Interactive CardioVascular and Thoracic Surgery (2017) 1–7
doi:10.1093/icvts/ivx171

Cite this article as: Duynstee F, Keunen RW, van Sonderen A, Keyhan-Falsafi AM, Hoohenkerk GJ, Stephens G *et al.* Impact of the Haga Braincare Strategy on the burden of haemodynamic and embolic strokes related to cardiac surgery. Interact CardioVasc Thorac Surg 2017; doi:10.1093/icvts/ivx171.

Impact of the Haga Braincare Strategy on the burden of haemodynamic and embolic strokes related to cardiac surgery

Friso Duynstee[a], Ruud W.M. Keunen[a,*], Agnes van Sonderen[a], Ali M. Keyhan-Falsafi[b], Gerard J.F. Hoohenkerk[b], Gayleen Stephens[b], Erik Teeuws[b], Jan W.K. van Alphen[c], Dénes L.J. Tavy[a], Arne Mosch[a], Sebastiaan F.T.M. de Bruijn[a], Hans van Overhagen[d], Frank E.E. Treurniet[d], Lucas C. van Dijk[d] and Paulien M. van Kampen[e]

[a] Department of Neurology and Clinical Neurophysiology, Haga Teaching Hospitals, The Hague, Netherlands
[b] Department of Cardiosurgery, Haga Teaching Hospitals, The Hague, Netherlands
[c] Department of Cardioanaesthesiology, Haga Teaching Hospitals, The Hague, Netherlands
[d] Department of Intervention Radiology, Haga Teaching Hospitals, The Hague, Netherlands
[e] Haga Academy, Haga Teaching Hospitals, The Hague, Netherlands

* Corresponding author. Department of Neurology, Haga Teaching Hospitals, Leyweg 275, 2545 CH The Hague, Netherlands. Tel: +31-70-2100000; e-mail: r.keunen@hagaziekenhuis.nl (R.W.M. Keunen).

Received 16 January 2017; received in revised form 17 April 2017; accepted 26 April 2017

Abstract

OBJECTIVES: This study prospectively evaluates the impact of the Haga Braincare Strategy (HBS) on the occurrence of haemodynamic and embolic stroke in a cohort of patients who underwent coronay artery bypass grafting (CABG), valve replacement of a combination of both types of surgery between 2012 and 2015 at the Haga Teaching Hospitals.

METHODS: The HBS is a dual strategy based on a preoperative vascular work-up of the cerebral circulation by transcranial Doppler and a perioperative monitoring of the cerebral circulation by cerebral oximetry. Duplex of the carotid arteries and/or computed tomography angiography prior to surgery was performed in high-risk patients. Patients with severe carotid artery stenosis were scheduled for carotid angioplasty prior to surgery or waived from surgery.

RESULTS: A total of 1065 patients were included. Poor cerebral haemodynamics were identified by transcranial Doppler in 2.1% of patients ($n = 22$). Based on the HBS, 3 patients were waived from surgery, 4 received preoperative carotid angioplasty followed by cardiac surgery and the remaining patients were operated while being monitored with bilateral cerebral oximetry sensors. In all, 2.2% of the study group experienced a stroke ($n = 23$), of which none were classified as haemodynamic. Most of the remaining presumed embolic strokes showed a minor to moderate stroke severity.

CONCLUSIONS: In this single-centre prospective follow-up study, surveillance of cerebral perfusion by the HBS eliminated the occurrence of haemodynamic stroke while most of the residual strokes had a good to favourable prognosis.

Keywords: TCD • cerebral oximetry • CABG • Stroke

INTRODUCTION

Perioperative stroke (POS) can be a devastating complication following cardiac surgery. The incidence of POS in the literature varies between 1 and 5% [1, 2]. POS is an important cause of morbidity and mortality after cardiac surgery. Most of POS are embolic in nature and presumed to be the result of intraoperative surgical manipulation of the aortic arch or postoperative atrial fibrillation (AF). However, a substantial number of the POS are haemodynamic in nature. Haemodynamic strokes are due to the combination of (i) high-grade stenosis or occlusions of conductance vessels (for instance the brachiocephalic artery, carotid and/or middle cerebral arteries [MCAs]), (ii) poor collaterals and/or (iii) a drop in systemic blood pressure and/or blood oxygenation. On computed tomography (CT) and magnetic resonance imaging a haemodynamic stroke appears as a so-called watershed infarct (see Fig. 1). With the ischaemia sensitive diffusion weighted magnetic resonance imaging watershed infarcts can be seen in up to 48% of the patients following a cardiosurgical procedure [3]. A recent systemic review and observational studies estimated that 10–50% of POS in cardiac surgery are haemodynamic in nature [4–6]. Recent CABG trials in patients with occlusive cerebrovascular disease showed stroke/death ratios ranging from 3.8% to 20.6%, indicating that poor-cerebral perfusion is associated with poor outcome.

