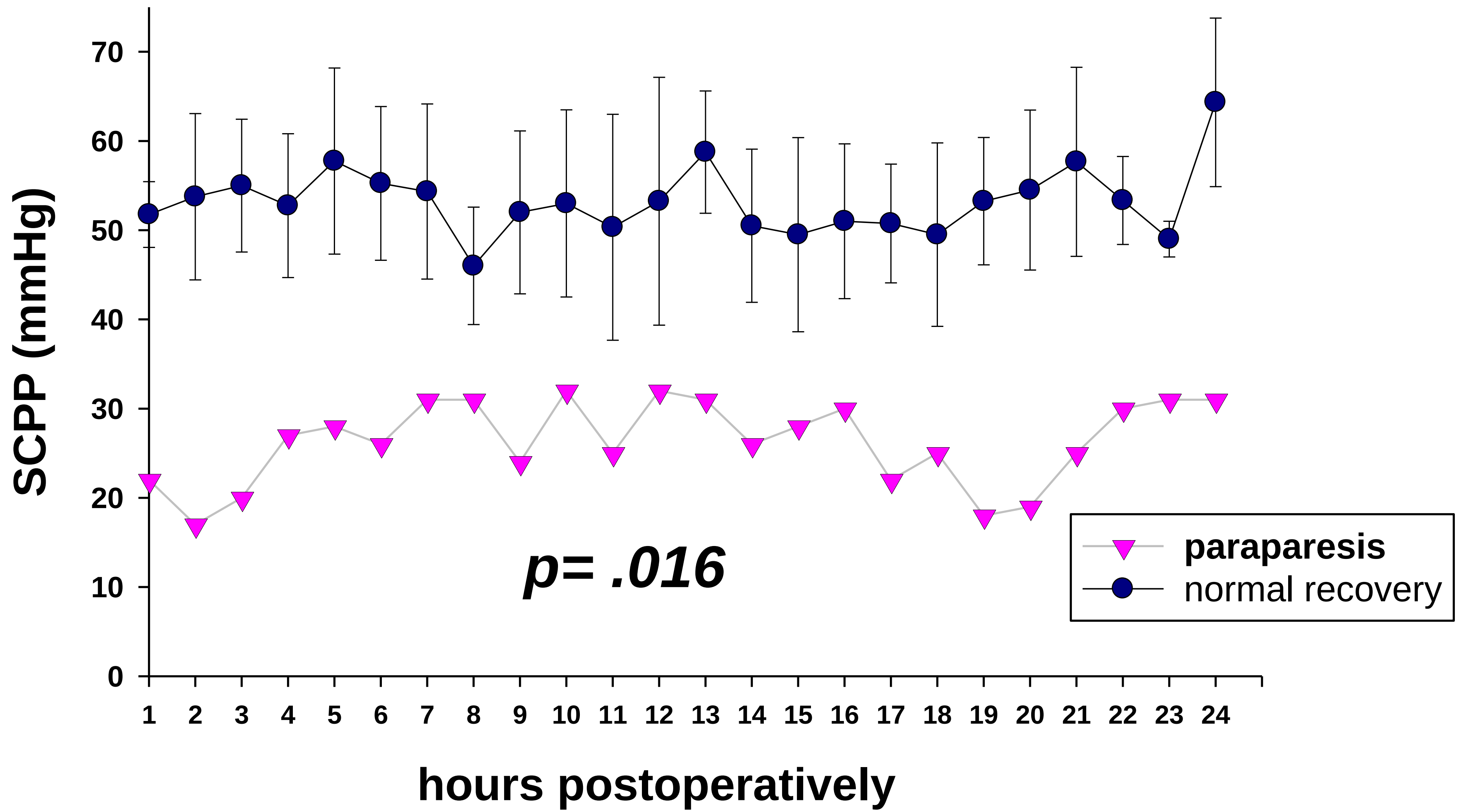


SCPP = CN pressure – CSF pressure



SCPP = CN pressure – CSF pressure

Five patients 9 ± 3 SA sacrificed



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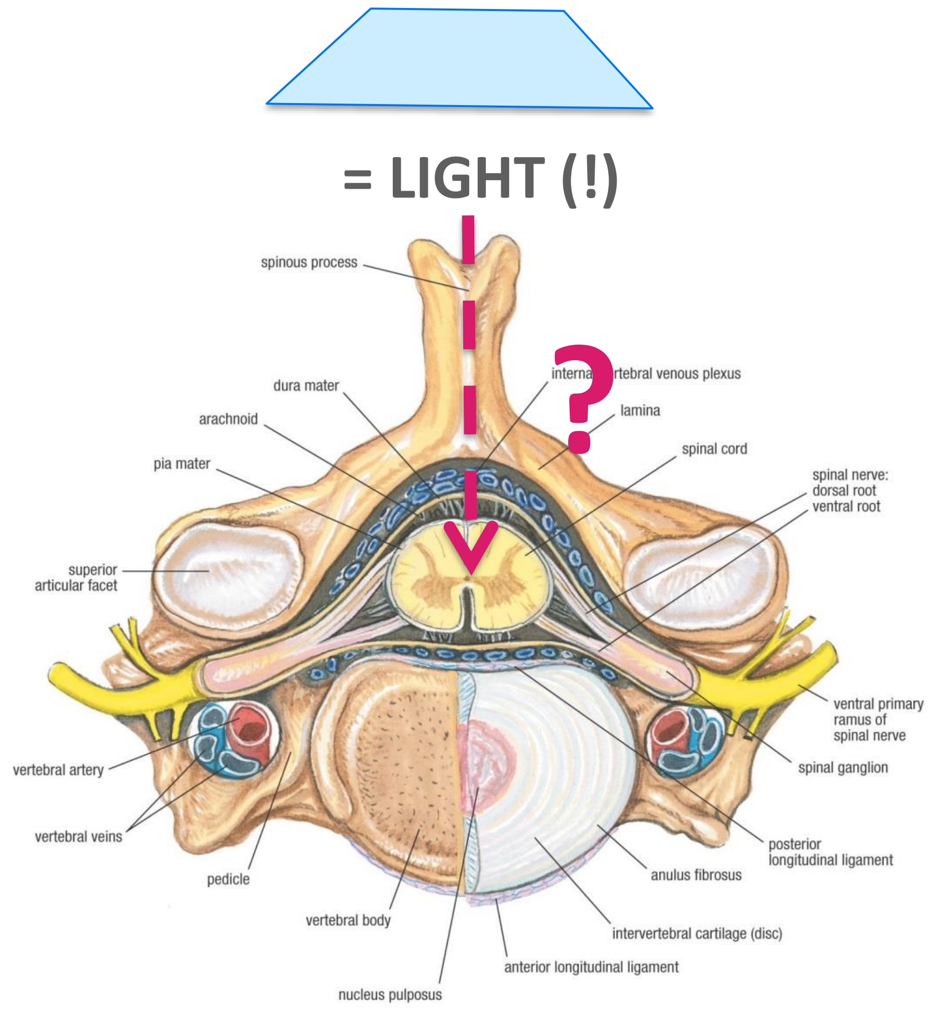
CN NIRS

Detection of ischemic spinal cord injury during and after extensive open or endovascular TAA/A repair utilizing SSEP and/or MEP monitoring: <u>invasive and expensive</u>

Spinal cord monitoring

Modality						
SSEP	-	-	-	+	-	-
MEP	-	-	-	+	+	-
Direct SCPP	-	+	+	+	+	-
Laser Doppler	-	+	+	+	+	-
cnNIRS	+	+	+	+	+	+

SSEP= Somatosensory evoked potentials; MEP=Motor evoked potentials
SCPP=Spinal cord perfusion pressure; cnNIRS=near-infrared spectroscopy of the collateral network


= LIGHT (!)
?
spinous process
dura mater
arachnoid
pia mater
interna rtebral venous plexus
lamina
spinal cord
spinal nerve:
dorsal root
ventral root
superior
articular facet
ventral primary
ramus of
spinal nerve
spinal ganglion
vertebral artery
vertebral veins
pedicle
posterior
longitudinal ligament
anulus fibrosus
vertebral body
intervertebral cartilage (disc)
anterior longitudinal ligament
nucleus pulposus

