Determination of selective antegrade perfusion flow rate in aortic arch surgery to restore baseline cerebral near-infrared spectroscopy values: a single centre observational study

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Key Question: What flow rate is necessary to maintain rSO_2 baseline during selective antegrade perfusion in aortic arch surgery?
Key finding(s): rSO2 was lower than baseline at 6ml/kg/min. Flow rates of 8 and 10 ml/kg/min resulted in rSO2 that did not differ from the baseline.
Take-home message: Baseline rSO2 is more likely met at 8 than 6 ml/kg/min. A flow rate of 10 ml/kg/min does not further increase the rSO2 significantly.

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Abstract

Objective

Neuroprotection during aortic arch surgery involves selective antegrade cerebral perfusion. The parameters of cerebral perfusion, e.g. flow rate, are inconsistent across centers and are subject of debate. The aim of this study was to determine the cerebral perfusion flow rate during hypothermic circulatory arrest required to meet preoperative awake baseline regional cerebral oxygen saturation (rSO_2).

Methods

Patients scheduled for aortic arch surgery with hypothermic circulatory arrest were enrolled in this prospective observational study. After initiation of hypothermic circulatory arrest, bilateral selective antegrade cerebral perfusion was established and cerebral flow rate was continuously increased. The primary endpoint was the difference of cerebral saturation from baseline during cerebral perfusion flow rates of 6 ml/kg/min, 8 ml/kg/min, and 10 ml/kg/min.

Results

A total of 40 patients were included. During antegrade cerebral perfusion rSO_2 was significantly lower than the baseline at 6ml/kg/min (-7.3, 95%-CI: -1.7,-12.9; p=0.0015). In contrast flow rates of 8 and 10 ml/kg/min resulted in rSO_2 that did not significantly differ from the baseline (-2; 95%-CI: -4.3,8.3; p>0.99 and 1.8; (95%-CI: -8.5%, 4.8%; p>0.99). Cerebral saturation was significantly more likely to meet baseline values during selective antegrade cerebral perfusion with 8ml/kg/min than at 6ml/kg/min (44.1%; 95%-CI: 27.4%,60.8% vs 11.8%; 95% CI: 0.9%,22.6%; p=0.0001).

Conclusion

At 8 ml/kg/min cerebral flow rate during selective antegrade cerebral perfusion regional cerebral oximetry baseline values are significantly more likely to be achieved than at 6 ml/kg/min. Further increasing the cerebral flow rate to 10 ml/kg/min does not significantly improve rSO_2.

Introduction:

Aortic arch surgery requires neuroprotective techniques to protect the brain from transient ischemia. The mainstay of neuroprotection includes systemic hypothermia and regional cerebral perfusion. Lowering the body temperature generally reduces the metabolic rate of a tissue. This is especially important for the brain tissue that only has a limited tolerance for malperfusion and hypoxemia. Cerebral metabolism decreases markedly with decreases in body temperature.[1, 2] A technique to reduce the metabolic demands of the brain by cooling the patient on cardiopulmonary bypass (CPB) and then arresting the circulation for the duration of aortic arch repair, the hypothermic circulatory arrest (HCA), applies this concept to aortic arch surgery.[3] Furthermore, HCA in combination with regional cerebral perfusion prolongs the window for cessation of aortic blood flow, as supply with cold oxygenated blood to the brain is maintained. This technique is proven to be feasible and save.[4-6] Whereas many techniques of delivering cerebral perfusion have been described, bilateral selective antegrade perfusion (sACP) of the right and left common carotid artery is the standard in many centers.[7] The detailed parameters applied for flow rate and perfusion pressure during sACP remain subject of debate. Animal studies showed that the lower threshold for selective antegrade flow rate is 6 ml/kg/min before cerebral tissue ischemia develops,[8] whereas high flow rates have the burden of luxury perfusion, an increase in intracranial pressure and risk of cerebral edema.[9] While the optimal flow rate for selective antegrade cerebral perfusion in humans remains yet unknown, maintaining regional cerebral oxygenation (rSO_2) as measured by near infrared spectroscopy (NIRS) at awake baseline values is a commonly employed strategy. The objective of this study was to determine what flow rate is necessary to maintain awake baseline cerebral oxygenation during selective antegrade perfusion in aortic arch surgery. We hypothesized that a flow rate between 6 and 10 ml/kg/min will be necessary to achieve this endpoint.

Methods

With local ethics committee approval (Cantonal Ethics Committee Bern, Switzerland), patients scheduled for elective aortic arch repair with planned hypothermic circulatory arrest and bilateral sACP were included in this prospective observational single centre study. Patients were enrolled from June, 2018 until December, 2020. Informed consent was obtained before study inclusion. This study was registered on clinicaltrials.gov (NCT03484104).

