Sonographic Changes in Optic Nerve Sheath Diameter Associated with Supra- versus Infrarenal Aortic Aneurysm Repair

Michael Ertl, Wilma Schierling, Piotr M. Kasprzak, Reinhard Kopp, Corinna Brückl, Felix Schlachetzki, Karin Pfister

From the Neurology Department, Klinikum Augsburg, Stenglinstr. 2, 86165, Augsburg, Germany (ME); Department of Surgery, Vascular and Endovascular Surgery, University of Regensburg, Franz-Josef-Strauss Allee 11, 93053, Regensburg, Germany (WS, PMK, RK, CB, KP); and Neurology Department, University of Regensburg, Universitätsstraße 84, 93053, Regensburg, Germany (FS).

ABSTRACT

BACKGROUND AND PURPOSE: Quantification of changes in optic nerve sheath diameter (ONSD) using ocular sonography (OS) constitutes an elegant technique for estimating intracranial and intraspinal pressure. Aortic aneurysm repair (AAR) is associated with a reasonable risk of increased spinal fluid pressure, which is largely dependent on the extent of aneurysm repair (supra- vs. infrarenal). The aim of this study was to compare ONSD measurements in patients with suprarenal AAR (sAAR) or infrarenal AAR (iAAR).

METHODS: Thirty patients who underwent elective endovascular repair of infrarenal aortic aneurysms (Group iAAR) were included in the study; the characteristics in these cases were prospectively analyzed and compared with those in a previously investigated group of 28 patients treated for suprarenal aortic aneurysms (Group sAAR). Six measurements of ONSDs were performed in each patient at five consecutive time points. Statistical analysis was performed using the Wilcoxon test. A P value $< .05$ was considered statistically significant.

RESULTS: A highly significant difference between pre- and postinterventional values could be detected in both patient groups ($P < .01$). In Group sAAR, there was a mean .3-mm increase of the ONSD, whereas in Group iAAR, a mean .2-mm decrease could be detected. Both groups roughly reached baseline values by the end of their inpatient stay.

CONCLUSIONS: ONSD changes seem to be a reliable marker to estimate spinal perfusion. Since OS provides a suitable bedside tool for rapid reevaluation, it may guide physicians in the identification and treatment of patients at high risk for spinal cord ischemia.

Correspondence: Address correspondence to Michael Ertl, Clinic for Neurology and Neurophysiology, Klinikum Augsburg, Stenglinstr. 2, 86156 Augsburg, Germany. E-mail: Michael.Ertl@klinikum-augsburg.de

Disclosures: None.

Introduction

Paraplegia is one of the most dreaded complications of thoracoabdominal aortic aneurysm repair (AAR). Open aortic surgery carries a significantly higher risk than endovascular aortic repair (EVAR).[1]

The risk of spinal cord ischemia (SCI) is attributed to various factors such as the need for cross clamping the aorta, dislocation of thrombotic material, and systemic blood pressure–all of which differ between open aortic surgery and EVAR.[2,3]

The length of the aorta covered by a stent seems to be associated with a higher risk for paraplegia.[4,5] In correlation with the patient's vascular supply and the length of the covered aorta, infrarenal AAR (iAAR) is associated with only a marginal risk for spinal ischemia.[6]

Intraspinal pressure in conjunction with arterial blood pressure defines spinal cord perfusion pressure. We previously demonstrated that changes in spinal cerebrospinal fluid (CSF) pressure following suprarenal EVAR can be monitored using sonographic measurements of the optic nerve sheath diameter (ONSD).[7] In 5 of the 28 patients comprising that study, we observed significant increases in the ONSD. The only patient who developed permanent paraplegia due to SCI was part of that group. Patients who received spinal cord catheters had significantly lower ONSDs, suggesting a protective effect in the presence of increased intraspinal pressure.

In the present study, we compared our previously characterized group of patients who had undergone EVAR for suprarenal AAR (sAAR) with a new group of patients who underwent EVAR for iAAR. We hypothesized that differences in intraspinal perfusion pressure (ISPP) associated with sAAR and iAAR could be identified by performing consecutive ONSD measurements.

