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Transcranial Doppler for Risk Assessment in Subarachnoid Hemorrhage

Laurence Poirier

lapoirier@toh.ca

Hôpital d'Ottawa: Ottawa Hospital https://orcid.org/0009-0009-9382-0836

Sanaz G. Biglou

Hôpital d'Ottawa: Ottawa Hospital

Vincent Brissette

Hôpital d'Ottawa: Ottawa Hospital

Shane English

Hôpital d'Ottawa: Ottawa Hospital

Célina Ducroux

Hôpital d'Ottawa: Ottawa Hospital

Dar Dowlatshahi

Hopital d'Ottawa: Ottawa Hospital

Tim Ramsay

Ottawa Health Research Institute: Ottawa Hospital Research Institute

Brian Dewar

Ottawa Health Research Institute: Ottawa Hospital Research Institute

Michel Shamy

Hôpital d'Ottawa: Ottawa Hospital

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Abstract

Background and Purpose:

Vasospasm is an important complication of subarachnoid hemorrhage (SAH) resulting in significant morbidity and mortality. Risk stratification attempts designed to identify patients most at risk of developing vasospasm have not led to significant practice changes. We sought to validate a prognostic utility criterion to identify patients at lowest risk of vasospasm.

Methods:

We conducted a single-centre retrospective observational study using transcranial doppler (TCD) readings of patients with SAH from 2018 to 2024. Through chart review, we extracted patient's mean blood flow velocities in the bilateral middle cerebral artery (MCAs) throughout their admission. We defined patients at low-risk of vasospasm as: MCA velocities on TCD had to remain below 120 cm/s and velocities had to have peaked and started to decrease by the 7th day post SAH. Our primary outcome was to analyze the predictive ability of our low-risk criteria to identify patients less at risk of developing vasospasm, defined as the presence of moderate to severe vasospasm (mean velocity in the middle cerebral artery exceeding 160 cm/s).

Results:

We collected data on 210 consecutive patients, of whom 196 met inclusion criteria; 107 (55%) met our low-risk criteria. Only 3 (2.8%) patients meeting our low-risk criteria developed vasospasm ($p < 0.001$), while 46 (52%) patients not meeting our low-risk criteria developed vasospasms (RR 18.4). The Positive Predictive Value (PPV) for not developing vasospasm in our low-risk group was 97.2% (95% CI: 92.0% – 99.4%).

Conclusion:

Our low-risk criteria based on TCD patterns in the first 7 days since SAH can identify a cohort of patients at very low risk of moderate to severe vasospasm. Our low-risk criteria for vasospasm could be used in future prospective studies to evaluate the safety of early discharge from the intensive care unit.

Introduction

Aneurysmal subarachnoid hemorrhage (aSAH) accounts for 5% of strokes worldwide(1), but carries significant morbidity and mortality. In Canada between 2004 and 2015, in-hospital mortality for patients with aSAH was 21.5%(2). Approximately 10% of patients presenting to a hospital with SAH are left with

moderate to severe long-term disability, rendering them dependent on care (modified Rankin Scale (mRS) 3–5)(3).

Delayed cerebral ischemia (DCI) is a complication of SAH often described in relation to cerebral vasospasm(4), which occurs in approximately 40% to 70% of cases (5). It significantly contributes to morbidity and mortality(6). The incidence of vasospasm follows a bimodal distribution, preceding the onset of DCI by 1–2 days and peaking near the 7th day(7) and up to day 14 after initial hemorrhage. Current guidelines for the management of SAH suggest admitting patients to an intensive care unit (ICU) for a period of 14 to 21 days(8) to monitor for signs of vasospasm. Several scales and scoring systems, such as the Modified Fischer Scale(9), Hunt and Hess Grade(10) or World Federation of Neurosurgeons (WFNS) Classification(11) are used to assess the severity of aneurysmal SAH (aSAH). Risk of vasospasm and DCI are higher in patients with worse aSAH, as scored using these systems. The VASOGRADE Score uses the above scoring systems to stratify aSAH patients according to their risk of DCI(12). However, limited data exist to identify patients with SAH who have a very low risk of vasospasm and who might safely be spared extended and invasive monitoring in hospital. To our knowledge, no validated scoring system exists to rule out vasospasm and DCI confidently.