Anesthesia technique

Patients were monitored with standard monitoring tools according to American Society of Anesthesiology, including bilateral frontal NIRS optodes. Anesthesia induction was conducted according to institutional practice. After measurement of the rSO_2baseline at room air intravenous access was obtained. A single dose of 1 mg midazolam was applied before placement of an arterial line. Prior to induction, patients were oxygenated with 100% oxygen until the expiratory oxygen fraction reached 80%. During preoxygenation a sufentanil bolus of 0.5 mcg/kg adjusted to total body weight (TBW) was administered. Induction was initiated with titration of propofol (1-2 mg/kg TBW) or etomidate (0.2-0.6 mg/kg TBW), followed by rocuronium (1 mg/kg adjusted to ideal body weight (IBW)) after loss of consciousness. Following endotracheal intubation every patient had a central venous line and a multi access catheter preferably placed in the right internal jugular vein. Temperatures were monitored at four sites: bladder (via Foley catheter, considered as reference for body core temperature), pharynx and tympanum bilaterally. Anesthesia maintenance was provided with isoflurane (via ventilator and during CPB via vapor in fresh gas flow to oxygenator).

Neuromonitoring

Bifrontal rSO_2 measurement by NIRS was started prior to anesthesia induction and continuously recorded throughout the case with a Masimo Root®, O3® (Irvine, CA, USA) regional oximetry device. This technique is recommended by international societies for aortic arch procedures and is widely accepted for monitoring sACP during HCA.[10] The initial measurement obtained in the awake patient breathing room air was defined as baseline. EEG monitoring was initiated with a Masimo Sedline® (Irivine, CA, USA) utilizing the same Masimo Root® device at the same time.

Hypothermic circulatory arrest and selective antegrade cerebral perfusion

HCA and sACP were performed according to institutional standards: After central aortic cannulation and initiation of CPB cooling was started and ice pads were placed on the forehead. When reaching a core temperature of 26-28°C on CPB, HCA was initiated. After opening the aortic arch and visualizing the orifices of the supra-aortic branches, balloon perfusion catheters were inserted into the left and right carotid arteries (via the innominate artery). Cerebral perfusion was performed using a separate roller pump and the two balloon-tipped perfusion catheters (distal perfusion catheter 12 F, LeMaitre Vascular Inc. Burlington, MA, USA). Cerebral perfusate was drawn from the CPB oxygenator, the temperature of the perfusate was 20°C, and the pressure in the common ACP line was monitored close to the roller pump.

Flow through the perfusion catheters was consecutively slowly increased in every patient by the perfusionist according to institutional routine. The effect of sACP was monitored by bifrontal NIRS. The increase in perfusion flow was halted when the cerebral perfusion met rSO_2 values that were approximating those recorded on CPB before initiation of HCA. However, if the line pressure was meeting values of >300 mmHg, the increase in flow was stopped and the flow decreased to maintain a pressure below 300mmHg.

Study specific data collection

rSO_2 values were continuously recorded in the anesthesia documentation system. For this study rSO_2 values were specifically noted by a study nurse at awake baseline, after preoxygenation, on CPB before HCA, after initiation of HCA at sACP flow of 6, 8 and 10 ml/kg ideal body weight per min, at the end of sACP, back on CPB and after administration of protamine after separation from CPB. For the objective of this study the observational data collection at the initiation of sACP was of utmost importance. During this phase of the procedure continuous increase of the sACP flow rate exposed the individual patient to sACP flow alterations and subsequent variations in rSO_2.

Clinical endpoints

The primary outcome was the bifrontal rSO_2 value at 6 ml/kg/min, 8 ml/kg/min and 10 ml/kg/min sACP flow rates. We calculated the difference from those values to the awake baseline rSO_2 as primary endpoint. An important secondary clinical outcome was the occurrence of neurologic deficits. Those were defined as neurological deficits that were not present before the day of surgery and included ischemic stroke, transient ischemic attack (TIA), delirium and postoperative cognitive decline (POCD).

Sample size

Until now no data for sACP flow that is necessary to meet the awake rSO2 baseline were reported. Based on a lack of evidence and derived from clinical observations (of a steep increase of rSO2 during initiation of sACP) we assumed a medium standardized effect size and opted for a sampling with a sample size of 40 patients.

Statistical analysis

Categorical variables are reported as frequency and percentages. Continuous variables are reported as mean and standard deviation in case of normally distributed values and as median and interquartile range otherwise.[11] The repeated measurements of rSO2 values were statistically modelled using a Generalized Estimation Equation (GEE) model (R package *geepack*) with an exchangeable correlation structure.[12] A binomial outcome distribution of the GEE allowed the computation of the probability of reaching the baseline rSO_2 values as a function of the flow rate. Predicted probabilities are illustrated using estimated marginal means (R package *emmeans)*.[13] A Gaussian outcome distribution in a separate GEE allowed the pairwise comparisons of rSO2 values at different timepoints whose *p* values were adjusted using Tukey's method. Pairwise comparisons of rSO2 were only possible for those patients arriving a 10 kg/ml/min flow rate (N=13). A p value < 0.05 was considered significant and statistical analysis was performed with R version 4.0.2.[13, 14]

Results

Population

A total of 40 patients with HCA and sACP were enrolled in this study. Fifteen patients (38%) were female (Table 1). Mean body weight and BMI were 83.3 ± 15.7 kg and 27.8 ± 5 kg/m2, respectively. One case was a redo procedure. Thirty-two patients (80%) had arterial hypertension and 18 (45%) patients had concomitant coronary artery disease (CAD). One patient had a history of myocardial infarction. Renal insufficiency (>grade 1, KDIGO) was present in 13 (33%) patients. Two patients had a history of stroke. Atrial fibrillation was known in 6 (15%) patients. The median Euroscore II was 3.93 [IQR:2.26-6.46].