Methods

Subject Groups and Ethical Considerations

Between July 2014 and June 2015, 30 patients designated to undergo EVAR for infrarenal aortic aneurysms were enrolled in this prospective study. Written informed consent was obtained from these patients prior to enrollment. The study protocol was approved by the local ethics committee in accordance with guidelines of the Declaration of Helsinki.

Characteristics in these patients (Group iAAR) were compared with those in a previous group of patients with suprarenal

Table 1. Patient Characteristics and Information Regarding Interventions and Spinal Catheters in Patient Groups with Suprarenal (sAAR) or Infrarenal Aortic Aneurysm Repair (iAAR)

	Mean Patient Age	Sex	Mean Duration of Intervention	Spinal Catheters (*n*)	Spinal Catheters (Removed)
sAAR ($n = 28$)	65 (50-77)	24 male patients (86%)	273 (SD ± 100) minutes	20/28 (71%)	Post 2: 6 Post 3: 14 Post 4: 20
iAAR ($n = 30$)	69 (51-87)	28 male patients (93%)	192 (SD ± 130) minutes	0/30 (0%)	

n = number of patients; sAAR = suprarenal aortic aneurysm repair; iAAR = infrarenal aortic aneurysm repair; SD = standard deviation.

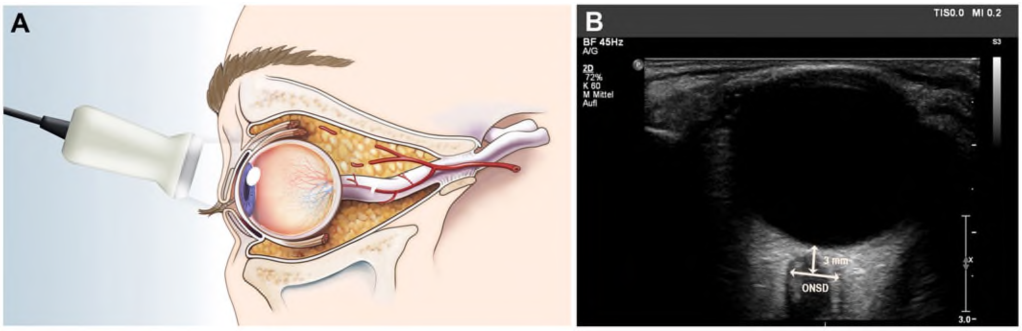

Fig 1. (A) Anatomy of retrobulbar structures: optic nerve and surrounding structures. © 2011, M. Ertl, with permission. (B) The optic nerve sheath diameter (ONSD) is measured 3 mm behind the optic disc; this is done by measuring the distance between the hyperechogenic borders of the optic nerve sheath.

aortic aneurysms (Group sAAR: $n = 28$, 22 patients with aortic aneurysms, 3 patients with aortic dissections, and 3 patients with a combination of both); findings in Group sAAR were published previously.[7] The mean patient age in Group sAAR was 65 years (range 50–77 years) and that in Group iAAR was 69 years (range 51–87 years); 24 patients (86%) in Group sAAR were male, as were 28 patients (93%) in Group iAAR.

In contrast to Group sAAR, no patients in Group iAAR received a spinal catheter because of the low odds of SCI following iAAR (<.1%).[6] Patients characteristics, durations of interventions, and information regarding spinal catheters are given in Table 1.

Performance and Reliability of the ONSD Measurements

Five consecutive values of ONSD were reported for each patient during his or her stay in the hospital. The first measurement was made before intervention ("baseline"); the second immediately after the procedure (post1); the third (post2) and fourth (post3) measurements on days 1 and 2, respectively, after the intervention; and the final measurement (post4) before hospital discharge.