Using transcranial doppler (TCD) imaging, we sought to identify patients at the lowest risk of vasospasm by testing the prognostic utility of a novel low-risk criterion: mean middle cerebral artery (MCA) velocities on TCD that peaked and remained below 120 cm/s by day 7. The primary exposure of interest in our study was meeting our defined low-risk criteria. These criteria were based on clinical inferences observing the TCD readings and clinical outcomes of patients over many years at several tertiary care stroke centres offering daily TCD, specialized neurocritical care, neurosurgery, and interventional neuroradiology services. Our primary outcome of interest is the presence of moderate to severe vasospasm, as defined by mean blood flow velocities ≥ 160cm/s in the MCA territories. Secondary outcomes included the presence of any vasospasm in the MCA territories (velocities ≥ 120cm/s), presence of hydrocephalus, need for endovascular intervention after day 7, days in ICU and death in hospital. Because data beyond hospitalization had not been systematically collected, we did not include long-term clinical outcomes.

Methods

Institutional review board approval was obtained from the Ottawa Health Science Network Research Ethics Board (OHSN-REB Protocol #20230559-01H). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed in reporting this study.

We conducted a retrospective observational study using TCD readings of consecutive patients aged 18 years or older admitted to The Ottawa Hospital from 2018 to 2024 with a first episode of SAH (excluding peri-mesencephalic SAH). Our intended sample size was 200 patients. As we had no specific statistical parameters to guide this decision, we chose this number in consultation with expert methodologists as we felt it was likely feasible and would likely support our hypothesis about a meaningful difference in

rates of vasospasm. After reviewing 100 charts, we identified a baseline rate of vasospasm of about 40%. Hence we began collecting data from patients in 2023–2024 and continued backwards until we had collected data from 200 patients. We included all patients aged > 18 years of aged diagnosed with SAH who underwent TCD ultrasonography, with at least one TCD measurement obtained within 7 days of ictus. Data extracted include sex, age at SAH diagnosis, date of SAH and baseline mRS, presence or absence of aneurysm, location of aneurysm (if applicable), clinical severity (WFNS classification(11) and Hunt and Hess scale(10)) and radiographic severity (Modified Fischer Scale(9)). When scores were not available in the chart, they were assigned by our study team comprised of Stroke and TCD experts based on clinical information from chart review.

Mean blood flow velocities in the bilateral MCAs (cm/s) were extracted from all TCD recordings. Patients were classified as "low risk" if they met the following criteria: 1) MCA blood flow velocities that remained below 120 cm/s AND 2) that had peaked AND were declining, both by day 5, 7 and 10. Our primary hypothesis related to outcomes based on TCD readings at day 7. In order to assess whether other time points might provide better discriminative value, we also performed the same analyses at days 5 and 10. Descriptive statistics are presented either as mean and SD, or median with interquartile range for continuous variables, and number and percentage of the subtotal for categorical variables. Categorical variables were compared using $\chi 2$ or Fisher exact tests, and continuous variables using the student t test or Mann Whitney U test where appropriate. In each group, we directly calculated the relative risk of vasospasm comparing high- and low-risk patients from the contingency table. Statistical analyses were performed using RStudio Version 1.4.1106. Temporal trends of TCD value in high versus low-risk patients are depicted in Fig. 1.

We defined a rate of moderate to severe vasospasm below 5% as likely being indicative of a population at very low risk of vasospasm, given that no available clinical scoring system had yet to define a population with a risk of vasospasm below 23%(13).