Surgical procedures

Overall surgical procedures were mostly combinations of procedures including replacement of the of the supracoronary aorta in 22 (55%) patients and a composite graft (Bentall procedure) in 18 patients (45%). Out of these two groups two patients had a replacement of the aortic arch, one with and one without a Bentall procedure (Table 2). Every patient had at least an open distal anastomosis for which bilateral sACP was needed. The median duration of surgery was 272 [IQR:236-331] min, whereas the duration of cardiopulmonary bypass run was 154 [IQR:133-178] min. The median HCA duration was 16 [IQR:13.0-19.2] min, including 11 [IQR:8.0-14.0] min for bilateral sACP.

Cerebral oximetry

Median awake cerebral oximetry was 63.0 [IQR:59.9-65.1] (Table 3). Preoxygenation resulted in an increase of rSO_2 to 67.5 [IQR:64.4-70.5]. During sACP the median NIRS values were 57.0 [IQR:53.0-61.9], 60.5 [IQR:56.5-65.4] and 61.5 [IQR:57.1-63.6] with the corresponding sACP flow rates of 6, 8 and 10 ml/kg/min respectively.

The rSO_2 was significantly lower than the baseline at 6ml/kg/min for patients that reached all three levels of sACP flow rates (difference: -7.3; 95%-CI: -1.7, -12.9; p=0.0015, pairwise comparison Table A3). In contrast flow rates of 8 and 10 ml/kg/min resulted in rSO_2 that did not significantly differ from the baseline awake rSO_2 (difference: -2; 95%-CI: -4.3, 8.3; p>0.99 and 1.8; 95%-CI: -8.5%, 4.8%); p>0.99). Table 4 shows the number of patients that reached each level of sACP flow rate.

The predicted probability to achieve the baseline rSO_2 during sACP with a flow of 6ml/kg/min was 11.8% (95%-CI: 0.9%, 22.6%) for the cohort of 34 patients that achieved perfusion steps 6 and 8 ml/kg/min. The probability was significantly higher at a flow of 8 ml/kg/min (44.1%; 95%-CI: 27.4%,60.8%; p=0.0001) (Fig.2 A).

For the cohort of patients that achieved three perfusion rate levels (6-8-10ml/kg/min) the probability was 7.1% (95%-CI: -6.3%,20.6%), 42.9% (95%-CI: 16.9%,68%) and 57.1% (95%-CI: 32.2%,83.1%) (Fig 2 B) for 6, 8 and 10ml/kg/min flow rate, respectively. The difference in probabilities was significant between 6 and 8ml/kg/min and 6 and 10 ml/kg/min flow. Although 10ml/kg/min flow achieved higher probabilities than 8ml/kg/min the difference was not significant (p=0.278).

Clinical outcomes

Fourteen (35%) patients in our cohort had neurologic deficits. Nine (23%) patients had postoperative delirium, 4 (10%) motor deficits, and 2 (5%) patients had a reduction in visual acuity. All neurologic deficits were transient, and all patients were symptom-free at discharge. In 9 (23%) patients cerebral neuroimaging with either computed tomography or magnetic resonance imaging was performed and showed ischemic lesions in 4 (10%) patients. Three of these lesions were described embolic (Appendix Table A4). There were no statistically significant differences in patients with and without neurological deficits concerning the proportion of patients meeting the baseline rSO_2 values and the flows that were achieved during sACP (Appendix Tables A1 and A2). No patient died during hospitalization.

Discussion

In this study of 40 patients undergoing aortic arch surgery with HCA, we found that sACP flows of 8 and 10ml/kg/min were able to approximate the baseline rSO_2, whereas a flow of 6ml/kg/min resulted in significantly lower rSO_2 than baseline. The probability of achieving awake cerebral oximetry baseline values with an sACP flow of 6 ml/kg/min was significantly lower than with 8 ml/kg/h. Further increase of flow rate to 10ml/kg/min did not result in a significant increase in the probability to achieve the baseline rSO_2.

This study is the first to report sACP flow rates, resulting rSO_2 values with the flow rates and probabilities to achieve the baseline cerebral oximetry measurements in humans during HCA for surgical interventions of the thoracic aorta.

Evidence on how to perform sACP until now was derived from animal studies. Haldenwang et al. used similar flow rate of 8ml/kg/min in an animal model and compared it to 18ml/kg/min, with the latter leading to increased intracranial pressure and not providing any benefit.[9] In our study there was no significant increase in probability to meet the baseline when further increasing the flow to 10ml/kg/min when baseline value were not achieved with 8ml/kg/min. However, a recent survey revealed an average flow of 10-15ml/Kg/min used for sACP in many centers.[7] The majority of our patients did not meet these flow rates. Nevertheless, our measurements of cerebral oximetry as well as our clinical results are reassuring of our strategy. Higher flow rates were hindered in our setting by in-line pressures that were approaching the hemolysis threshold. Due to that pressure build up in the 3/16” sACP perfusion line, the increase in sACP flow was halted routinely, when reaching 300mmHg and maintained at the achieved level. The line pressure was measured close to the roller pump of the sACP line. It is important to consider that most of the pressure build up is due to in-line resistance to flow of the 150 cm long line and does not equal the intra-vascular or cerebral perfusion pressures. That may indicate that generating high intra-line pressures may not be worth the risk of hemolysis because flow rates beyond 8ml/kg/min might have limited effects on additional tissue oxygenation. Higher flow may also increase cerebral perfusion pressure and animal data show that high-pressure perfusion did not result in better outcomes than a low-pressure approach.[15]