Every measurement consisted of six assessments of the ONSD at each time point (three assessments made on the left side and three assessments made on the right side); on the basis of these measurements, mean values and standard deviations were calculated. Measurements were performed by a single experienced examiner (CB, a vascular surgeon who is accredited by the German Medical Ultrasound Society [DEGUM]); the correctness of all scans was reevaluated by a second DEGUM-accredited neurologist (FS), who was blinded to each patient's specific disease and clinical outcome. Concomitantly, additional parameters, such as positive end-expiratory pressure (PEEP) in ventilated patients as well as mean arterial pressure, were monitored and documented.

Technical Aspects, Safety Considerations

Ocular sonography was performed as previously published.[7] In brief, patients were placed supine with their eyes closed. A layer of acoustic gel was applied to the closed eyelids, after which the transducer was placed on the upper lid with the examiner's hand resting on the patient's orbital margin (Fig 1A). The ONSD is measured 3 mm behind the optic disc; the diameter is determined by measuring the distance between the hyperechogenic borders of the ONS (Fig 1B). For safety considerations and machine parameters, see Ertl et al.[8]

Statistical Analysis

Statistical analysis was performed using Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA, USA) and SPSS 13.0 (SPSS Inc., Chicago, IL, USA). The statistical significance of different ONSD values after infrarenal and suprarenal EVAR, in comparison to baseline values, was calculated using the Wilcoxon test. A P value < .05 was considered statistically significant, and a P value < .01 was deemed a highly significant difference. Correlations were calculated using Pearson's correlation coefficient, with a positive correlation defined as $P < .05$.

Results

Measurements were obtained six times at each time point. Minimum and maximum values, mean values, and standard deviations for both groups are listed in Table 2.

In Group sAAR, a paired comparison of ONSDs revealed highly significant differences between baseline and post1 measurements (mean baseline value = 4.86 mm, mean post1 value = 5.03 mm [$P = .006$]). At all other time points, there

Table 2. Comparison of Optic Nerve Sheath Diameters at Different Time Points in Patients Who Underwent Suprarenal (sAAR) or iAAR

					Left Side						Right Side
sAAR	**Min**	**Max**	**Mean**	**Standard Deviation**	**Confidence Interval (95%)**	**sAAR**	**Min**	**Max**	**Mean**	**Standard Deviation**	**Confidence Interval (95%)**
baseline	4	5.8	4.851	.3979	4.784-4.917	baseline	3.8	5.7	4.861	.4104	4.793-4.930
post 1	3.9	6.5	5.119	.6453	5.014-5.225	post 1	4	6.4	5.03	.5703	4.937-5.123
post 2	3.5	6.5	4.967	.6851	4.855-5.078	post 2	3.8	6.4	4.915	.6097	4.817-5.014
post 3	3.9	6.2	4.856	.5708	4.763-4.950	post 3	3.9	6.2	4.819	.5468	4.729-4.908
post 4	4.1	6.5	4.882	.5224	4.796-4.969	post 4	3.7	6.7	4.829	.5501	4.738-4.920

					Left Side						Right Side
iAAR	**Min**	**Max**	**Mean**	**Standard Deviation**	**Confidence Interval (95%)**	**iAAR**	**Min**	**Max**	**Mean**	**Standard Deviation**	**Confidence Interval (95%)**
baseline	4.3	7.6	5.332	.6416	5.181-5.463	baseline	4.3	7.6	5.302	.6184	5.167-5.438
post 1	4.3	6.8	5.188	.5351	5.072-5.304	post 1	4.4	6.6	5.163	.4812	5.059-5.268
post 2	4.2	6.5	5.117	.4972	5.013-5.221	post 2	4.4	6.6	5.077	.4717	4.978-5.175
post 3	4.4	6.5	5.159	.4601	5.063-5.255	post 3	4.2	6.5	5.14	.4644	5.043-5.237
post 4	4.5	6.5	5.149	.4187	5.061-5.237	post 4	4.6	6.5	5.131	.4027	5.047-5.215

Diameters are stated in millimeters. Values include minimum (Min), maximum (Max), and mean diameters as well as standard deviations and 95% confidence intervals. Baseline = the first measurement before intervention; post1 = the second measurement immediately after the procedure; post2 = the third measurement on day 1 after the intervention; post3 = the fourth measurement on day 2 after the intervention; post4 = the final measurement before hospital discharge; sAAR = suprarenal aortic aneurysm repair; iAAR = infrarenal aortic aneurysm repair.

were no significant differences between baseline measurements (Table 1 and Figs 2A and C).