Collateral Network

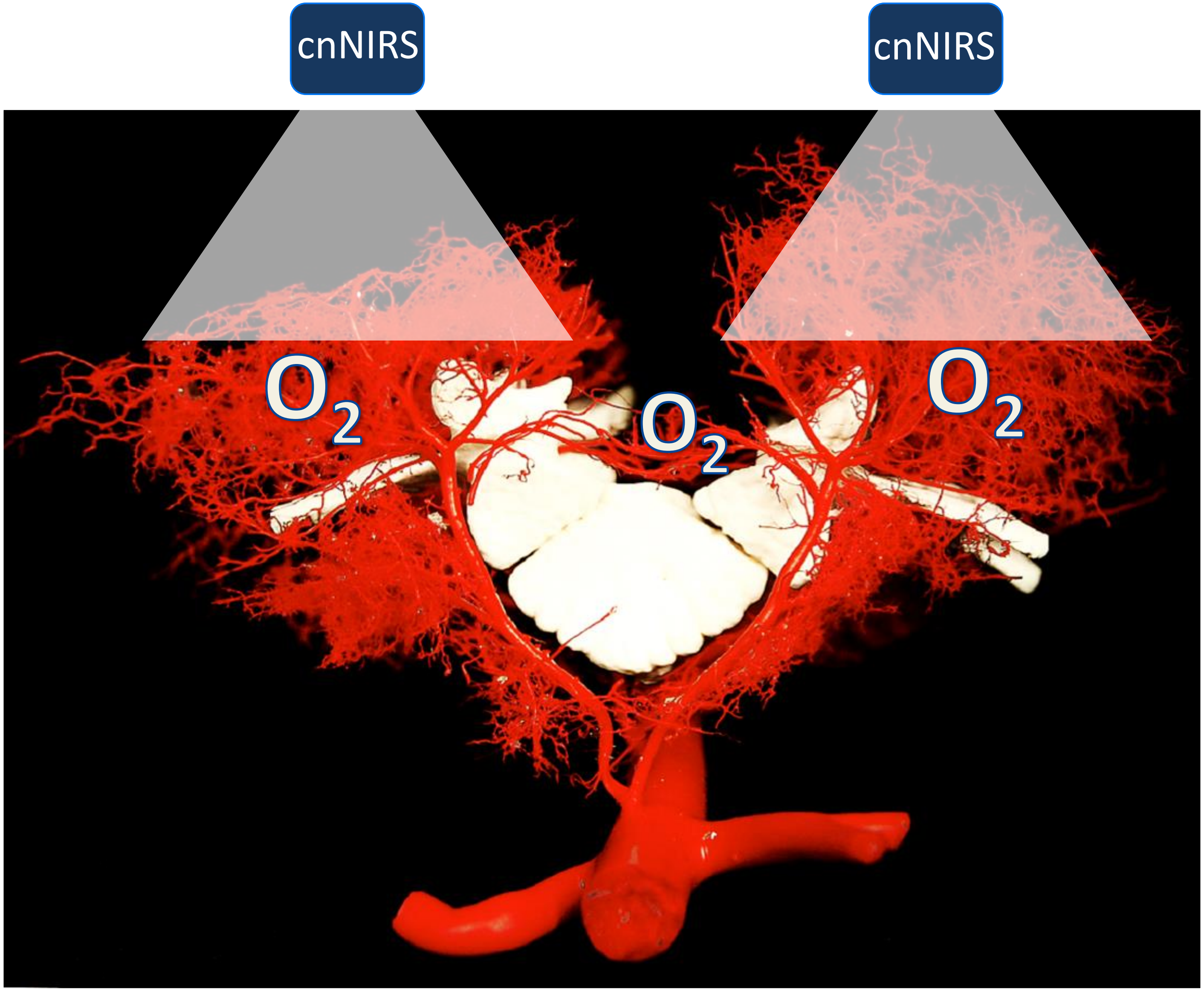


Image from J Thorac Cardiovasc Surg. 2011, The Collateral Network Concept: A Reassessment of the Anatomy of Spinal Cord Perfusion

FIRST IN-MAN SERIES

Near-infrared Spectroscopy Monitoring of the Collateral Network Prior to, During, and After Thoracoabdominal Aortic Repair: A Pilot Study

C.D. Etz [a,b,*,d], K. von Aspern [a,d], S. Gudehus [c], M. Luehr [a], F.F. Girrbach [a], J. Ender [c], M. Borger [a], F.W. Mohr [a]

[a] Department of Cardiac Surgery, University of Leipzig, Heart Center Leipzig, Saxony, Germany
[b] Department of Cardiothoracic Surgery, Mount Sinai School of Medicine, New York, NY, USA
[c] Department of Anesthesiology, University of Leipzig, Heart Center Leipzig, Saxony, Germany

① **Lumbar cnNIRS** sensitive to X-clamping & distal perfusion

① **Diminished** lumbar **cnNIRS** = postoperative **SCI***

Eur J Vasc Endovasc Surg. 2013; * comparing patients with and without postoperative spinal cord injury

HYPOTHESIS

Perfusion & oxygenation of the **collateral network** directly **reflects spinal cord** microcirculation?