The lower flow rate of 6ml/kg/min resulted in a low probability to achieve baseline rSO_2. In addition a relative decrease of 20% in rSO_2 from baseline is acknowledged as the threshold to initiate treatment measures during adult cardiac surgery.[16] Thus, the lower flow rate of 6ml/kg/min in our study was not able to prevent a substantial decrease of rSO_2 of this magnitude in all patients. This observation is in line with an animal study that suggests an ischemic threshold with sACP at 20°C is close to the flow rate of 6ml/Kg/min.[8] Furthermore a retrospective analysis in surgical patients showed that blood flow in the middle cerebral artery during sACP, measured by trans cranial doppler, was not detectable below a flow of 5ml/kg/min.[17]

Although a flow of 8ml/Kg/min restored baseline values with a probability of 42.9% close observation of the individual response to initiation of sACP on cerebral oximetry is obligatory. Our records suggest that there is a wide interindividual variation for demands of flow rate during sACP (Figure 3). Real time monitoring with cerebral oximetry can augment the adjustment of the flow rate to each individual patient.

Due to the limited volume of brain tissue monitored by bifrontal NIRS multimodal neuromonitoring with EEG and transcranial doppler may be able to expand the amount of dependent brain tissue monitored and to survey the effective flow delivered. Further studies to evaluate the practice of sACP and impact of different flow rates on cerebral oximetry and clinical outcome are needed to confirm our findings and add to generalizability. These findings must be interpreted in the context of the study design as the nature of this study is observational the sACP was commenced according to institutional standards. The sACP flow was continuously increased to approximate the reference rSO_2 values on CPB before HCA in each patient. We utilized that initiation phase to observe the effect of different flow rates on rSO_2. However, there was no study specific protocol for sACP commencement and flow rates. This allowed also for individual adaption of the flow rate and surgical demands. We did not monitor the intra-vascular cerebral perfusion pressure (or estimates thereof in the right radial-, carotid- or temporal artery). This is not a routine procedure in our institution. Thus, we cannot correlate flow rates and resulting cerebral oximetry values to achieved intravascular cerebral perfusion pressures. Since the right-sided perfusion catheter was introduced through the innominate artery a potential run-off of perfusate into the right arm cannot be excluded. As described above the in-line pressure in the sACP perfusion line limited the increase beyond 8ml/kg/min in 27 patients, resulting in a limited number of patient going through all three levels of flow rates (6, 8 and 10ml/kg/min). In general HCA in our population were short in duration (Table 2). However, they were longer than safe HCA durations suggested earlier for the given core temperatures without sACP, thus justifying the sACP even for relatively short durations. Our results with our institutional approach may not ad hoc be generalizable to other institutions. Thus, our findings need to be confirmed in other settings. However, the results indicate that prior evidence from animal studies concerning the lower limit of sACP flow rates may be applicable to human patients.

Conclusion

At 8 ml/kg/min cerebral flow rate during selective antegrade cerebral perfusion, cerebral oximetry baseline values are significantly more likely to be achieved than at 6 ml/kg/min. Further increasing the cerebral flow rate to 10 ml/kg/min does not significantly increase the probability to achieve baseline rSO_2.

Data Availability Statement

The data underlying this article will be shared on reasonable request to the corresponding author and after approval of the local ethics committee according to local regulations.

Table 1: Patient demographics and comorbidities

Gender (female)	15/40 (38%)
Height (cm)	173 (10.1)
Weight (kg)	83.3 (15.7)
BMI (kg/m^2)	27.8 (5.00)
Ideal body weight (male; kg)	73.9 (6.65)
Ideal body weight (female; kg)	55.7 (5.37)
Prior cardiac surgery	1 (3%)
Cerebrovascular disease	0 (0%)
Prior Stroke†	2 (5%)
TIA	3 (8%)
Atrial Fibrillation:	6 (15%)
Coronary artery disease	18 (45%)
History of myocardial infarction	1 (3%)
COPD	2 (5%)
Arterial hypertension	32 (80%)
Diabetes	1 (3%)
Renal failure (> grade I, KDIGO):	13 (33%)
Creatinine at 1st day of hospital stay [mmol/L]	81.5 [IQR: 67.0-90.8]

Table 1: Summary of patient demographics and comorbidities. BMI: body mass index, TIA: transient ischemic attack, COPD: chronic obstructive pulmonary disease, KDIGO: Kidney Disease: Improving Global Outcomes (Scale for grading kidney disease).

