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Circle of Willis – An Essential Part of Pre-Operative Assessment Before Carotid Endarterectomy

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Abstract

Objective: During Carotid Endarterectomy cerebral perfusion is maintained by the existence of collateral circulation through the Circle of Willis. Most patients tolerate Internal Carotid artery clamping and several intraoperative methods are used to evaluate cerebral perfusion and subsequently the need of extra-anatomical shunt. However, no current method allows reliable pre-operative prediction of the need for shunt placement. In this study we try to determine pre-operative variables that may predict the need for shunt.

Design: Single-center retrospective cohort study.

Methods: A total of 102 patients with severe carotid artery stenosis who underwent carotid endarterectomy in Carmel Medical Center were enrolled.

Demographical data, comorbidities and pre-operative anatomical parameters were registered.

Predictive parameters assessed were (1) degree of stenosis, (2) degree of calcification, (3) completeness of the anterior circulation of circle of Willis, (4) existence of symptoms in the past 6 months. During surgery the indication for shunt placement was neurological changes (under local anesthesia) or stump pressure measurements (under general anesthesia). 30-days morbidity and mortality were documented.

Results: Of 102 cases, 101 were included in the analysis. Extra-anatomical shunt was used in 12 procedures (11.9%). Demographics and co-morbidities, as well as symptoms and degrees of stenosis and calcification, did not differ between shunted and non-shunted patients. Incomplete circle of Willis was significantly higher in the shunted group (83.3% *vs* 11.2% respectively, P< 0.001). Lack of a complete circle of Willis was the only parameter that correlated significantly with stump pressure below 50mmHg (76.5% vs 8.3% in patient with stump pressure above 50mmHg, P<0.0001). There was no significant difference in 30-days morbidity and mortality between the two groups.

Conclusions: Lack of a complete circle of Willis can serve as a predictor for the need of extra-anatomical shunt during carotid endarterectomy. Further research with larger cohort is needed.

Keywords: Carotid endarterectomy; Circle of Willis; Shunt; Perfusion

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Introduction

During Carotid Endarterectomy (CEA), the Common, External, and Internal Carotid arteries are clamped, and cerebral perfusion is usually maintained by the existence of collateral circulation through the Circle of Willis (COW). Although most patients tolerate Internal Carotid Artery (ICA) clamping without consequences, CEA may require extra-anatomical shunt placement to ensure adequate cerebral perfusion and prevent ischemic strokes or cerebral damage [1].

There are several intraoperative methods to evaluate cerebral perfusion and subsequently the need of shunt during CEA: Electroencephalography (EEG) monitoring, Stump Pressure (SP) measurements, Transcranial Doppler (TCD), brain oxygen saturation monitoring by jugular venous bulb monitoring or cerebral oximetry, and neurological status evaluation if the patient is under local anesthesia [2,3]. However, no current method allows to reliably predict the need for shunt placement pre-operatively.

The ability to predict a patient's probability for shunt placement would result in more efficient

staff allocation as shunting makes CEA technically more challenging requiring supervision of competent surgeon and vascular anesthetist [4]. Furthermore, it would enable a more accurate preoperative risk assessment that, considering the gravity of the possible complications such as higher prevalence of arterial damage and embolization [5], could potentially affect the treatment plan, e.g., endovascular treatment instead of endarterectomy.

In this study we try to determine whether there are pre-operative clinical, anatomical and lesion characteristics variables that can predict the need of a shunt [6].

Material and Methods

We examined a total of 102 cases of patients with severe carotid artery stenosis who underwent carotid endarterectomy at the Department of Vascular and Endovascular Surgery, Carmel Medical Center, between December 2018 and January 2020.

The cohort consisted of 75 men and 27 women with a mean age of 68.7years.

Collected demographic data included patient age, gender, existence of risk factors for atheromatous disease such as a history of smoking, diabetes, hypertension, obesity, hyperlipidemia, and other comorbidities such as Ischemic Heart Disease (IHD) and Chronic Obstructive Pulmonary Disease (COPD).

All patients underwent Computed Tomographic Angiography (CTA) or Magnetic Resonance Angiography (MRA) prior to surgery and the relevant data were revised and extracted.