Can **cnNIRS depict spinal cord oxygenation?**

Experimental setup

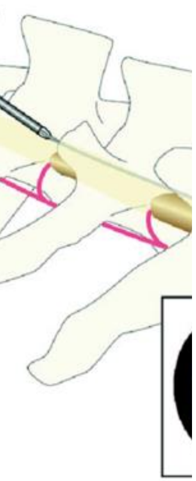
✧ Sev

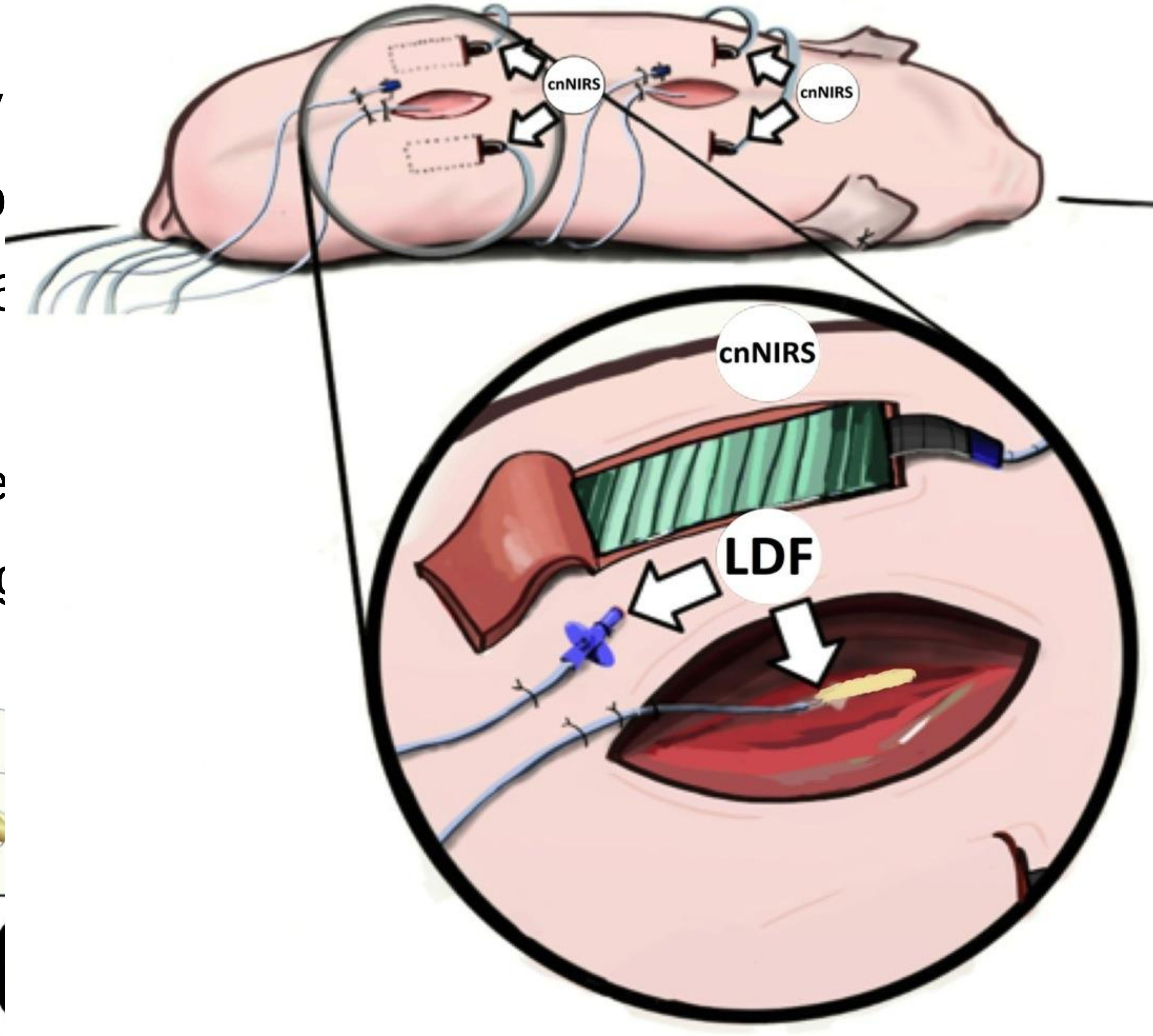
✧ Sub

T5/6

✧ Dire

oxyg

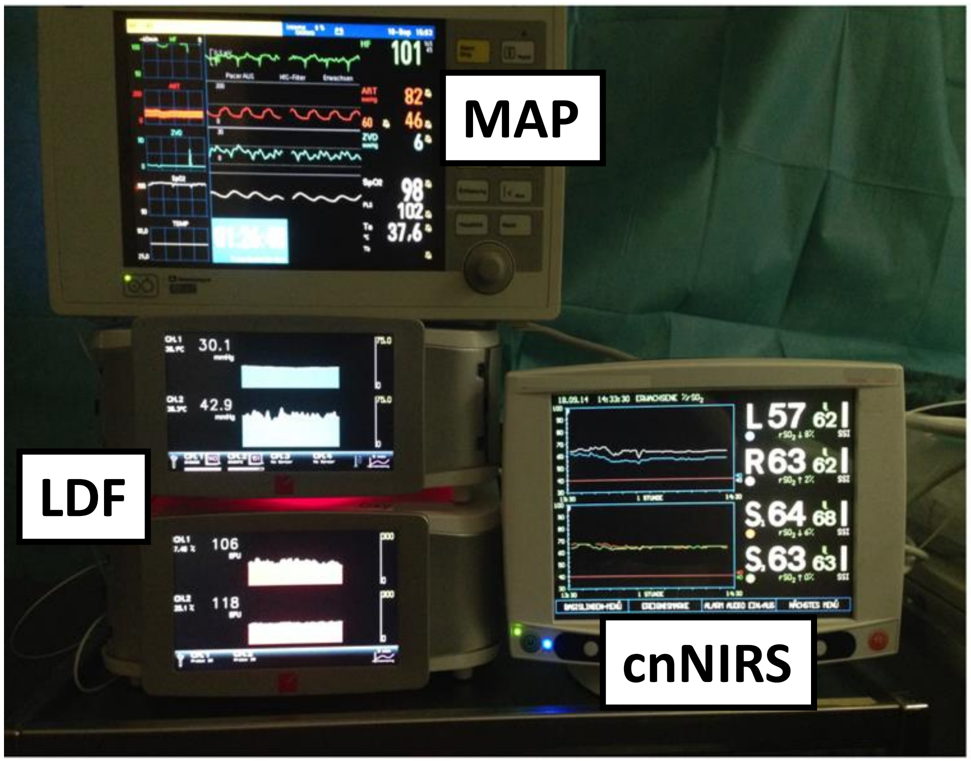


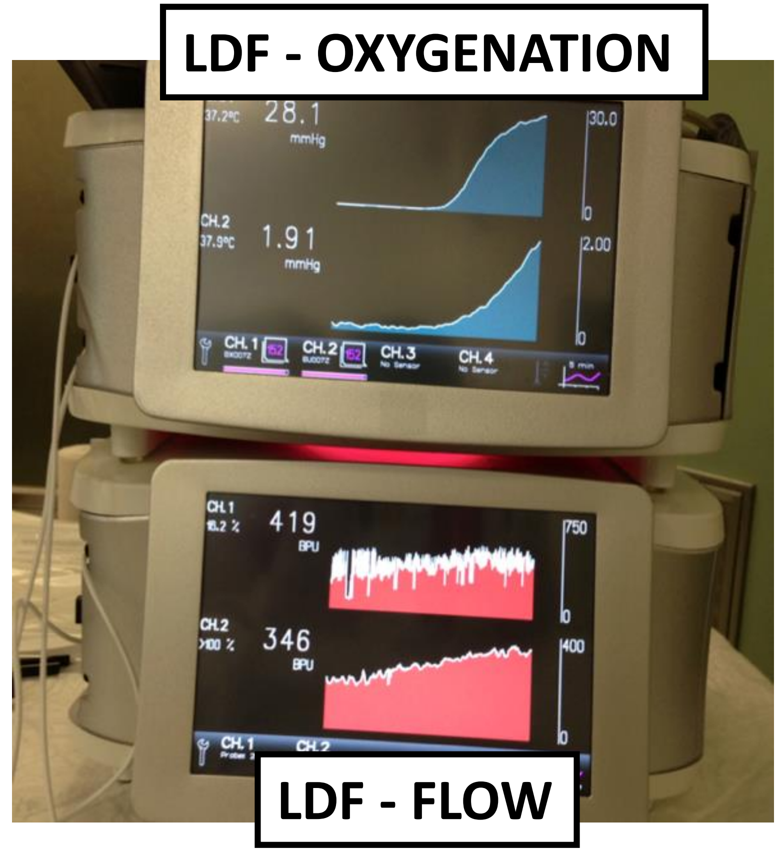