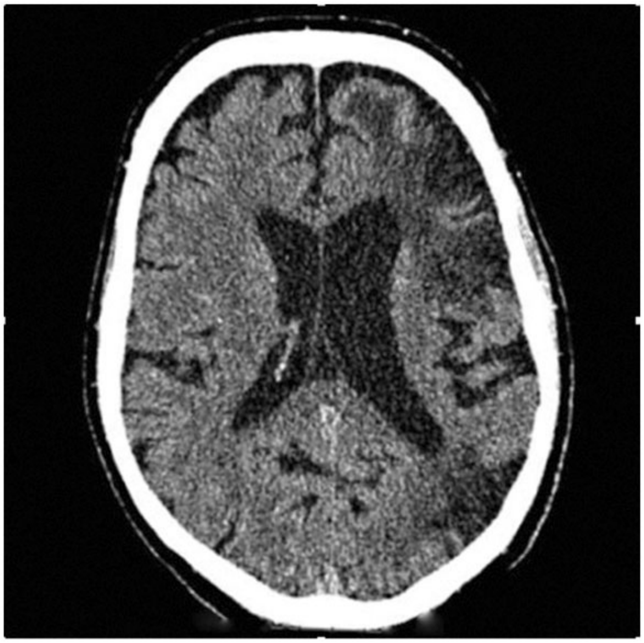

Figure 1: CT imaging 6 months after an acute postoperative left hemispheric stroke related to cardiac surgery. The vascular territories involved are the left sided anterior and posterior watershed areas. Duplex scanning of the carotid arteries after surgery showed bilateral high-grade carotid artery stenosis.

Between 2006 and 2007, a small number of devastating haemodynamic strokes were observed at the Haga teaching Hospitals. All patients suffered from watershed infarcts and occlusive cerebrovascular diseases. Following these strokes, we felt we should re-evaluate the stroke prevention strategy related to cardiac surgery. We hypothesized that if we could reduce the incidence of the postoperative haemodynamic stroke rate we might simultaneously reduce the overall stroke severity and the overall stroke/death rate.

In an attempt to reduce burden of POS, we looked for a dual strategy that would identify both high-risk patients prior to surgery and cerebral low-flow states during and in the first hours after surgery. The dual strategy approach is based on the well-known fact that ischaemic/hypoxic postsurgery organ failure is most commonly seen in patients who exhibit poor organ flow and/or function prior to surgery. This applies not only for the brain but also for other perfusion sensitive organs such as the kidneys. Therefore, surveillance of both the presurgery cerebral haemodynamics and perisurgical saturation could potentially be the best combination to prevent postoperative cerebral haemodynamic stroke.

Routine carotid artery duplex screening and subsequent carotid revascularization in every detected carotid artery stenosis has been one of the strategies to reduce the risk for postoperative haemodynamic strokes. However, past literature shows that this strategy did not reduce the incidence of POS. The benefits of universal carotid artery revascularization procedures do not outweight the costs of screening nor does this strategy reduce the overall POS incidence [7, 8]. Instead of focussing on the patency of the carotid arteries, we examined the cerebral haemodynamics by transcranial Doppler (TCD) at the origin of both MCAs. The cerebral haemodynamics at the origin of the MCA reflect the net result of both patency of the carotid arteries and quality of collateral circulation [9]. Therefore, our hypothesis was that MCA haemodynamics should better identify patients at risk for haemodynamic strokes than the evaluation of the patency of the carotid arteries. Moreover, we combined preoperative TCD with non-invasive cerebral oximetry monitoring during and after the first hours of surgery in order to detect perioperative cerebral low-flow states. We called this dual strategy the 'Haga Braincare Strategy' (HBS). It turned out that implementation of the HBS reduced the incidence of ischaemic postoperative delirium at the Haga by more than 50% [10]. Since the last years, we have systematically implemented and documented the results of the HBS in a prospective follow-up study. In this article, we describe the results with special focus on the impact of the HBS on stroke epidemiology and how it influenced decision making.

METHODS

Inclusion/exclusion criteria

From August 2012 to November 2015, The Haga Teaching Hospitals (The Hague, Netherlands), 1065 consecutive patients were prospectively enrolled. Inclusion criteria were age >18 years, elective CABG and/or valve replacement surgery. Excluded were 86 other cardiosurgical procedures predominantly Maze procedures and aorta ascendens replacement surgery.

Outline of Haga Braincare Strategy

All patients were subjected to evaluation of cerebral haemodynamics prior to surgery by TCD (see Fig. 2). If TCD revealed poor collaterals, a duplex and/or CT angiography (CTA) was performed. If TCD was not possible, the status of the cerebral haemodynamics was established by duplex and/or CTA (see Fig. 3). After this work-up, patients could be identified with poor collaterals and carotid artery high-grade stenosis or occlusions without cerebral of intrathoracal stenosis. In case of ICA occlusion, they could be stratified for surgery with mild hypothermia (34–36°C) or—in case of a severe carotid artery stenosis—scheduled for elective carotid angioplasty prior to surgery. In case of severe multilevel occlusive cerebrovascular disease patients were waived from surgery. All patients who experience a stroke were subjected to a postoperative CT and duplex scan. Stroke outcome was established at discharge.