A highly significant decrease was detected between post1 and post3 measurements (mean post1 value = 5.12 mm, mean post3 value = 4.86 mm [$P < .01$]). Post1 measurements were obtained in the ICU following the intervention; post3 measurements were obtained 48 hours after the first postoperative measurement. At this time, 27 of the 28 patients had been extubated and were breathing spontaneously.

In Group iAAR, a highly significant decrease could be detected between all postinterventional measurements and the baseline values (Table 1, $P < .01$). In addition, a significant decrease could be noted between post1 and post2 measurements (mean post1 value = 5.16 mm, mean post2 value = 5.08 mm [$P = .02$]). ONSDs increased toward the end of the hospital stay, with a significant increase found between the post4 and post2 time points (mean post4 value = 5.13 mm, mean post2 value = 5.08 mm [$P = .04$]; Table 1 and Figs 2B and D).

As mentioned in Methods section, a high interrater reliability of ONSD measurements has already been demonstrated.[9] A reassessment of measurements by a second examiner blinded to treatment regime and time point (FS) confirmed correct values. Intrarater variations were minimized by obtaining the mean value of six measurements.

Discussion

To the best of our knowledge, the present study is the first in which researchers have prospectively analyzed the possibility of monitoring ONSD changes in different patient populations undergoing EVAR.

Patients undergoing iAAR have a significantly lower risk of developing a fatal increase in ISP due to spinal ischemia than patients undergoing sAAR.[6] The hypothesis that patients in the two groups would feature different courses of ONSD changes as an indirect marker for ISP could be confirmed in our prospective study: we demonstrated significant changes in ONSD after EVAR of sAA (increase, $P = .006$) and EVAR of iAA (decrease, $P = .02$). A relevant difference between both groups was also evident in the baseline ONSD values with higher mean values in iAAR patients (5.3 (SD .4) mm vs. 4.9 (SD .64 mm). Most likely this is due to the known high interindividual range of "normal" ONSD values.[10] Additionally, the standard deviation in the baseline values in this group was significantly higher, which might have shifted up the mean values of this smaller group. Once again, this observation underlines the importance of consecutive ONSD measurements rather than relying on absolute values.

A far more heterogeneous pattern of ONSD curves was identified in Group sAAR patients than in Group iAAR patients. This may be explained by the more complex and diverse interference in spinal blood supply brought about by EVAR of a greater length of the suprarenal aorta and interindividual variations of collateral vessels.

Comparison of Subgroups

A subgroup of 7 Group sAAR patients had a similar course of changes in ONSD diameters over time to that of Group iAAR patients (Figs 3A and B). In these cases, the ONSD decreased after baseline measurements to slowly recover toward initial values within several days after intervention. Interestingly, all of these sAAR patients were supplied with a relatively short suprarenal stent below the level of the celiac trunc, thus resembling the iAAR group concerning the interference with spinal vascular supply. This characteristic ONSD curve after measurements at consecutive time points might be consequence of general anesthesia: literature focusing on direct (intravenous, volatile anesthetics, PEEP during ventilation) and indirect (blood pressure alterations, volume distribution effects) effects of narcosis on intracranial pressure is scarce, and there are nearly no data concerning ISP. Intracranial pressure is lowered by general anesthesia, especially propofol-fentanyl-induced narcosis.[11] Obviously, this is only part of the truth, as most Group iAAR patients (96%) in our study were rapidly extubated after the intervention. Either a prolonged effect after narcosis or other factors, mainly a different volume management, might play a role.