Results

We identified 210 patients presenting to the Ottawa Hospital with SAH between 2018 and 2024. Of these, 196 patients met all inclusion criteria and had TCD recordings within 7 days of SAH and were included in the primary analysis. Table 1 shows baseline characteristics of these patients. The overall incidence of vasospasm was 43.9% for any vasospasm (>120 cm/s) and 25.0% for moderate to severe vasospasm (>160 cm/s). An aneurysm was identified in 147 patients (75.0%). Aneurysm characteristics are shown in Table 2. The overall length of stay in the ICU was 16.6 days (SD=13.1).

Primary Outcome

Among patients meeting low-risk criteria, 3 (2.8%, 95% CI 1.0–7.9%) developed the primary outcome of moderate to severe vasospasm and 7 (6.5%, 95% CI 3.2–12.9%) developed any vasospasm. Among the patients not meeting low-risk criteria, 46 (51.7%, 95% CI 41.5–61.8%) developed moderate–severe vasospasm and 79 (88.8%, 95% CI 80.5–93.8%) developed any vasospasm ($p<0.001$). In our low-risk

group, the positive predictive value (PPV) for the absence of moderate to severe vasospasm was 97.2% (95% CI: 92.0% - 99.4%) and the PPV for absence of any vasospasm was 93.5% (95% CI: 87.0% - 97.3%). Patients not meeting low-risk criteria were 18.4 times more likely to develop moderate to severe vasospasm and 13.6 times more likely to develop at any vasospasm.

Secondary Outcomes

The average ICU stay for patients in the low-risk group was 14.0 days (SD=12.1) as compared to 18 days (SD 20.2) among those in the high-risk group (p-value <0.005). Secondary outcome characteristics are shown in Table 3. Overall, patients meeting low risk criteria were less likely to have an endovascular intervention after day 7. A numeric difference was noted in the rate of death in hospital, though this was not statistically significant and there was no significant difference in the rate of development of hydrocephalus.

Criteria at Day 5

When applying our low risk criteria up to day 5 post SAH as opposed to day 7, 109 patients met low risk criteria of whom 20 (18.3%) developed any vasospasm (MCA velocities > 120 cm/s), and 8 (7.3%) developed moderate to severe vasospasm (MCA velocities > 160 cm/s), versus 60 (77.9%) and 8 (49.4%) respectively in the high-risk group (p value <0.001). In our low-risk group, the PPV for absence of moderate to severe vasospasm was 92.7% (95% CI: 86.1% - 96.8%) and PPV for absence of any vasospasm any in our low-risk group was 81.7% (95% CI: 73.1% - 88.4%).

Criteria at Dy 10

When extending our low-risk criteria up to day 10 post SAH, 107 patients met low risk criteria. In low-risk patients, 2 (1.9%) developed primary outcome of vasospasm, and 1 (0.9 %) developed moderate to severe vasospasm, versus 84 (94.4%) and 48 (53.9%) respectively in the high-risk group (p value <0.001). In the low-risk group, the PPV for absence of moderate to severe vasospasm was 99.1% (95% CI: 94.9% - 100.0%) and PPV for absence of any vasospasm in our low-risk group was 98.1% (95% CI: 93.4% - 99.8%)

Discussion

This study uses TCD mean velocity trends in the MCA territories as a predictor of vasospasm in SAH patients and shows great predictive value for absence of vasospasm in those meeting our at day 7 days post SAH. When applying the same criteria over a shorter period of 5 days, the positive predictive value decreased, but when extended to Day 10, 99% of patients classified as low risk by our criteria did not go on to develop the primary outcome of moderate to severe vasospasm. Patients who met low-risk criteria at 5, 7, and 10 days post-SAH had favorable clinical trajectories, including shorter ICU stays and a reduced need for endovascular rescue after Day 7.