Outcome definitions

The primary outcome was the incidence of haemodynamical strokes. A haemodynamic stroke was defined as every stroke within the run-off territory of a >70% carotid artery stenosis with a post-stroke CT, a pattern indicative for recent watershed infarcts. Patients with bilateral recent watershed infarcts and no carotid artery occlusions were also classified as haemodynamic strokes. All other strokes were defined as embolic unless the CT scan revealed an intracranial haemorrhage. Secondary outcome measurements were stroke rate, stroke severity, type of strokes (ischaemic/haemorrhagic) and stroke mortality.

Evaluation of cerebral haemodynamics by transcranial Doppler/duplex

The TCD examinations were performed by cardiosurgical nurse practitioners with a 2-MHz pulsed bidirectional TCD (Delica 9-series, Delicate Manufacturer, Shenzhen, China). Poor

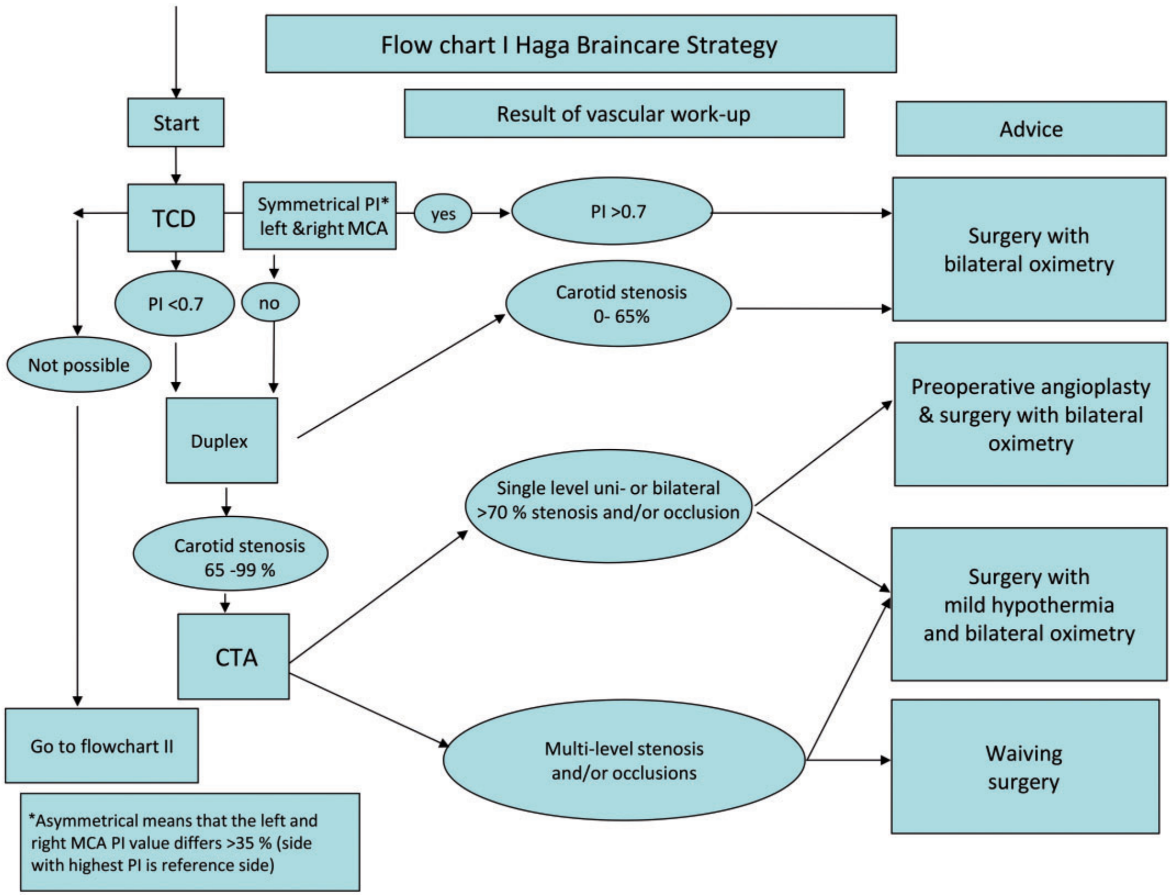

Figure 2: Flowchart I. CTA: computed tomography angiography; MCA: middle cerebral arteries; PI: pulsatility index; TCD: transcranial Doppler

haemodynamics were defined by a pulsatility index (PI) <0.70 and/or a left/right asymmetry of the PI at the origin of the MCA (or carotid syphon) of more than 50% compared from the reference side (which is the side with the highest PI). The reason for the asymmetry criterion was that in the higher age groups, the PI reference value can increase above the value of 2.0. Consequently, a PI value of for instance 1.0 which would otherwise be regarded as normal in a patient aged 60 years could be indicative for poor collaterals in a patient aged 90 years. If poor collaterals were identified, patients were further analysed by duplex scanning (Toshiba Xariow, Ultrasound Imaging System, SSA-680 A) of the carotid arteries. In case of a high-grade carotid artery stenosis, a CTA was performed. CTA allowed to classify the underlying cerebrovascular abnormalities into single- or multilevel abnormalities. Three levels were used for scoring the vascular abnormalities: Level a. intrathoracic (for instance a brachiocephalic artery stenosis), Level b. carotid bifurcation and Level c. base of the brain (for instance a MCA M1 stenosis). Single level abnormalities were defined as high-grade stenosis on at least levels a, b or c. Multi-level abnormalities were combination of stenotic lesions at 2 or more levels. If neither the transtemporal nor the transorbital approach was feasible, the patients were analysed by duplex (see Fig. 3). In case of high-grade duplex stenosis, a CTA was performed and based on the absence or presence of the anterior and posterior communicating arteries patients were graded as having good or poor cerebral collaterals.