Table 2: Procedural data

Primary aortic procedures	
Supracoronary aortic replacement	22 (55%)
Composite Graft (Bentall procedure)	18 (45%)
Further cardiac or aortic procedures (combined procedures)	
Aortic arch replacement (Frozen elephant trunk, FET)	2 (5%)
Aortic valve procedure (replacement/repair including Composite grafts/Bentall procedures)	29 (73%)
Tricuspid valve procedure	1 (3%)
CABG	14 (35%)
PFO Closure	9 (23%)
ASD Closure	1 (3%)
Aortic segments included in procedure:	
aortic root	18 (45%)
zone 0	40 (100%)
zone 1	3 (8%)
zone 2	2 (5%)
zone 3	2 (5%)
Procedure duration (min)	272 [236;331]
CPB time (min)	154 [133;178]
Aortic cross-clamp time (min)	106 (36.8)
HCA time (min)	16.0 [13.0;19.2]
sACP time (min)	11.0 [8.00;14.0]
Length of hospital stay (days)	9.00 [7.00;13.0]
Euroscore 2	3.93 [2.26;6.46]

Legend **Table 2**: Summary of procedural data. CABG: coronary artery bypass graft, PFO: persistent foramen ovale, ASD: atrial septal defect, CPB: Cardiopulmonary bypass, HCA: hypothermic circulatory arrest. sACP: selective antegrade cerebral perfusion.

Table 3: Intraoperative data

	Awake Baseline	Preoxygenated	After intubation	CPB before HCA	sACP 6ml/kg/min	sACP 8ml/kg/min	sACP 10ml/kg/min	At end of sACP	At end of CPB	After separation from CPB (after protamine)
Flow of 6ml/kg/min achieved	.	.	.	.	40 (100%, 95%-CI: 91.2% - 100%)	.	.	.	.	.
Flow of 8ml/kg/min achieved	.	.	.	.	.	34 (85.0%, 95%-CI: 70.2% - 94.3%)	.	.	.	.
Flow of 10ml/kg/min achieved	.	.	.	.	.	.	13 (32.5%, 95%-CI: 18.6% - 49.1%])	.	.	.
Total flow (ml/min)	.	.	.	.	402 (SD:64.7)	523 (SD:86.7)	585 (SD:107)	543 (SD:87.9)	.	.
rSO_2 left	62.5 [59.8;65.2]	68.5 [63.0;71.0]	65.5 [62.8;70.0]	65.0 [59.0;72.0]	58.0 [51.5;63.0]	60.0 [57.0;66.0]	62.5 [57.2;64.8]	63.0 [57.0;69.0]	63.0 [57.8;67.2]	63.0 [59.5;67.0]
rSO_2 right	64.0 [59.0;66.2]	68.0 [65.8;71.0]	67.0 [63.0;71.0]	66.0 [61.0;73.0]	57.0 [53.8;61.2]	59.5 [55.0;66.8]	61.0 [56.2;66.2]	62.5 [58.0;68.2]	64.0 [58.8;67.2]	64.0 [62.0;68.5]
rSO_2 averaged	63.0 [59.9;65.1]	67.5 [64.4;70.5]	66.0 [62.4;71.6]	65.0 [59.5;72.1]	57.0 [53.0;61.9]	60.5 [56.5;65.4]	61.5 [57.1;63.6]	62.5 [58.8;66.6]	62.8 [57.6;67.6]	64.0 [60.8;67.2]
Hb (g/l)	.	.	130 [122;140]	104 [92.5;115]	.	.	.	.	98.5 [88.5;105]	98.5 [89.0;104]
Temperatures (°C)										
left tympanal	.	.	.	24.6 [23.6;26.1]	24.9 [23.4;25.6]	24.9 [23.4;25.5]	25.1 [24.9;25.6]	23.6 [22.6;24.4]	.	.
right tympanal	.	.	.	24.2 [23.3;25.7]	24.3 [23.2;25.4]	24.4 [23.3;25.5]	25.2 [23.9;25.4]	23.6 [22.5;24.3]	.	.
bladder (core)	.	.	.	28.3 [27.1;29.4]	27.5 [26.6;28.8]	27.6 [26.7;28.6]	27.5 [26.8;28.0]	27.5 [26.6;28.5]	.	.
Naso-pharyngeal	.	.	36.2 [35.9;36.3]	24.8 [23.8;26.3]	24.8 [23.7;26.3]	25.1 [23.7;26.2]	25.3 [24.5;25.9]	23.4 [22.8;24.9]	.	.
etCO2 (mmHg)	.	.	33.0 [31.8;35.0]	.	.	.	.	.	.	32.5 [29.0;34.8]
pH	.	.	7.35 [7.33;7.37]	7.31 [7.28;7.34]	.	.	.	.	.	7.33 [7.32;7.36]
pCO2 (mmHg)	.	.	45.0 [42.2;48.3]	47.5 [44.0;51.2]	.	.	.	.	.	45.8 [42.0;48.0]
pO2 (mmHg)	.	.	47.4 [42.4;50.7]	348 [304;397]	.	.	.	.	.	45.6 [41.8;50.0]