Experimental Sequence

- ✧ **Baseline**
- ✧ **X-clamping** (ischemia: 8 min.)
- ✧ **Clamp release** (recovery)

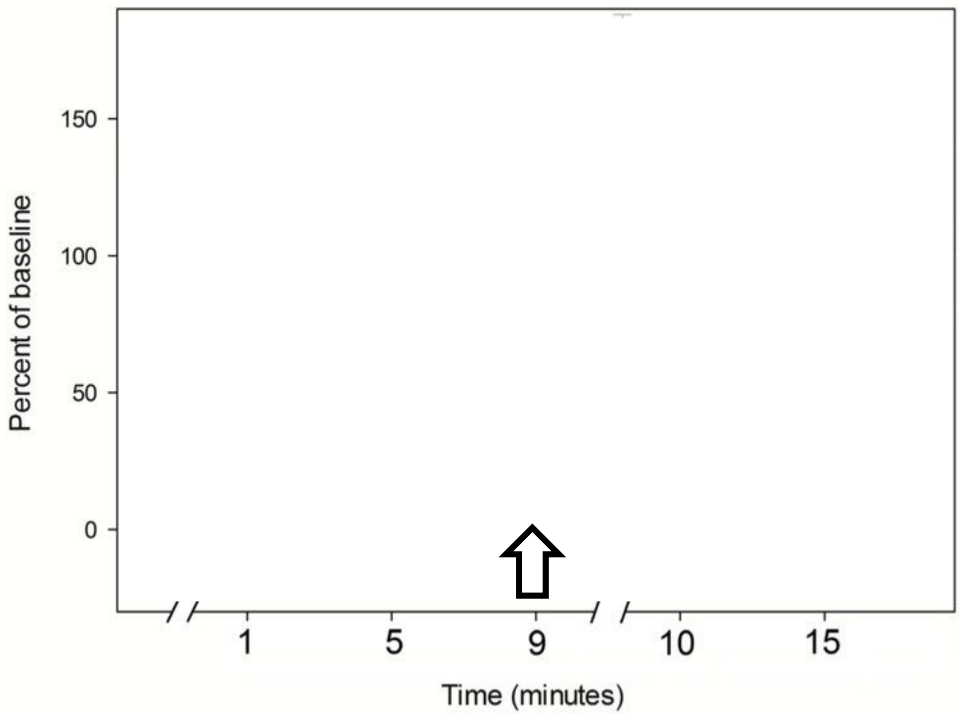
} consecutively 4 times



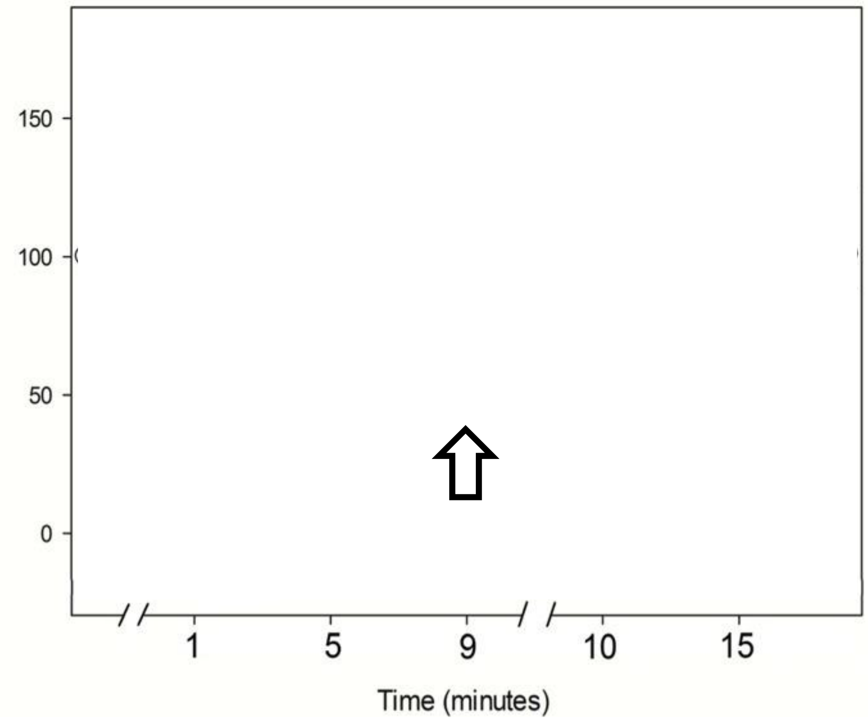


Direct Invasive Laser Doppler (LDF)