Follow-up of patients with poor-cerebral haemodynamics

Based on the outcome of the vascular work-up, 3 options pursued: (i) waiving surgery (in case of CT angiographically proven very poor cerebral flow due to bilateral multilevel occlusions in the cardio-cerebral arterial tree), (ii) restoration of cerebral flow in case of unilateral single level high-grade carotid artery stenosis by angioplasty or (iii) protecting the vulnerable brain during surgery using mild hypothermia in case of unilateral single level carotid artery occlusion. The idea of selective angioplasty was based on the assumption that carotid angioplasty is presumably safer in CABG patients than carotid surgery [10]. Post-procedural close TCD ultrasound and blood pressure surveillance was performed in the patients scheduled for angioplasty. Tight control of systemic blood pressure lasted for 2 weeks after angioplasty to prevent a postoperative cerebral hyperperfusion syndrome.

Surgical procedures

The surgical team used uniform anaesthesia, surgical and perfusion techniques. All of the CABG and CABG plus procedures were performed with a cardiopulmonary bypass. Standard flow rates of 2.2–2.4 l/min were used to maintain a mean arterial pressure >60 mmHg, partial pressure of carbon dioxide (arterial) maintained

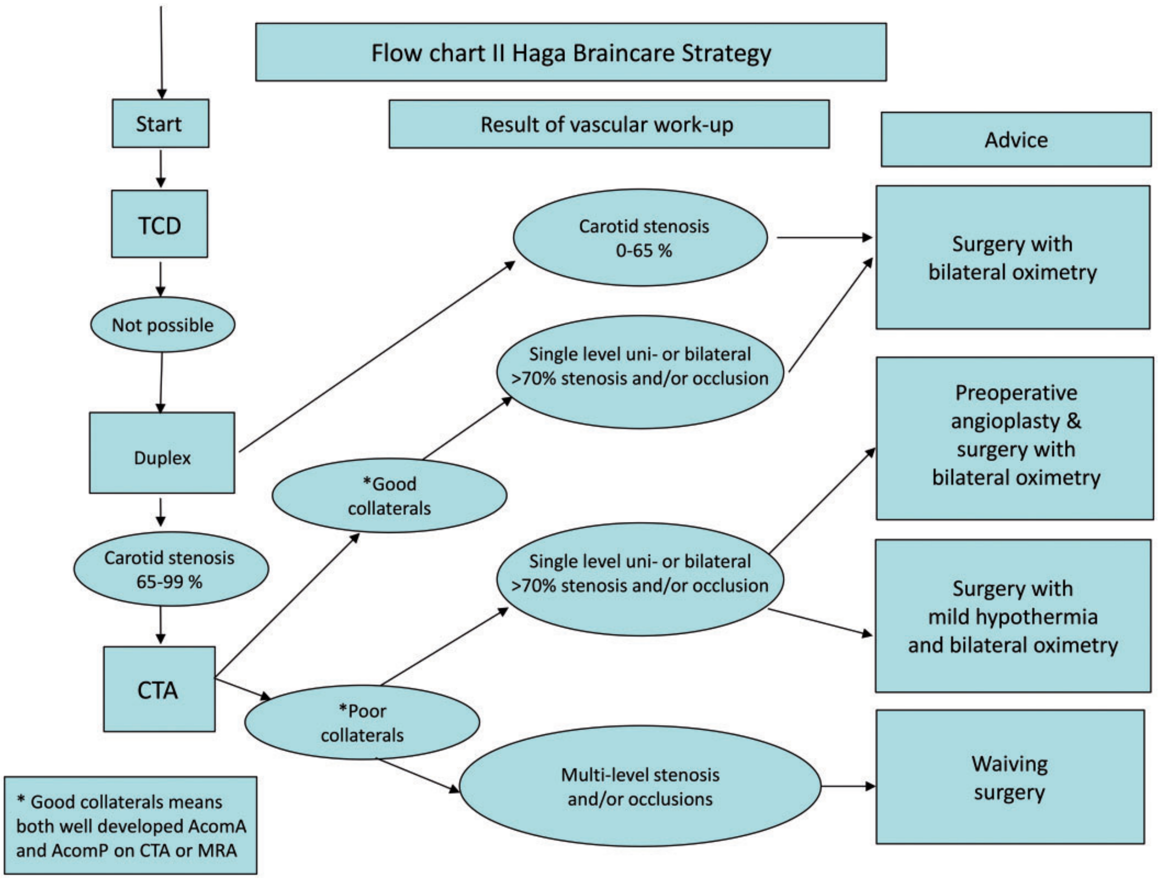

Figure 3: Flowchart II. CTA: computed tomography angiography; TCD: transcranial Doppler.

at ≥40 mmHg by alpha-stat management, and haematocrit maintained above 22%. All patients were monitored with near-infrared spectroscopy (NIRS) (INVOS 5100; Somanetics Corporation, Troy, MI, USA). Further details of the cardiovascular procedures and NIRS have been published earlier by Palmbergen *et al.* [10].