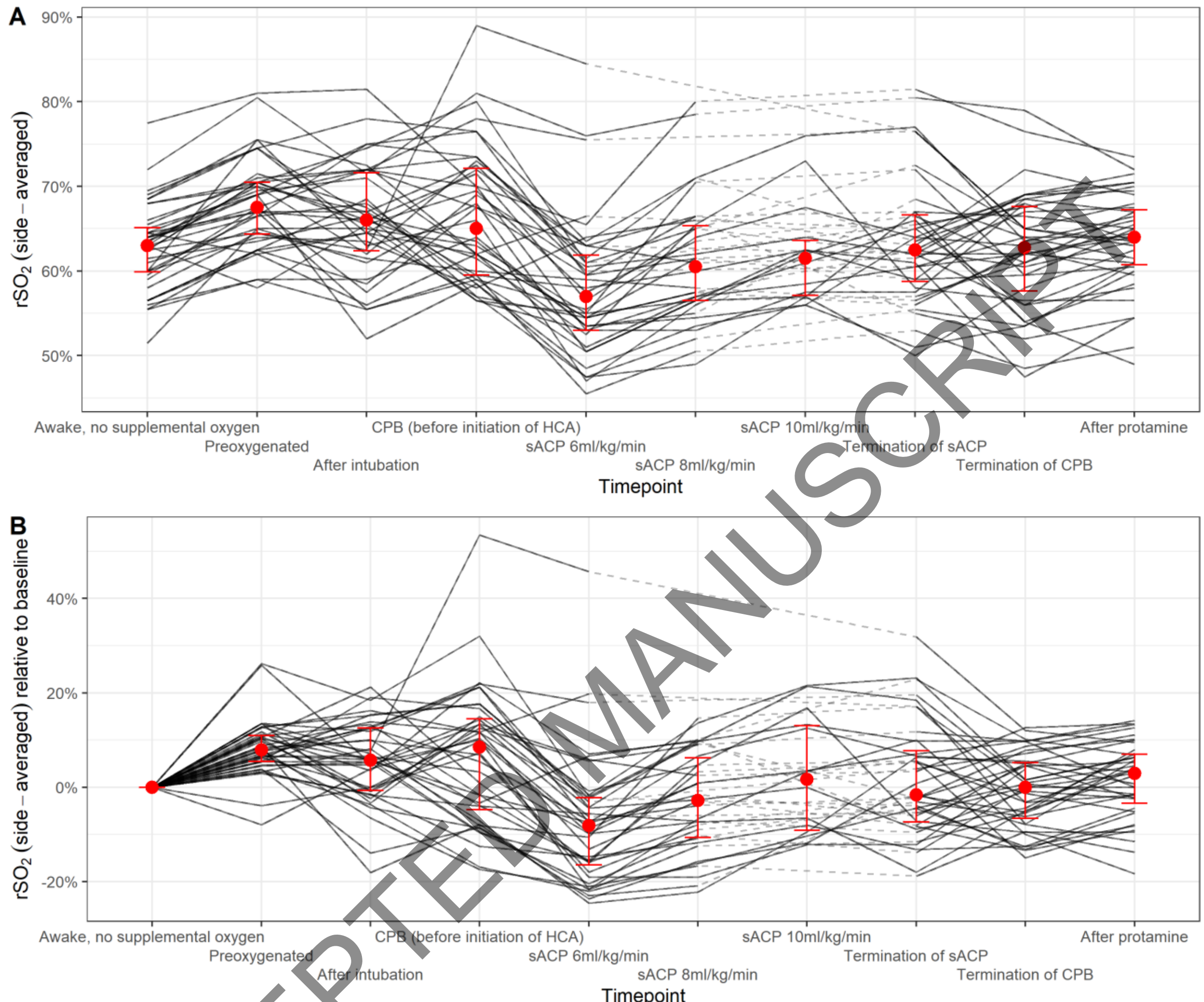
Legend **Table 3**: Summary of. sACP: selective antegrade cerebral perfusion. rSO_2: regional cerebral oxygenation, Hb: hemoglobin,

Table 4. Number of patients at or above the baseline rSO_2 during sACP (side-averaged).

Time point	Patients at or above baseline rSO2
Preoxygenated	38/40 (95%)
After intubation	29/40 (73%)
sACP 6ml/kg/min	7/40 (18%)
sACP 8ml/kg/min	15/34 (44%)
sACP 10ml/kg/min	8/13 (62%)
Termination of sACP	19/40 (48%)
Termination of CPB	21/40 (53%)

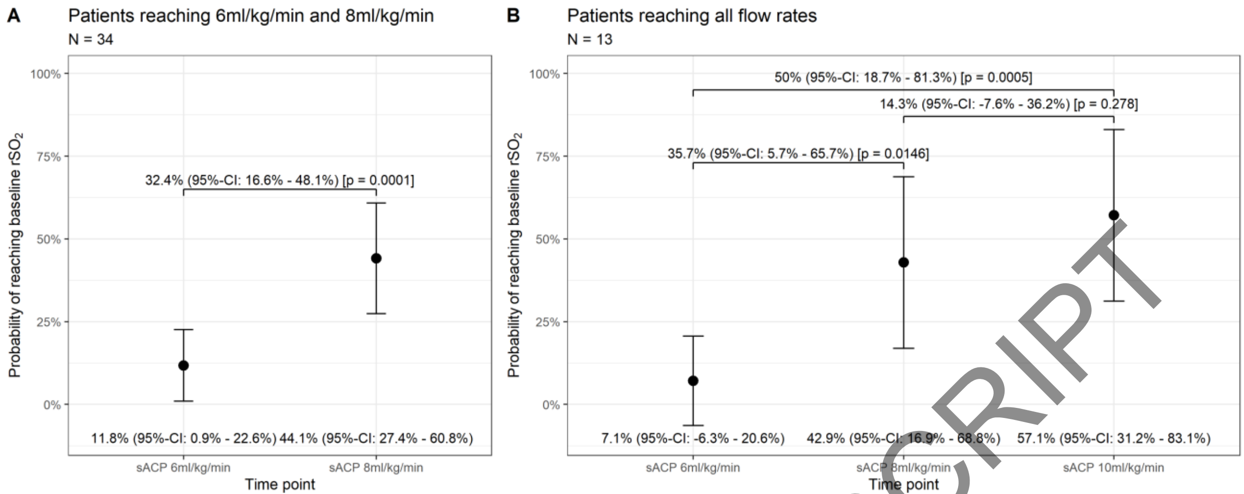
Legend **Table 4:** Summary of patients that achieved or exceeded their exact baseline rSO_2 at various time points during the procedure. rSO_2: regional cerebral oxygenation, sACP: selective antegrade cerebral perfusion, CPB: Cardiopulmonary bypass.