The pre-operative factors that were considered included (1) degree of stenosis determined by calculating the cross sectional percentage of blocked area out of the total cross section area of the artery at the point of greatest stenosis (2) degree of calcification determined by calculating the cross sectional percentage of calcified area out of the total cross section area of the artery at the point of greatest stenosis (3) completeness of the anterior circulation of COW, concluded by visualization of patent Anterior Communicating (ACOM) and Anterior Cerebral (ACA) arteries in CTA or MRA and (4) existence of symptoms suggesting ICA unstable atheromatous disease such as ipsilateral ischemic stroke or Transient Ischemic Attack (TIA) in the past 6 months.

Patients' indications for surgery were in line with The North American Symptomatic Carotid Endarterectomy Trial (NASCET)6 and the Asymptomatic Carotid Surgery Trial (ACST) [7].

During CEA, Common, External, and Internal Carotid arteries are exposed and eventually clamped to facilitate access to the operated section and prevent bleeding. After clamping the external carotid artery, and before clamping the ICA, SP was recorded in all patients by needle insertion in the Common Carotid Artery (CCA), confirming CCA pressure is similar to pressure reading from the peripheral arterial line, and clamping the common carotid artery proximal to the needle. Prior to clamping, systolic blood pressure was routinely elevated to exceed 180 mmHg [8].

In patients who have undergone General Anesthesia (GA), SP<= 50 mmHg, which was measured as peak systolic pressure, indicated the use of a shunt. In awake patients i.e., under cervical plexus block anesthesia, SP was also recorded, however, the indication for shunt placement was neurological changes (blurred speech, disorientation, or extremity weakness) during cross clumping. Importantly, the shunt was not placed in patients under local anesthesia with SP under 50 mmHg and no neurological changes during clamping. Both methods are widely accepted and commonly used by vascular surgeons8. During the study period, CEA was performed by several surgeons and the applied technique (eversion, primary closure, or patch angioplasty) was based on the surgeon preference and according to the anatomic compatibility. Overall, 64% of patients underwent primary closure, 11% patch closure and 25% eversion.

Intra-operative variables such as the stump pressure and the use of extra-anatomic shunt were gathered from the surgery report.

Follow-up morbidity and mortality were gathered based on medical files of the patients.

This controlled retrospective observational study was conducted in accordance with the Institutional Review Board.

Statistical Analysis

Statistical analysis was performed by using IBM Statistics (SPSS) version 24 software. The continuous variables are presented by mean ± std and/or median & IQR. The categorical variables are presented in percentages.

Correlation between shunt usage / SP (<=50 *vs* >50) and clinical characteristics was analyzed using Mann-Whitney test for the continuous variables and Chi square test or Fisher exact test for the categorical variables.

P<0.05 was considered statistically significant.

Results

Of the original 102 cases, a total of 101 were included in the final analysis as one patient eventually refused surgery and was thus excluded.

The patients' demographic data is summarized in Tables 1a and 1b.

Local anesthesia was used in 64 cases (63%), and general anesthesia was performed in all other cases (37%). The default anesthesia method was local, and only in cases of patient's refusal or non-cooperation, general anesthesia was performed.

Shunt Usage

Extra-anatomical shunt was used in 12 procedures (11.9%).

Out of those 12 patients, only 1 had significant stenosis of the contralateral ICA. All other 11 patients had patent contralateral ICA. Primary closure (66% *vs* 50%), patch closure (10% *vs* 17%) and eversion (24% *vs* 33%) techniques were used in the non-shunt versus shunt groups, respectively.

Among the patients who underwent shunt placement 50% were symptomatic in the past six months compared with 40.4% in the non-shunt group. Although an interesting finding, it is not statistically significant (p-value = 0.548). Higher degree of arterial stenosis and calcification were found in the shunted group although this difference, too, was not statistically significant (p-value = 0.264 and 0.177 respectively).

83.3% (n=10) of patients in whom a shunt was inserted were absent of ACOM or ACA compared with only 11.2% (n=10) in the non-shunt group. The correlation between the usage of shunt and lack of ACOM/ACA was significant with p-value < 0.001.

Table 1a: Patient's demographics.