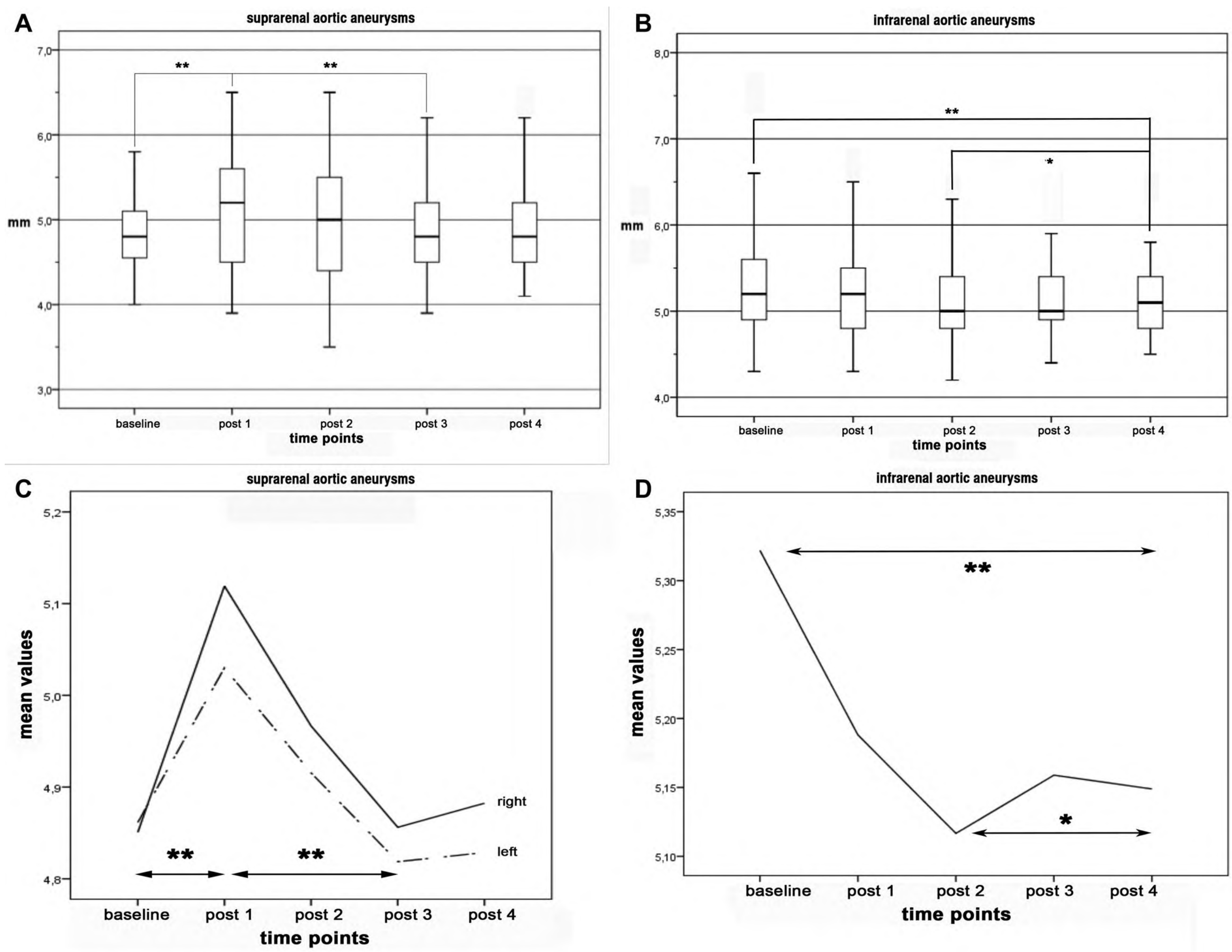

Fig 2. Groups with suprarenal aortic aneurysm repair (AAR) (A) and infrarenal AAR (B): Box-plot diagrams showing mean values of optic nerve sheath diameters (ONSDs) (calculated in millimeters, *y*-axes) at different measurement time points (*x*-axes). *significant differences; **highly significant differences. Groups suprarenal AAR (C) and infrarenal AAR (D): Line diagrams showing mean values of ONSDs (calculated in millimeters, *y*-axes) at different measurement time points (*x*-axes). *significant differences; **highly significant differences.