Assessment of disability

The modified Ranking Score (mRs) (http://en.wikipedia.org/wiki/Modified_Rankin_Scale) was used to estimate the amount of dependence or disability in daily activities. It is a numeric scale which ranges from 0 to 6, where 0 means no disability or discomfort and 6 means the death of the patient. In case a POS occurred, a neurologist was consulted. The neurological consultation included a neurological examination, CT scan of the brain and if indicated a carotid artery duplex to estimate the presence or absence of a carotid artery stenosis. Stroke severity was estimated by using the National Health Institute Stroke Scale (NIHSS) (http://www.ninds.nih.gov/doctors/NIH_Stroke_Scale.pdf). The NHISS ranges from 0 to 42. Scores between 1–4 and 5–15 were classified as respectively minor to moderate. Higher scores were classified as moderate to severe (16–20) or severe (21–42).

Data management

The following data were collected preoperatively using electronic case record forms: background demographics, type of surgery, modified Rankin Score, results of TCD exams, duplex and/or CTA examinations, preoperative neurological consultations, preoperative carotid surgery or angioplasty and the use of cerebral oximetry. Postoperative outcome parameters were stroke rate, stroke severity at discharge and stroke mortality. Since 2014, the EuroSCORE (European System for Cardiac Operative Risk Evaluation) was added to this list. The case record forms were stored in an internet-based data management system that allowed online statistical analysis (Mediwebdesignin© Netherlands).

Statistical analyses

Categorical values are presented as numbers (percentages) and were analysed using chi-square tests or Fisher's exact tests. The Fisher's exact test was used instead of the chi-squared test when the expected frequencies calculated from the marginal totals were (considerably) <5 in cross tables (as the normal approximation of the binomial distribution will then be less appropriate). For numerical data whose distributions approximate normality, data was presented in mean and 95% CI and an independent *t*-test was used. Numerical data which was not normally distributed was presented in median and range. Logistic regression was used to calculate the odds ratios for POS. Statistical significance was considered at $P < 0.05$. SPSS (v 17.0) statistical software was used for statistical analysis.

Ethical aspects

The study is not subdued to Medical Research Involving Human Subjects Act. The board of directors of the Haga Teaching Hospitals agreed with the study (T15-065).

Table 1: Baseline demographics

	Study group
Year of observation	2012–2015
Number	1065
Age, mean (95% CI)	68.6 years (67.9–69.2)
Gender, number of females (%)	288 (27)
Number of grafts, mean (95% CI)	2.8 (2.7–3.0)
Type of surgery	
CABG (%)	717 (67.3%)
Valve surgery (%)	316 (29.7%)
CABG + valve (%)	32 (3.0%)
EuroSCORE[a], mean (95% CI)	3.1 (3.0–3.3)

[a]Available in 927 patients.
CI: confidence interval; CABG: coronay artery bypass grafting.

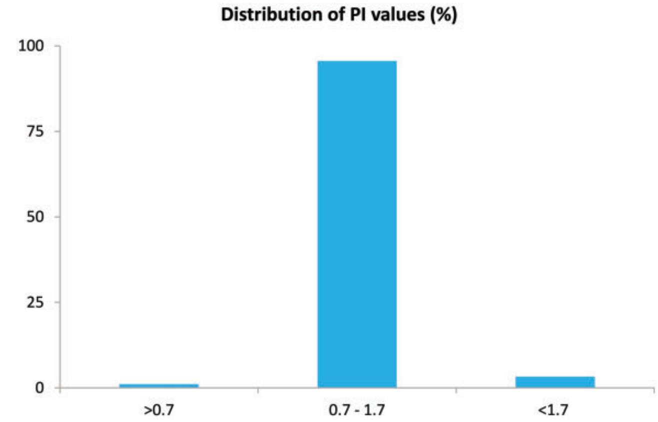

Figure 4: Histogram of the PI values expressed in a percentage. PI: pulsatility index.

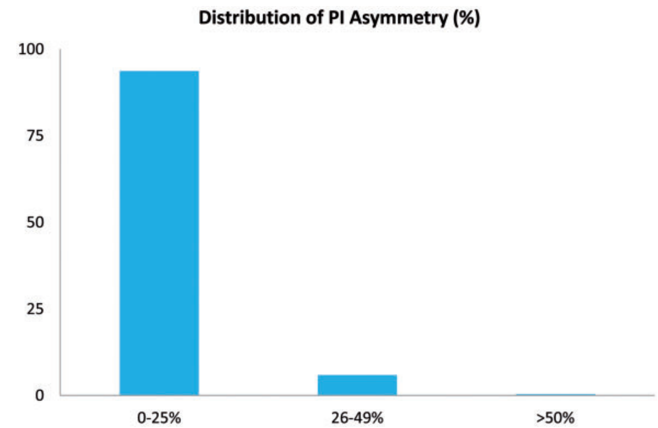

Figure 5: Histogram of the PI left/right asymmetry expressed in a percentage. PI: pulsatility index.