Criteria	
Gender	Males: 73.5%, Females: 26.5%
Age (mean [SD], yrs.)	68.7 [12]
Smoking	Currently: 37.3%, Previously: 11.8%
Diabetes	46%
Hyperlipidemia	75.5%
Obesity	32.4%
Hypertension	78.4%
Chronic Heart disease	32.3%
COPD	9.8%
Symptomatic	41.2%

Table 1b: Comparison of demographics and comorbidities data between patients who required a shunt and non-shunted patients.

	Shunt		No shunt	
	N = 12	% = 11.9%	N = 89	% = 88.1%
Age (mean yrs.)	72.1		68.3	
Sex				
Male:	8 (66.7%)		66 (74.2%)	
Female:	4 (33.3%)		23 (25.8)	
Smoking				
Currently:	5 (41.7%)		32 (36%)	
Previously:	2 (16.7%)		10 (11.2%)	
Diabetes	7 (58.3%)		39 (43.8%)	
Hyperlipidemia	11 (91.7%)		65 (73%)	
Obesity	6 (50%)		26 (29.2%)	
Hypertension	10 (83.3%)		69 (77.5%)	
IHD	2 (16.7)		31 (34.8%)	
COPD	0		9 (10.1%)	

Table 2: Correlations between pre-operative factors examined and shunt usage.

	No shunt	Shunt	p-value
Stenosis degree (%)	82.1 ± 9	85.4 ± 6.4	0.264
Calcification degree (%)	38.4 ± 26.8	48.3 ± 22.8	0.177
Lack of ACOM/ACA (%)	11.2	83.3	<0.0001
Symptomatic patients (%)	40.4	50	0.548

Table 2 summarizes the correlations between all four pre-operative factors examined and shunt usage.

Stump Pressure

17 out of 101 patients (16.8%) had a stump pressure equal or less than 50 mmHg, 10 of which required a shunt. 84 patients had a stump pressure more than 50 mmHg, 2 of which required a shunt.

Even though the decision for shunt usage was mostly based on this factor, it was also influenced by intra-operative change in neurological status in those who underwent local anesthesia. In the final cohort, discrepancies between the two methods resulted in 2 patients with a stump pressure above 50 still requiring a shunt while in 7 patients with a stump pressure of 50 or less a shunt was not placed. The decision in these patients was made by the surgeon during the procedure, which was held under local anesthesia in all that cases. In these cases, the decision was made based on neurological status of the patient after clamping, and regardless of the stump pressure. Therefore, we also examined the relationship between stump pressure and the possible predicting factors. As expected, the results are similar. There was no significant difference between the group with stump pressure over 50mmHg and the group with stump pressure of 50mmHg and under in terms of degree of stenosis or calcification and existence of symptoms.

There is a significant difference between the two groups in term of complete COW (p-value < 0.0001).

Table 3 summarizes the correlation between all four pre-operative factors examined and SP measurements.

Table 3: Correlation between pre-operative factors examined and SP measurements.

	Stump pressure ≤ 50 mmHg	Stump pressure > 50 mmHg	p-value
Stenosis degree (%)	85.2 ± 5.8	82 ± 9.3	0.264
Calcification degree (%)	48.5 ± 27.4	37.8 ± 26	0.143
Lack of ACOM/ACA (%)	76.5	8.3	<0.0001
Symptomatic patients (%)	52.9	39.3	0.298

30-Day Morbidity and Mortality

Out of the non-shunted group (n=89), 9% of patients (n=8) experienced neurologic events during 30 days follow-up, from whom 5 had TIA's and 3 had CVA's. 2 patients experienced MI and 4 patients had other complications. There were no mortality cases during the 30-days follow-up.

Out of the shunted group (n=12), only one patient experienced CVA during 30-days follow-up. There were no other morbidity or mortality events during that follow-up period.

Discussion

Shunt placement during CEA remains controversial as some advocate for routine shunting in all patients while others defer from shunting entirely. A more common approach, such as the one practiced in our department, advocate for selective shunting using intraoperative monitoring [3]. However, the optimal intraoperative method to evaluate cerebral ischemia is also debatable. The most accepted methods are neurological changes in awake patients under regional anesthesia and SP or EEG or both under GA [9-10]. Based on our findings, SP of 50mmHg or lower, doesn't always indicate neurological impairment. Thus, our study advocates assessment of neurological changes as the preferable decision method for shunt placement in awake patients. However, in GA, the usage of SP, or other modality, is crucial for intraoperative neurological assessment.