Many previous studies have attempted to prognosticate risk of vasospasm and DCI in patients with aneurysmal SAH patients, mainly using clinical and radiographic criteria(14,15). In the VASOGRADE study, the Modified Fischer Scale (9) and WFNS Classification (11) were used to stratify patients into 3 distinct risk categories according to their risk of vasospasm and DCI. Patients classified as VASOGRADE-Red were found to be at 3-fold increased risk of DCI as compared to those in VASOGRADE-Green, the lowest risk category. However, those patients considered lowest risk still had a 23% incidence of vasospasm and a 15% incidence of DCI. This still represents only a 50% reduction from the baseline incidence of DCI of around 30%(4). Other work looking at age as a predictor of vasospasm found that patients older than 65 years of age demonstrated an 8-fold reduced risk of vasospasm relative to younger individuals, possibly due to physiologic changes associated with aging, including atherosclerosis, altered immune responses, and shifts in CSF flow, that may limit vascular narrowing in the context of SAH(16). Our study also shows a trend towards older patients being at lower risk of vasospasm, with our low-risk group having an average age of 60.0 versus 54.3 in the high-risk group (p-value <0.001).

It is important to note that our low-risk group, did not differ in terms of WFNS Classification, Hunt and Hess Score or Modified Fischer Scale as compared to high-risk patients who developed vasospasm in a significantly greater proportion. This highlights that despite these advances in understanding clinical risk factors leading to the development of vasospasm, our ability to reliably predict its occurrence clinically remains limited (17) due to the complex nature of vasospasm and multifactorial pathophysiology of DCI(4). Hence, there is great potential value for a prognostic tool like the one we have tested here using only data from routine TCD.

TCD is a frequently used tool for the diagnosis of vasospasm, and subsequently for prediction of DCI. A meta-analysis found a pooled sensitivity of 90% and negative predictive value of 92%, but a specificity of 71% and positive predictive value of 57% to diagnose vasospasm(18). These statistics supports the utility of TCD in excluding vasospasm, though they illustrate its limited capacity to confirm the diagnosis, with a notable likelihood of false-positive findings. Therefore, if clinicians could use a tool like the one tested here to accurately identify patients at lowest risk of vasospasm, this could mitigate the need for invasive and expensive care thereby decreasing costs and the risk to patients resulting from any intensive care.

In Canada, the mean costs of ICU admissions for SAH are as high as $92,794 per patient. This is 1.7 times higher than ICU costs for spontaneous intracerebral hemorrhage(19). A Mayo Clinic-based feasibility study that tested “fast track” criteria for the discharge of patients from hospital after aSAH applied similar TCD criteria to ours (no vasospasm clinically or on TCD after 7 days) along with a number of other clinical factors. In that study, patients meeting “fast track” criteria had a low rate of vasospasm and of DCI, though direct comparison between that study and ours is not possible due to differences in study protocol. Early discharge was projected to yield $864,000 in savings over a 5-year period(8). Notably, only 36 of 377 patients screened met the “fast track” criteria, and the study does not appear to have been replicated.

Although a much higher proportion of our low-risk patients remained vasospasm-free, required fewer repeat endovascular interventions, and had an earlier discharge from ICU, their in-hospital mortality rate, while numerically lower, was not statistically different from that of high-risk patients. This may in part reflect our inability to consistently assess post-discharge outcomes, potentially underestimating differences in longer-term morbidity and mortality between groups. Since mortality did not align with vasospasm rates, it is unlikely to have been driven by hydrocephalus, which was equally prevalent in both groups. These data differ from previous studies reporting vasospasm, aneurysm re-bleed (leading to additional endovascular treatment), DCI and intraventricular hemorrhage (causing hydrocephalus) as the biggest contributors to mortality in SAH patients(20). Medical complications, such as refractory cerebral edema, cardiopulmonary dysfunction and sepsis are also known to play a role in driving mortality rates(20), but were not recorded in the present study.