Pathophysiology of ISP Alterations in Group sAAR

The most likely explanation for the increased ISP in the sAAR group is ischemia-related edema of the spinal cord in combination with reperfusion edema after partial reconstitution of the spinal microcirculation.[12] A long-segment thoracic aortic coverage had been widely identified as a significant risk factor in predicting clinically evident SCI.[4,5,13,14] Moreover, the involvement of multiple vascular territories was identified as an additional risk factor for SCI.[15]

Within 24 hours after the first postoperative measurement, a significant decrease in the mean ONSD was detected. This effect may partly be explained by a reduction in CSF pressure due to the spinal catheter, which obviously is only one component. One argument for additional components is the fact that patients with spinal catheters had lower ONSD values at any time point but exhibited the same diameter curve as patients without a spinal drain. Second, ONSD values further decreased spontaneously after the spinal catheters were removed. The reason for this may be a combination of ISP regression due to partial resolution of intramedullar edema and a higher net efflux fraction of CSF reabsorbed into the venous system due to a change in the pressure gradient. In contrast to pathological intracranial conditions, in which venous drainage pathways may also be compressed, an isolated increase in spinal pressure does not lead to an effect on physiological intracranial CSF flow.

Identification of Patients at Risk for Spinal Vascular Injury

The recognition of "hazardous" ONSD profiles could be a helpful clinical application of OS in suprarenal EVAR or surgery of open AAR. As could be observed in our study, the subgroup of patients in whom post2 ONSDs were higher than baseline and post1 ONSDs carried a higher risk of irreversible paraplegia. Dysfunction of spinal drains caused by dislocation, congestion, or kinking is a common problem: therefore, ONSD controls might be especially useful in patients not accessible for neurologic assessment (eg, during narcosis or sedation). Increasing ONSD values should trigger a thorough investigation of spinal drain functionality.

On the other hand, Group sAAR patients demonstrating a similar pattern to Group iAAR patients could be classified as low risk with respect to spinal vascular injury and could be spared from the possibly harmful complications of a spinal