RESULTS

A total of 1065 consecutive patients were identified for inclusion in the study group. Patients demographic data and their comorbidities are presented in Table 1.

Transcranial Doppler, duplex and computed tomography angiography findings

Complete TCD exams of both MCAs could be performed in 86.3% of the patients. The PI values of the MCA ranged from 0.42 to 2.95. The mean PI was 1.23. Figure 4 shows a histogram of the observed PI values. Reduced PI values <0.7 were observed in 1.0% ($n = 9$).

Figure 5 shows the PI left/right asymmetry expressed in a percentage in these patients. Asymmetrical PI values more than 50% were observed in 0.5% of the patients ($n = 4$). A >50% PI asymmetry could be indicative for a high-grade ipsilateral carotid artery stenosis or occlusion in combination with poor cerebral collaterals. As there was an overlap between patients with asymmetrical PI and reduced PI, the total number of patients with poor cerebral haemodynamics was 1.1% ($n = 10$).

In 7 of the 10 patients with poor collaterals by TCD, a duplex scan was performed. The duplex scan revealed patent carotid arteries in 72%, (5 patients) a unilateral carotid artery stenosis was observed in 28% (2 patients). The remaining 3 patients in whom the duplex scanning was not performed are discussed under the subject protocol violations. In 13.7% of the patients ($n = 146$), a TCD could not be performed either by absent temporal windows. All except 4 of the 146 patients were examined by duplex scanning. Nearly 90% of these patients exhibited patent carotid arteries. Nine patients exhibited unilateral carotid artery stenosis. Only 1 patient experienced bilateral stenosis/occlusions.

Follow-up of patients with a high-haemodynamic stroke risk profile

After TCD and duplex findings, CTA examinations revealed 4 patients who were scheduled for angioplasty and 3 patients who were waived from surgery. Therefore, the HBS TCD/duplex/CTA work-up of patients resulted in identification of 0.28% of the initially scheduled patients who were waived from surgery and 0.37% of the patients who were scheduled for angioplasty. None of the patients, who were scheduled for angioplasty, experienced neither a stroke nor a cerebral hyperperfusion syndrome. None of the high-risk patients were operated under mild-hypothermic conditions. One patient experienced an inguinal haematoma due to the angioplasty. Two of 3 patients who were waived from surgery underwent an uncomplicated coronary angioplasty. One of them (Male 69 years) died 2 years later from lung cancer. The other patient (Male 55 years) recovered from New York Heart Association Class II to Class I after angioplasty. One (Male 83 years) refused coronary angioplasty. Now 2 years later, he still has New York Heart Association functional Class II. He did neither experience a stroke nor a myocardial infarction during follow-up.

Postoperative stroke epidemiology (study group)

Twenty three patients experienced a stroke (2.2% of the patients). All strokes in these cohorts were ischaemic in nature. None of the strokes were observed distally to a subtotal or occluded internal carotid artery (ICA). Two patients exhibited a stroke distally to a 70% ICA stenosis. These strokes occurred during the postoperative phase and showed no CT abnormalities. Atrial fibrillation (AF) and a valve thrombotic lesion were found as co-findings. These strokes were classified as embolic. In 1 patient, a postoperative operative duplex was not available. Based on CT/TCD findings, his stroke was classified as embolic rather than

Table 2: Demographics of patients with and without a postoperative stroke

	No POS	POS	Odds ratio
Number	1042	23	
Age, mean (95% CI)	68.4 (67.7–69.0)	77.6 (73.7–81.6)	1.11 (1.05–1.16)
Gender, number of females (%)	279 (27)	9 (64)	1.76 (0.75–4.11)
Percentage of valve surgery (%)	306 (29)	10 (50)	2.31 (0.95–5.61)
N grafts, mean (95% CI)	2.8 (2.7–3.0)	2.9 (2.1–3.8)	1.02 (0.82–1.27)
Preoperative mRs mean (95% CI)	2.1 (2.0–2.1)	2.1 (2.0–2.3)	1.60 (0.58–4.42)
EuroSCORE[a], mean (95% CI)	3.1 (3.0–3.3)	4.1 (2.6–5.7)	1.12 (0.96–1.31)
Blood flow velocities (cm/s)	41 (39–41)	48 (40–55)	1.06 (1.02–1.10)[a]
PI	1.2 (1.2–1.3)	1.3 (1.1–1.4)	1.30 (0.24–7.07)[a]
mRs at discharge mean (95% CI)	2.3 (2.3–2.4)	3.4 (2.8–4.0)	5.67 (3.18–10.13)
Mortality number (%)	9 (1)	2 (9)	10.93 (2.22–53.71)
Delirium number (%)	68 (7)	6 (26)	5.06 (1.93–13.24)
Mean length of ICU stay, mean days (95% CI)	1.4 (1.3–1.5)	2.8 (1.4–4.3)	1.13 (1.03–1.24)
Mean length of stay, mean days (95% CI)	6.9 (6.4–7.4)	11.4 (8.3–14.5)	1.02 (1.00–1.03)

[a]Available in 16/23 stroke patients.
PI: pulsatility index; ICU: intensive care unit; POS: postoperative stroke; CI: confidence interval.

haemodynamic. This means that all the strokes in this cohort were qualified as embolic. No devastating haemodynamic stroke distally to an occluded carotid artery stenosis was observed in this cohort of patients. The majority of the strokes were observed in the MCA territory. Table 2 shows the data of the baseline demographics and clinical parameters and outcome of patients with and without POS in the study group.