Our study had some inherent limitations due to its retrospective observational design; potential selection bias due to exclusion of patients with missing data, and information bias stemming from non-standardized documentation of vasospasm. Additionally, unmeasured confounders, such as variations in ICU management or treatment thresholds, may have influenced both risk classification and outcomes. Our mortality rates could have been affected by decisions to withdraw care, for example in older patients whose goals of care did not align with the potential morbidity associated with SAH or prolonged hospitalization. Lastly, the high-risk group had more frequent repeated endovascular interventions after Day 7, which has the potential to cause iatrogenic vasospasm(21). Additionally, the lack of prespecified protocolized imaging or monitoring could introduce variability in vasospasm detection. While our results are promising, prospective validation in external cohorts is necessary to confirm the reproducibility and clinical utility of these criteria.

The reliability of our findings is supported by the relatively large sample size and the inclusion of both aneurysmal and non-aneurysmal SAH cases, thereby reflecting real-world practice and enhancing the generalizability of our low-risk criteria. The high positive predictive value (PPV) of 97% for absence of moderate to severe vasospasm in the low-risk group suggests that our criteria are robust for identifying patients at minimal risk of vasospasm in the post-hemorrhage period. These simple criteria could be used in future prospective trials to identify patients suitable for safe early discharge from intensive monitoring settings and therefore reducing hospitalization costs.

Table 1: Baseline Characteristics of Included Patients Stratified by low risk status

Characteristics	Meets low risk criteria (N=107)	Does not meet low risk criteria (N=89)	*P* value
Sex (Female)	71 (66.4%)	59 (66.3%)	1.0
Age (Mean)	60.0	54.3	<0.001
Baseline mRS	0.24	0.22	0.4923
WFNS	2.0	2.5	<0.005
Hunt and Hess	2.2	2.6	0.0338
Modified Fisher scale	2.5	2.9	0.01291

Table 2: Aneurysm Characteristics

Characteristic	n (%)
Patients with identified aneurysm	147 (75.0)
Aneurysm location	
Anterior communicating/Anterior cerebral artery (AComm/ACA)	60 (40.8)
Middle cerebral artery (MCA)	26 (17.7)
Posterior communicating/Posterior cerebral artery (PComm/PCA)	19 (12.9)
Internal carotid artery (ICA)	15 (10.2)

Table 3: Patient Outcomes on day 7 post-SAH

	Low risk patients day 7 n=107	High risk patients day 7 n=89	P-value
Mild vasospasm, n (%)	7 (6.5)	79 (88.8)	<.0001
Moderate/high vasospasm, n (%)	3 (2.8)	46 (51.7)	<.0001
Days in ICU, mean (SD)	14.0 (12.1)	19.8 (13.6)	0.003881
Death in Hospital, n (%)	13 (12.1)	18 (20.2)	0.1876
Second endovascular intervention after Day 7, n (%)	13 (12.1)	31 (34.8)	0.0003
Hydrocephalus, n (%)	41 (38.3)	49(55.1)	0.028

Declarations

This manuscript complies with all instructions to authors and all authorship requirements have been met.

Author contributions:

- Study design: Michel Shamy, Laurence Poirier, Tim Ramsay
- Data collection: Laurence Poirier, Sanaz G. Biglou, Vincent Brissette
- Data analysis : Sanaz G. Biglou
- Manuscript redaction : Laurence Poirier, Sanaz G. Biglou, Michel Shamy
- Manuscript revision : Michel Shamy, Vincent Brissette, Shane English, Célina Ducroux, Dar Dowlatshahi, Brian Dewar, Tim Ramsay

The final manuscript was reviewed and approved by all authors.

This manuscript has not been published elsewhere and is not under consideration by another journal.

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STROBE checklist was used to review this manuscript.