Figure 1: Time evolution of cerebral rSO_2 over the course of the procedure



Legend **Figure 1**: **A** rSO_2 plotted over time points of procedures. **B** relative rSO_2 changes from the awake rSO_2 baseline values (0%). Median and interquartile ranges are shown in red. Individual patients are shown in black lines. Dotted lines indicate that the sACP flow was not achieved. rSO2: regional cerebral oxygenation, sACP: selective antegrade cerebral perfusion

Figure 2: Predicted probabilities for rSO_2 values with specific SACP flow



Legend **Figure 2**: Predicted probabilities to achieve the baseline rSO_2 with each sACP flow rate. **A** patients that were perfused with sACP flow rates of 6ml/kg/min and increased to 8ml/kg/min. **B** patients that were perfused with increase from 6ml/kg/min through 8ml/kg/min and 10ml/kg/min. rSO2: regional cerebral oxygenation, sACP: selective antegrade cerebral perfusion.

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Figure 1

Click here to access/download;Figure;Figure1.png

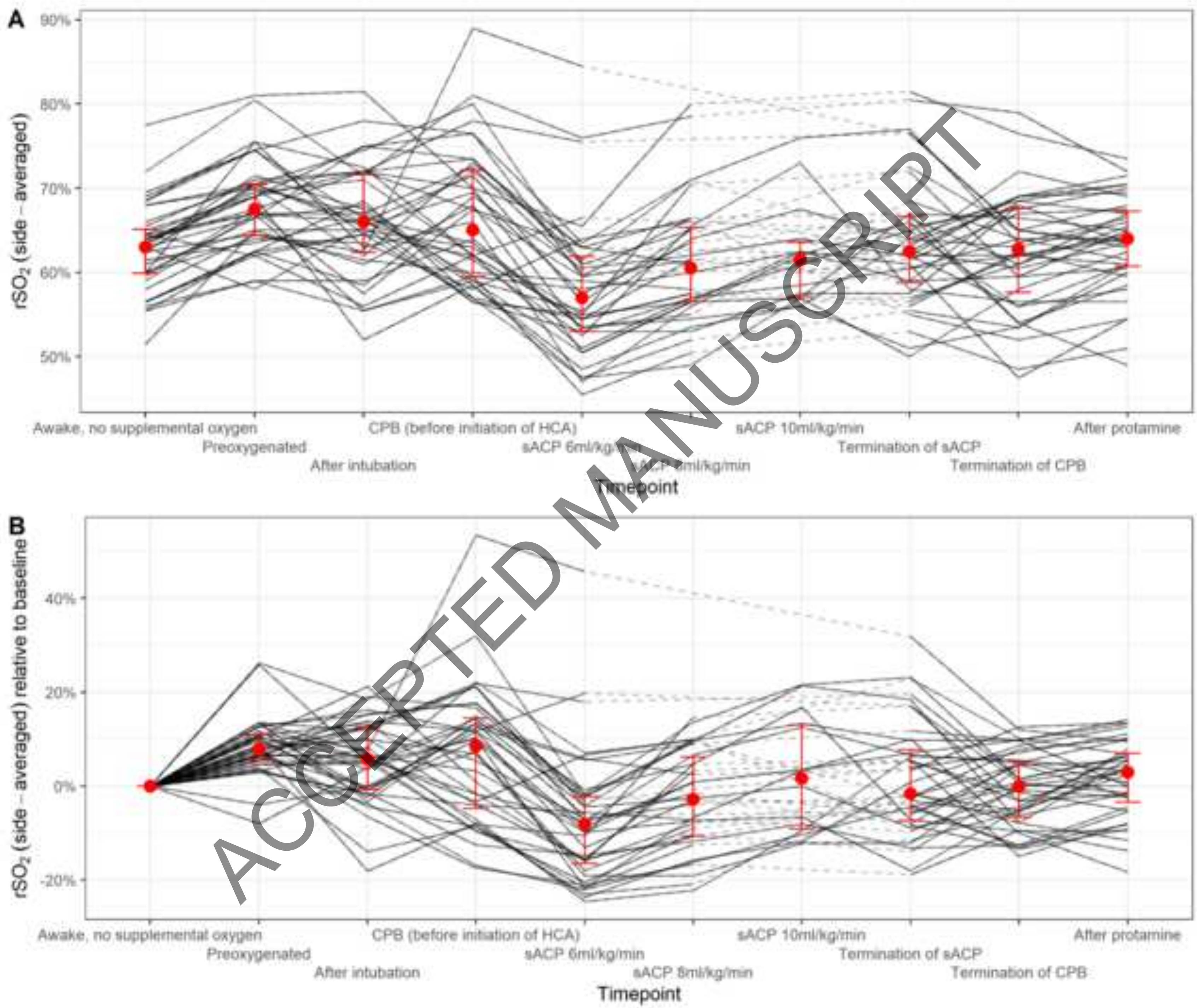