Patients who experienced a stroke were approximately 10-years older compared to those who did not experience a stroke. Strokes were often seen in patients with cardiac valve surgery. As expected TCD haemodynamics were not discriminative in this HBS cohort. However, outcome parameters were all significantly worse for stroke patients. Stroke patients stayed significantly longer at the hospital and were significantly longer admitted at the intensive care unit compared to none stroke patients. The chance to experience a postoperative delirium was 5 times higher in stroke patients and the chance to die was more than 10 times higher. We reckon these data should be taken with care due to the low numbers in these groups. Table 3 shows stroke epidemiology in relation to type of surgery.

The stroke incidence for CABG patients and valve replacement surgery was 1.3% and 3.0% respectively. Combined surgery was in this cohort associated with a unexpected high-stroke incidence of 9.3%. According to the NIHSS over 95% of these strokes were classified a minor ($n = 12$) or moderate ($n = 11$). Most stroke patients recovered substantially. Two stroke patients died: 1 patient died from multi-organ failure although his initial stroke severity was classified as minor. The other patient had a severe initial stroke and died from pneumonia. Therefore, mean stroke/death ratio was 8.6%.

Protocol violations

Protocol violations occurred in 9 of the 1065 patients (0.9%). Most of the violations occurred in the diagnostic work-up of patients. Four patients had absent temporal windows and 3 had poor collaterals by TCD. These patients skipped the duplex scanning protocol. None of these patients experience a postoperative stroke. Two protocol violations occurred in patients who were scheduled for carotid stenting, although they had good cerebral haemodynamics. None of the above mentioned protocol violations influenced the outcome of this study.

DISCUSSION

In this single-centre prospective follow-up study, surveillance of cerebral perfusion by the HBS eliminated the occurrence of haemodynamic strokes while nearly all of the residual embolic stroke were classified as minor or moderate. These results are consistent with the observation of Nakamura *et al.* [11] that intensive management of cerebral haemodynamics reduce stroke after coronary artery surgery. Moreover, the results support the current evolving concept that keeping the cerebral haemodynamics above the limits of cerebral autoregulation and securing cerebral oxygenation prevents cerebral ischaemia and improve outcome [12–14]. To our knowledge, this is the first systematic documentation of preoperative TCD findings in a large cohort of patients scheduled for cardiac surgery. Poor collaterals based on TCD criteria were observed in 2.1% of the patients of whom 36% had significant occlusive cerebro-vascular disease. In other words, poor-cerebral haemodynamics identified by TCD are a clinical relevant phenomenon and the cut-off PI values used in the present study seem to be sufficient to support the objective of the HBS: elimination of postoperative haemodynamic strokes. Having identified patients with high risk for postoperative haemodynamic stroke, the positive message is that the majority of patients with poor-cerebral haemodynamics could be safely operated. The implementation of the HBS seems to shifts the balance of haemodynamic versus embolic strokes towards embolic predominance. These emboli occur in relatively well-perfused areas of the brain and previous stroke studies have shown that emboli in well-perfused brain tissue result in smaller infarcts with a better clinical outcome and vice versa [15]. This might explain why most of these strokes occurring under HBS were classified as minor and moderate.

However, strokes may still have a negative impact on outcome. For instance, stroke patients had significantly longer hospital stays, as well as significantly longer stays in the intensive care unit. The chance to experience a postoperative delirium was 5 times higher in stroke patients. Ultimately, the mortality rate

CARDIOPULMONARY BYPASS

Table 3: Stroke epidemiology and type of surgery

Type of surgery	CABG	VR	CABG and VR
Number of patients	717	316	32
Gender, number of female (%)	141 (20)	134 (42)	13 (41)
Age, mean (95% CI)	67.4 (66.7–68.1)	70.9 (69.6–72.1)	71.3 (67.1–75.5)
Overall mortality, number (%)	5 (0.7)	5 (0.3)	1 (3.0)
Stroke, number (%)	10 (1.3)	10 (3.0)	3 (9.3)
Stroke type	All ischaemic	All ischaemic	All ischaemic
Stroke pathophysiology[a]	No haemodynamic	No haemodynamic	No haemodynamic
Stroke severity at onset	5.5	4.5	7.1
Stroke severity at discharge	2.6	9.0	3.4
Stroke mortality, number (%)	2 (20)	0 (0)	0 (0)

[a]Defined as strokes within the run-off territory of a >70% carotid artery stenosis with a post-stroke CT pattern indicative for recent watershed infarcts or strokes within the run-off territory of patent carotid arteries with a post-stroke CT pattern indicative for bilateral recent watershed infarcts.
CABG: coronary artery bypass grafting; CI: confidence interval; VR: valve replacement.

appeared to be 10-fold higher compared to those who did not experience a stroke. Therefore, increasing effort to reduce perioperative embolization and to identify of high-risk patients by TCD embolus detection is warranted.