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Figures

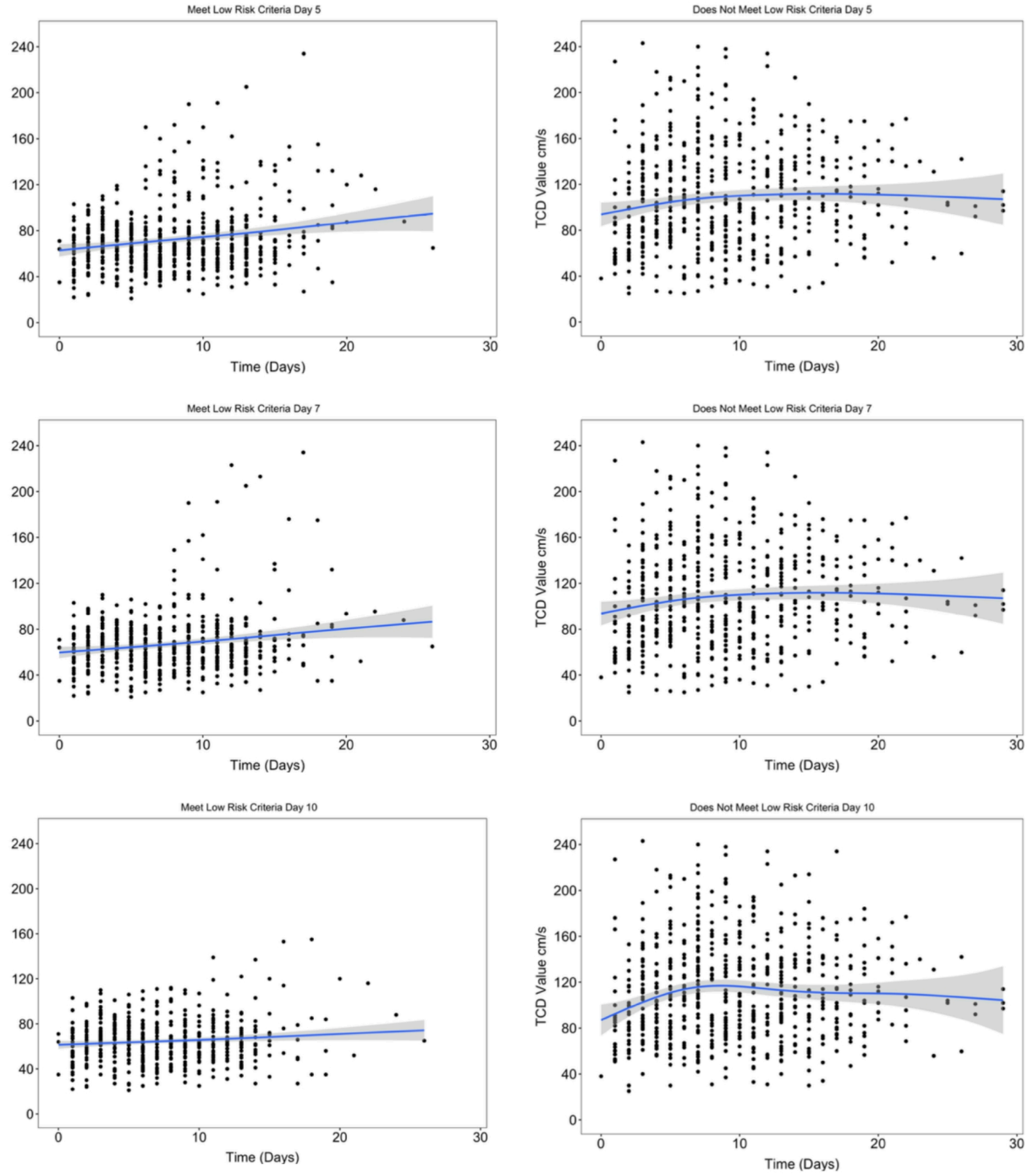


Figure 1

Temporal trends of transcranial doppler (TCD) value in high versus low-risk patients. Scatter plot depicting trends in TCD value of the left middle cerebral artery (LMCA) in patients 5-, 7-, and 10 days post subarachnoid hemorrhage (SAH). Patients were classified as low risk if they met the following criteria: Never more than 120 by day (5,7,10) AND peaks and comes down by day (5,7,10). Results are reported separately for Day 5, Day 7 and Day 10 patient cohorts.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- STROBEchecklist.docx