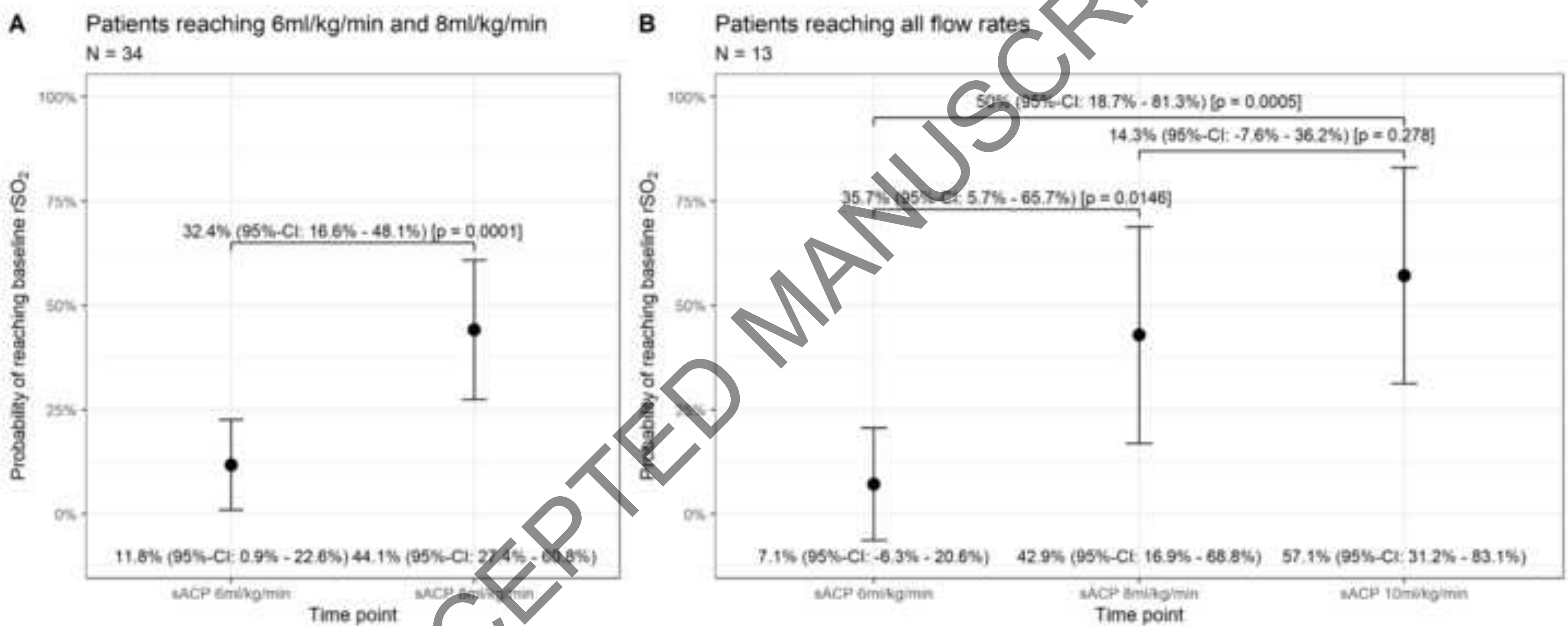


Figure 2


A
Patients reaching 6ml/kg/min and 8ml/kg/min
N = 34
Probability of reaching baseline rSO_2
32.4% (95%-CI: 16.6% - 48.1%) [p = 0.0001]
11.8% (95%-CI: 0.9% - 22.6%)
44.1% (95%-CI: 27.4% - 60.8%)
sACP 6ml/kg/min
sACP 8ml/kg/min
Time point
B
Patients reaching all flow rates
N = 13
Probability of reaching baseline rSO_2
50% (95%-CI: 18.7% - 81.3%) [p = 0.0005]
14.3% (95%-CI: -7.6% - 36.2%) [p = 0.278]
35.7% (95%-CI: 5.7% - 65.7%) [p = 0.0146]
7.1% (95%-CI: -6.3% - 20.6%)
42.9% (95%-CI: 16.9% - 68.8%)
57.1% (95%-CI: 31.2% - 83.1%)
sACP 6ml/kg/min
sACP 8ml/kg/min
sACP 10ml/kg/min
Time point

Central image

Key question

What flow rate is necessary to maintain rSO_2 baseline during selective antegrade perfusion in aortic arch surgery?

Key finding(s)

rSO2 was lower than baseline at 6ml/kg/min. Flow rates of 8 and 10 ml/kg/min resulted in rSO2 that did not differ from the baseline.

Take home message

Baseline rSO2 is more likely met at 8 than 6 ml/kg/min. Increasing to 10 ml/kg/min does not increase the probability to meet the baseline significantly.