Limitations

Several limitations of this study must be taken into consideration. Firstly, it is a single-centre study in a limited number of patients. We believe that validating these data in larger multi-centre studies is the next step to prove the value of the TCD screening strategy. Secondly, the study design was a prospective follow-up study rather than a randomized controlled trial. In other words, it showed the reduction of haemodynamic strokes in this patient cohort but did not prove the superiority of the HBS above a conventional stroke prevention regime. Third, although this study gives arguments that patients with a PI value >0.7 can be safely operated if the cerebral flow is closely monitored with cerebral oximetry, we do not know whether waiving surgery in patients with poor-cerebral haemodynamic and multilevel occlusive cerebrovascular disease is really the best option for these patients. A last limitation of this study is that we did not systematically look at the cerebral haemodynamics of the posterior circulation. Using observational TCD/duplex scanning, it may be interesting to study the relationship between the basilar cerebral haemodynamics and the neurological outcome of patients scheduled for cardiac surgery.

Conflict of interest: Ruud W.M. Keunen develops universal software for embolus detection by TCD which is distributed by SMT Medical in Germany on Delicate TCD instruments. Ruud W.M. Keunen presented stroke prevention lectures sponsored by Medtronic/Covidien. He served as advisor for Medtronic/Covidien.

REFERENCES

[1] Bucerius J, Gummert JF, Borger MA, Walther T, Doll N, Onnasch JF *et al*. Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. Ann Thorac Surg 2003;75:472–8.
[2] Naylor AR, Brown MJ. Stroke after cardiac surgery and its association with asymptomatic carotid disease: an updated systematic review and meta-analysis. Eur J Vasc Endovasc Surg 2011;41:607–24.
[3] Gottesman RF, Sherman PM, Grega MA, Yousem DM, Borowicz LM Jr, Selnes OA *et al*. Watershed strokes after cardiac surgery: diagnosis, etiology, and outcome. Stroke 2006;37:2306–11.
[4] Lee EJ, Choi KH, Ryu JS, Jeon SB, Lee SW, Park SW *et al*. Stroke risk after coronary artery bypass graft surgery and extent of cerebral artery atherosclerosis. J Am Coll Cardiol 2011;57:1811–8.
[5] Naylor AR, Mehta Z, Rothwell PM. A systematic review and meta-analysis of 30-day outcomes following staged carotid artery stenting and coronary bypass. Eur J Vasc Endovasc Surg 2009;37:379–87.
[6] Naylor AR, Brown MJ. Reprinted article "Carotid artery disease and stroke during coronary artery bypass: a critical review of the literature". Eur J Vasc Endovasc Surg 2011; 42 Suppl1:S73–83.
[7] Adams BC, Clark AM, Paap C, Goff JM Jr. There is no benefit to universal carotid artery duplex screening before a major cardiac surgical procedure. Ann Vasc Surg 2014;28:93–101.
[8] Naylor AR. Managing patients with symptomatic coronary and carotid artery disease. Perspect Vasc Surg Endovasc Ther 2010;22:70–6.
[9] Keunen RW, Eikelboom BC, Stegeman DF, Ackerstaff RG. Chronic cerebral hypotension induces a downward shift of the cerebral autoregulation: a hypothesis based on TCD and OPG-GEE studies in ambulatory patients with occlusive cerebrovascular disease. Neurol Res 1994; 16:413–6.
[10] Palmbergen WA, van Sonderen A, Keyhan-Falsafi AM, Keunen RW, Wolterbeek R. Improved perioperative neurological monitoring of coronary artery bypass graft patients reduces the incidence of postoperative delirium: the Haga Brain Care Strategy. Interact CardioVasc Thorac Surg 2012;15:671–7.
[11] Nakamura M, Okamoto F, Nakanishi K, Maruyama R, Yamada A, Ushikoshi S *et al*. Does intensive management of cerebral haemodynamics and atheromatous aorta reduce stroke after coronary artery surgery? Ann Thorac Surg 2008;85:513–9.
[12] Murkin JM, Adams SJ, Novick RJ, Quantz M, Bainbridge D, Iglesias I *et al*. Monitoring brain oxygen saturation during coronary bypass surgery: a randomized, prospective study. Anesth Analg 2007;104:51–8.
[13] Ono M, Brady K, Easley RB, Brown C, Kraut M, Gottesman RF *et al*. Duration and magnitude of blood pressure below cerebral autoregulation threshold during cardiopulmonary bypass is associated with major morbidity and operative mortality. J Thorac Cardiovasc Surg 2014; 147:483–9.
[14] Slater J, Guarino T, Stack J, Vinod K, Bustami RT, Brown JIII *et al*. Cerebral oxygen desaturation predicts cognitive decline and longer hospital stay after cardiac surgery. Ann Thorac Surg 2009;87:36–44.
[15] Caplan LR, Wong KS, Gao S, Hennerici MG. Is hypoperfusion an important cause of strokes? If so, how? Cerebrovasc Dis 2006; 21:145–53.