Collateral Network



Spinal Cord



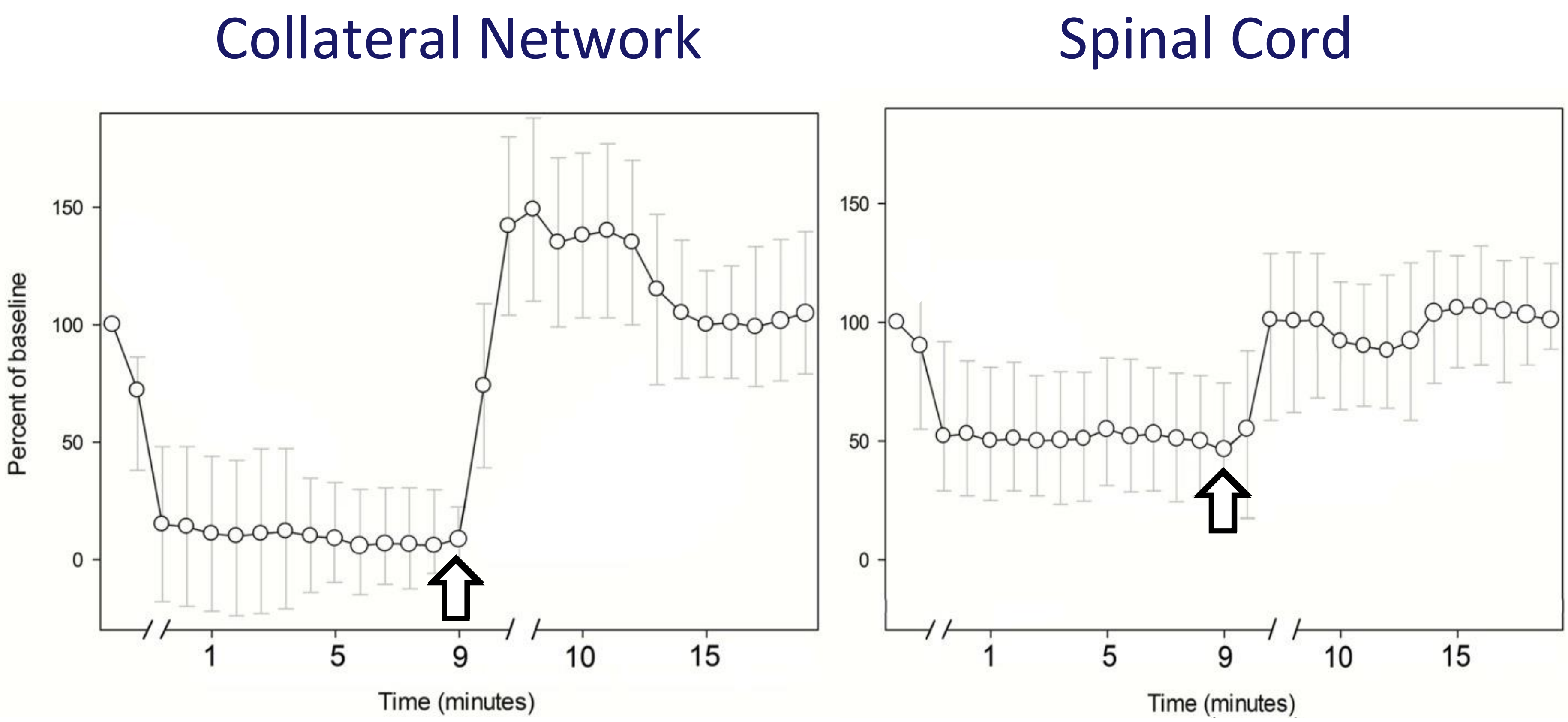
Oxygenation

Flo
w

X-clamp

Clamp release

Direct Invasive Laser Doppler (LDF)