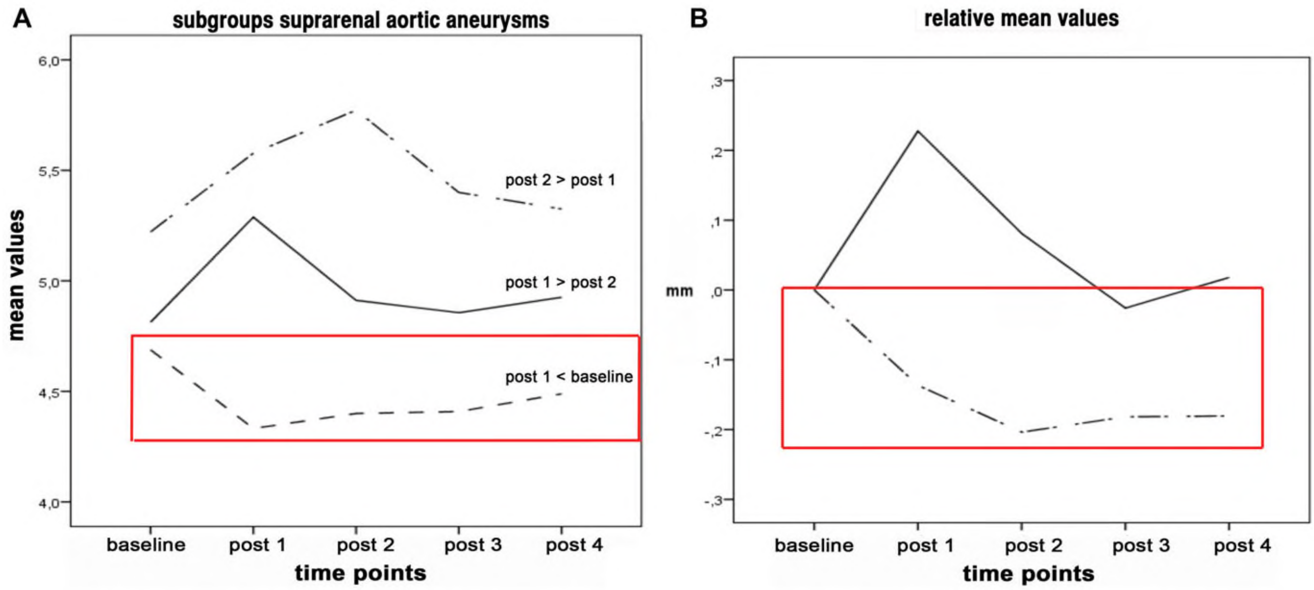

Fig 3. (A) Line diagram depicting subgroups of different optic nerve sheath diameters (ONSDs) in patients who underwent sAAR. Red box: similar ONSD curve in one subgroup of suprarenal aortic aneurysm repairs (AAR) and infrarenal AAR patients. (B) Line diagram showing relative ONSD values in patients who underwent suprarenal AAR (continuous line) and those who underwent infrarenal AAR (dotted line). Red box: similar ONSD curve in one subgroup of suprarenal AAR and infrarenal AAR patients.

catheter.[16] This hypothesis needs to be investigated in future trials.

Reliability of the results

A reliable correlation between ONSD values and invasive ICP measurements could be demonstrated,[17] and ONSD measurement has a high intra- and interobserver reliability.[9] In accord with results of other ONSD studies,[9,18,19] we found a high interindividual spread of baseline and consecutive values, which explains variances depicted in our box-plot diagrams. The bottom line therefore is the importance of consecutive measurements and the comparison to baseline values.

Limitations of the Study

We recognize several shortcomings of the present study:

> for example, the lack of a control group without endovascular stent implantation and the first examiner not having been blinded to pathological conditions and specific stent configurations. Only the second examiner, who confirmed the accuracy of the ONSD measurements, was blinded regarding specific patient information.

We relinquished the chance to examine a correlation between ISP and ONSD values, as sufficient evidence of a correlation with raised intracranial pressure already exists.[9,20,21]

A relevant bias might be caused by the lack of spinal catheters in Group iAAR. Catheters were associated with significantly lower ONSDs in sAAR patients, leading to the assumption that values might even have been lower applying catheters in patients with iAAR. The reason for relinquishing spinal catheters in iAAR patients was already stated previously.

In addition to absolute values at different time points, another aspect of ONSD dynamics may include the velocity of value changes. As we could demonstrate, the most striking relative differences occurred between baseline measurements and 48 hours thereafter. The contraction of measurement intervals within that period and the application of intraoperative examinations may be helpful to learn more about immediate pressure dynamics in different patients. One hypothesis may be that patients with a quick increase in ONSD may be more prone to clinically relevant spinal edema.

Conclusion

The present study gave some evidence for different changes of ONSD after sAAR and iAAR. This observation might be helpful to discover the individual risk for vascular spinal injury. This novel method may help guide clinical decision-making concerning the application and control of spinal catheters and should be evaluated in further studies.

References

1. Jonker FH, Trimarchi S, Verhagen HJ, et al. Meta-analysis of open versus endovascular repair for ruptured descending thoracic aortic aneurysm. J Vasc Surg 2010;51(4):1026-32.
2. Carroccio A, Marin ML, Ellozy S, et al. Pathophysiology of paraplegia following endovascular thoracic aortic aneurysm repair. J Card Surg 2003;18(4):359-66.
3. Ullery BW, Quatromoni J, Jackson BM, et al. Impact of intercostal artery occlusion on spinal cord ischemia following thoracic endovascular aortic repair. Vasc Endovascular Surg 2011;45(6):519-23.
4. Feezor RJ, Martin TD, Hess PJ, Jr, et al. Extent of aortic coverage and incidence of spinal cord ischemia after thoracic endovascular aneurysm repair. Ann Thorac Surg 2008;86(6):1809-14; discussion 1814.
5. Gravereaux EC, Faries PL, Burks JA, et al. Risk of spinal cord ischemia after endograft repair of thoracic aortic aneurysms. J Vasc Surg 2001;34(6):997-1003.
6. Kouvelos GN, Papa N, Nassis C, et al. Spinal cord ischemia after endovascular repair of infrarenal abdominal aortic aneurysm: a rare complication. Case Rep Med 2011;2011:954572.