The purpose of using shunt is obvious, nevertheless, it is not without disadvantages:

Shunt placement prolongs operation time and confers risks such as plaque or air emboli, arterial damage and dissection during the insertion. It usually requires general anesthesia and close monitoring which comes with risks of their own, such as increased cardiovascular perioperative morbidity. Moreover, the shunt may interfere with the ability of the surgeon to completely remove the distal extension of the plaque [10-13].

As the popularity of selective shunt increases, the technique of shunt placement is less preformed and young specialists are less

experienced in this complex procedure. Knowledge of preoperative predicting factor for shunt usage enables better allocation of senior surgeons, since unsurprisingly, the more experienced the surgeon and anesthetist, the lower the postoperative complication rate [14,15].

In our study we did not find a correlation between a history of symptoms and shunt usage. Domenick Sridharan N, et al [16] indicated that symptomatic disease was associated with clamped related intraoperative monitoring changes suggesting a relation to shunt usage. Their study population included patients who underwent GA only, and used EEG and somatosensory evoked potentials to assess cerebral ischemia. These methods, when combined, may be more sensitive than SP measurement [17]. However, our study combined GA and regional anesthesia and currently, neurological changes are considered the most reliable indicator for cerebral ischemia and thus shunt placement [18]. The different modality used to indicate shunt insertion could explain the different results, as well as other disparities such as study population size and surgical or anesthetic techniques.

Higher degree of artery stenosis or calcification inclined toward higher risk for shunt placement, but it did not reach statistical significance. similar results were achieved in Richard B. Schwartz' study [19] conducted on a smaller sample size, whereas In Tze-Woei article [20], ipsilateral stenosis of ICA was significant predictor for shunt usage as patient with moderate stenosis (50% to 79%) had higher rates of EEG changes suggestive of cerebral ischemia ($p = 0.003$). The discrepancy between the results can be explained by the different modality that was used to assess cerebral ischemia, the way the stenosis area was calculated, and by differences in surgical or anesthetic techniques.

In the current study incompleteness of COW was found to correlate with higher risk of shunt usage during CEA. COW provides collateral circulation that maintains cerebral perfusion even when blood flow to the brain is disrupted, as in cross clamping in CEA [21]. Those collaterals consist of the Anterior Communicating artery that allows inter-hemispheric blood flow and the Posterior Communicating artery that allows posterior to anterior flow [1].

Many variations exist in COW anatomy and even though the exact percentage of healthy individuals with incomplete COW is debatable, it is believed that more than 50% have at least one hypoplastic or absent artery [22,23].

The most common variation of incomplete COW is in the posterior circulation, and more specifically in the posterior communicating artery, suggesting that up to 27.8% of general population miss both of them [23]. Past studies did not find a correlation between those variations and a higher risk of cerebrovascular disease [23,24]. In contrast, a strong correlation between the function of the anterior communicating artery and ischemic strokes was found [25,26], suggesting a greater importance to this artery in terms of collateral function. In these studies, incomplete anterior COW was found in 22.8% of patients, while incomplete posterior COW in 70.6% of patients. Therefore, we decided to focus on the anterior circulation to predict the need of shunt. The result of this correlation was not surprising as several studies demonstrated a correlation between contralateral ICA occlusion and the need of shunt placement, implying flow disruption between the two hemispheres could require shunt insertion [14,27].

Conclusion

Our study was designed to find whether some pre-operative factors can reliably predict the use of extra-anatomical shunt during CEA. Our results show that lack of ACOM artery can serve as a predictor for patients with higher risk for extra-anatomical shunt placement. Our data suggests the need for shunting consideration in patients with lack of ACOM artery in general anesthesia, even if their stump pressure is above 50 mmHg.

The other factors we examined i.e., symptomatic disease and degree of artery stenosis and calcification, should be further studied as the literature is inconsistent about their relation to cerebral ischemia during cross clamping and shunt usage in CEA.

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