Oxygenation

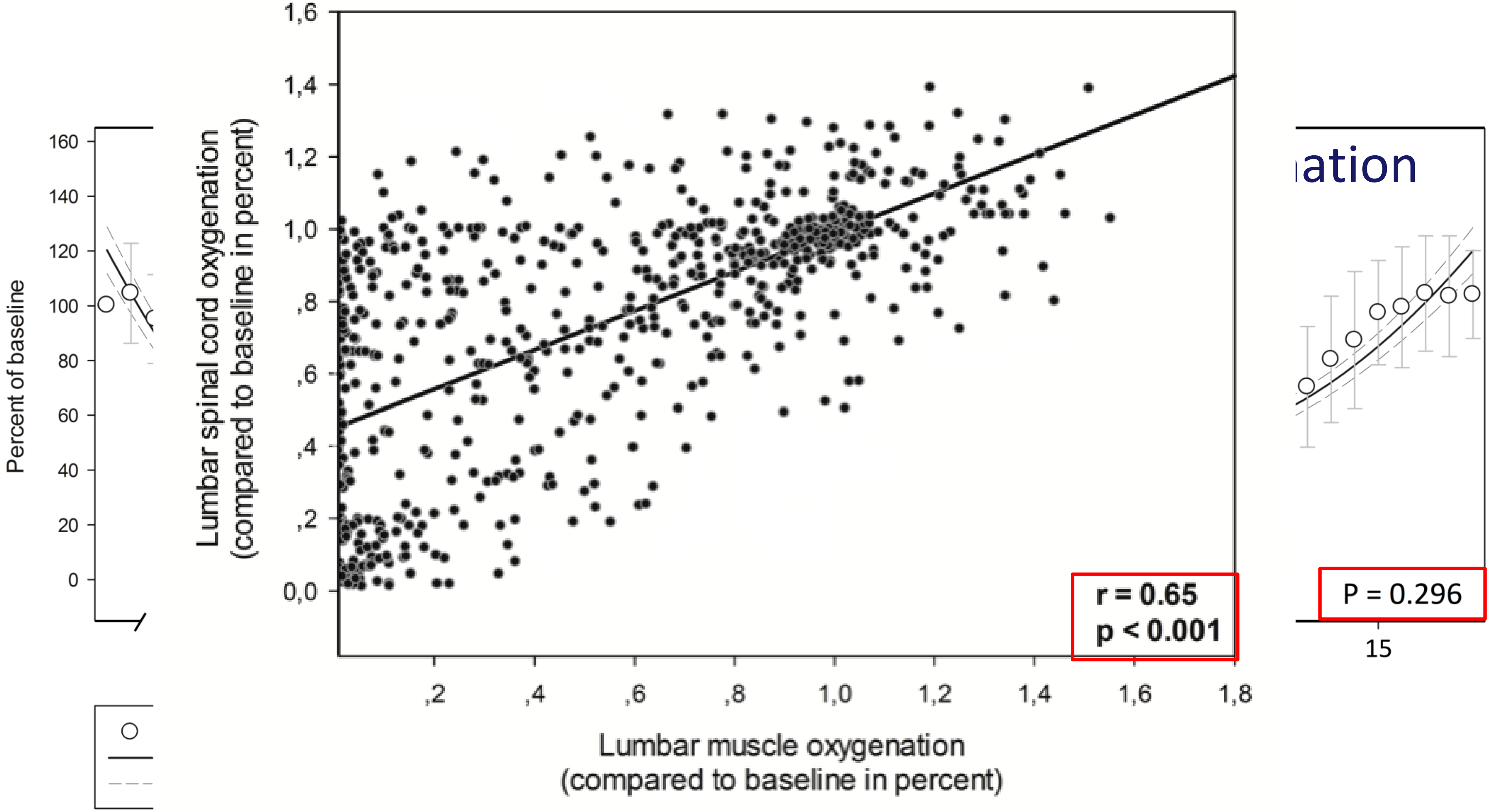
X-clamp

Flo
w

⇧ Clamp release

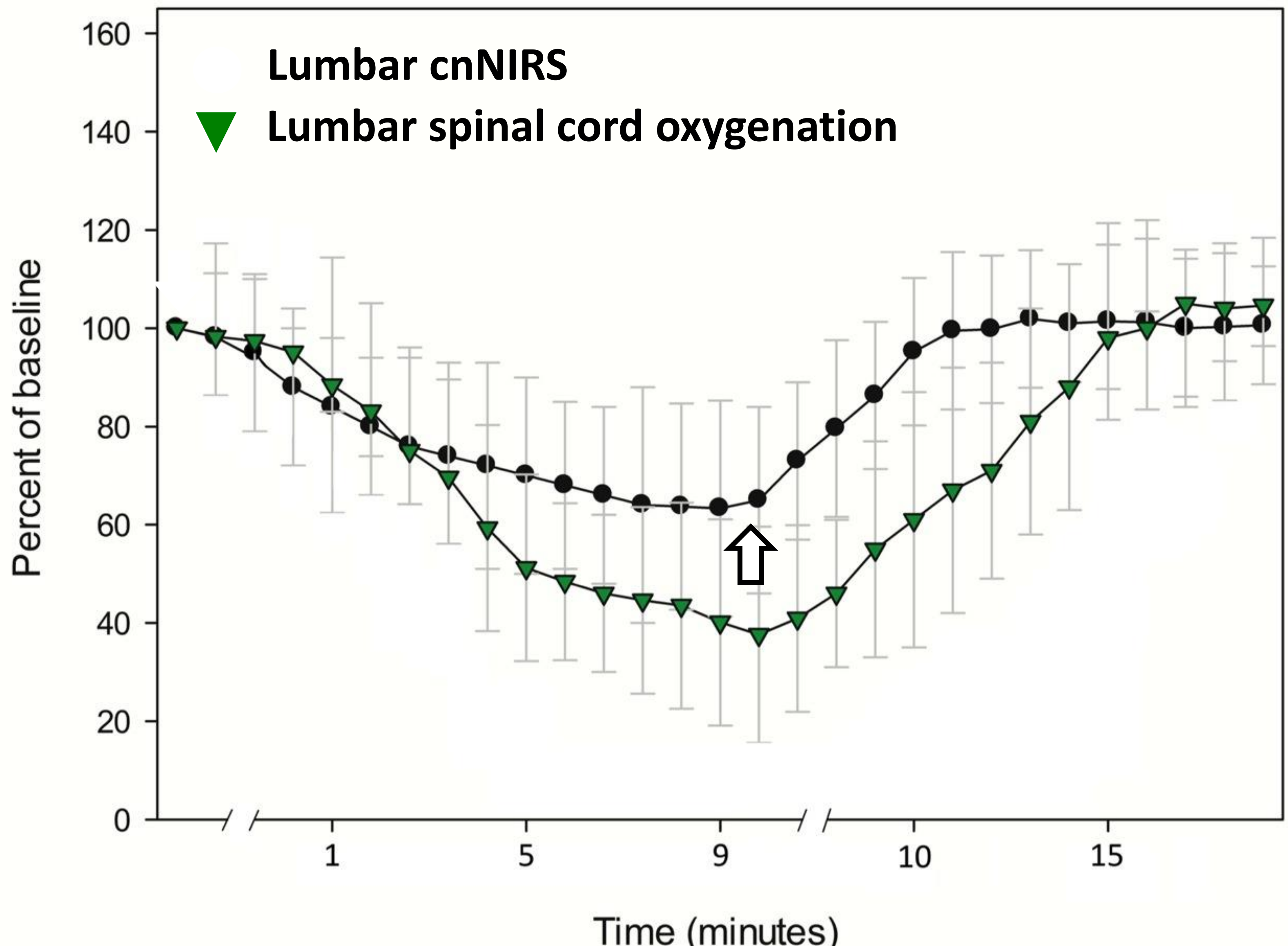
HYPOTHESIS: oxygenation of the **CN = spinal cord**? ☑