7. Ertl M, Schierling W, Kasprzak P, et al. Optic nerve sheath diameter measurement to identify high-risk patients for spinal ischemia after endovascular thoracoabdominal aortic aneurysm repair. J Neuroimaging 2015;25:910-5.
8. Ertl M, Barinka F, Torka E, et al. Ocular color-coded sonography - a promising tool for neurologists and intensive care physicians. Ultraschall Med 2014;35(5):422-31.
9. Bauerle J, Lochner P, Kaps M, et al. Intra- and interobsever reliability of sonographic assessment of the optic nerve sheath diameter in healthy adults. J Neuroimaging 2012;22(1):42-5.
10. Goeres P, Zeiler FA, Unger B, et al. Ultrasound assessment of optic nerve sheath diameter in healthy volunteers. J Crit Care 2016;31(1):168-71.
11. Petersen KD, Landsfeldt U, Cold GE, et al. Intracranial pressure and cerebral hemodynamic in patients with cerebral tumors: a randomized prospective study of patients subjected to craniotomy in propofol-fentanyl, isoflurane-fentanyl, or sevoflurane-fentanyl anesthesia. Anesthesiology 2003;98(2):329-36.
12. Jacobs TP, Kempski O, McKinley D, et al. Blood flow and vascular permeability during motor dysfunction in a rabbit model of spinal cord ischemia. Stroke 1992;23(3):367-73.
13. Schurink GW, Nijenhuis RJ, Backes WH, et al. Assessment of spinal cord circulation and function in endovascular treatment of thoracic aortic aneurysms. Ann Thorac Surg 2007;83(2):S877-81; discussion S890-2.
14. Greenberg R, Resch T, Nyman U, et al. Endovascular repair of descending thoracic aortic aneurysms: an early experience with intermediate-term follow-up. J Vasc Surg 2000;31(1 Pt 1):147-56.
15. Czerny M, Eggebrecht H, Sodeck G, et al. Mechanisms of symptomatic spinal cord ischemia after TEVAR: insights from the European Registry of Endovascular Aortic Repair Complications (EuREC). J Endovasc Ther 2012;19(1):37-43.
16. Youngblood SC, Tolpin DA, LeMaire SA, et al. Complications of cerebrospinal fluid drainage after thoracic aortic surgery: a review of 504 patients over 5 years. J Thorac Cardiovasc Surg 2013;146(1):166-71.
17. Dubourg J, Javouhey E, Geeraerts T, et al. Ultrasonography of optic nerve sheath diameter for detection of raised intracranial pressure: a systematic review and meta-analysis. Intensive Care Med 2011;37(7):1059-68.
18. Rohr A, Riedel C, Reimann G, et al. Pseudotumor cerebri: quantitative in-vivo measurements of markers of intracranial hypertension. Rofo 2008;180(10):884-90.
19. Bauerle J, Schuchardt F, Schroeder L, et al. Reproducibility and accuracy of optic nerve sheath diameter assessment using ultrasound compared to magnetic resonance imaging. BMC Neurol 2013;13:187.
20. Tamburrelli C, Salgarello T, Caputo CG, et al. Ultrasonographic evaluation of optic disc swelling: comparison with CSLO in idiopathic intracranial hypertension. Invest Ophthalmol Vis Sci 2000;41(10):2960-6.
21. Antonelli M, Azoulay E, Bonten M, et al. Year in review in Intensive Care Medicine, 2008: I. Brain injury and neurology, renal failure and endocrinology, metabolism and nutrition, sepsis, infections and pneumonia. Intensive Care Med 2009;35(1):30-44.