Collateral Network vs. Spinal Cord



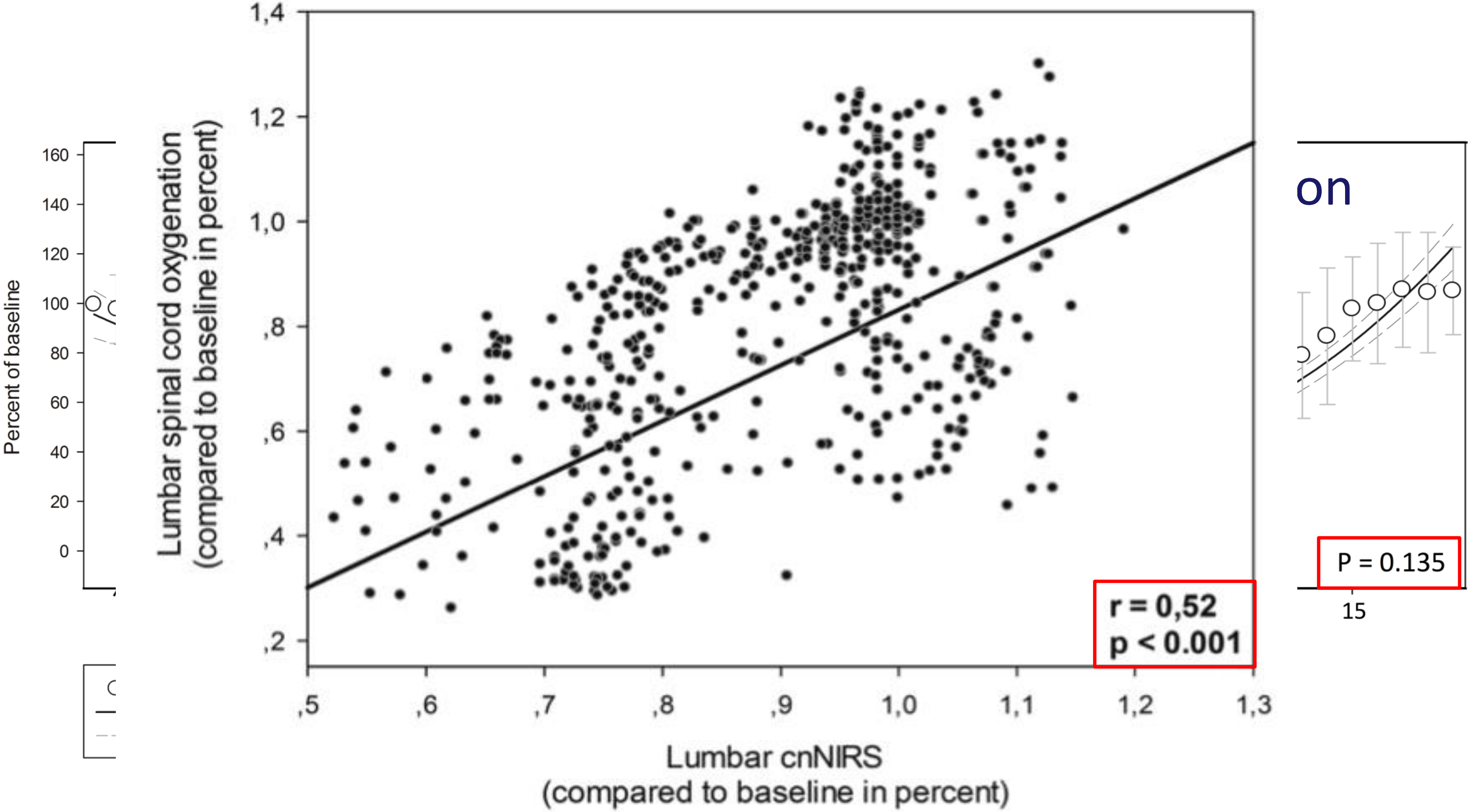
Paraspinous **CN** oxygenation directly reflects **spinal cord** tissue oxygenation

Non-invasive cnNIRS



Question: lumbar **cnNIRS** = **Spinal cord** oxygenation? ☑

cnNIRS vs. Spinal Cord Oxygenation



lumbar **cnNIRS** directly reflects **spinal cord** tissue oxygenation

Conclusions

① **CN** oxygenation reflects **spinal cord** oxygenation

① **Lumbar cnNIRS** reflects **spinal cord** oxygenation

Lumbar cnNIRS is an effective tool to non-invasively monitor spinal cord oxygenation