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Cerebral Hemodynamic Changes Induced by Simulated Tracheal Intubation: A Possible Role in Perioperative Stroke?

Magnetic Resonance Angiography and Flow Analysis in 160 Cases

Michael I. Weintraub, MD, FACP; Andre Khoury, MD

Background and Purpose—Perioperative stroke is a rare complication of generalized surgery (1% to 6%). Unexpected difficulties with tracheal intubation (TI), as well as the hyperextended position, may predispose a patient to or play a role in stroke. We sought to identify blood flow changes in carotid and vertebral arterial circulation during simulated TI and develop profile models for stroke risk before possible generalized surgery.

Methods—One hundred sixty consecutive patients with suspected cerebral vascular disease or pending surgery underwent MR angiography with flow analysis. Simulated TI position was maintained for 3 to 4 minutes per acquisition.

Results—The cohort consisted of 89 females (56%) and 71 males (44%) with a mean age of 66 years (range, 17 to 89 years). Hypoplastic vertebral arteries with flow less than 50 mL/s were present in 40 patients (25%). Profound alteration in basilar artery flow was noted in this group with increased frequency of microinfarctions on MRI (77% versus 38%). Unsuspected carotid occlusion (n = 6) and vertebral artery occlusion (n = 2) were associated with significant basilar artery flow changes. Flow reversal was present in five cases. Carotid arterial changes were not significant with simulated TI. No overt ischemic symptoms developed during these maneuvers.

Conclusions—Simulated TI is safe yet induces distinct and potentially detrimental flow abnormalities. Individuals identified with the biological markers of hypoplasia, carotid and vertebral occlusion, severe stenosis, or prior ischemic vascular disease should receive special attention to neck position not only during surgery but also in the postoperative period. Sustained neck hyperextension greater than 12 minutes appears to be a neglected potential hemodynamic factor that may play a pivotal role in the pathogenesis of perioperative stroke. (Stroke. 1998;29:1644-1649.)

Key Words: basilar artery ■ vertebral artery ■ stroke, perioperative ■ intubation, intratracheal

Despite advances in surgical and anesthetic techniques, perioperative stroke (POS) remains a significant problem. Estimates of its prevalence suggest a range from 1% to 6%,1-4 with a mortality rate approaching 60% in certain individuals with prior stroke.5 Preoperative risk assessment has proven to be unreliable and in fact is an imprecise science. Thus, clinicians and patients face an uncertain dilemma without definitive biological markers.

It has been assumed that POS and ischemic syndromes result from embolism, vasospasm, bleeding, hypoxia, or thrombosis during the surgical procedure.6,7 A relatively overlooked hypothesis is that tracheal intubation (TI) significantly induces hemodynamic and perfusional changes and may be a major link to the occurrence of this syndrome.8-10

On the basis of previous studies11,12 and the unique anatomy of the vertebral arteries passing through the foramen transversarium of the transverse processes of the vertebral column, we speculate that neck angulation induces mechanical compression with secondary luminal changes producing hemodynamic changes.

Subjects and Methods

We designed a prospective community-based study to determine whether dynamic MR angiography (DMRA) would serve as a useful screening test to predict risk of stroke. Specifically, the issue of changes induced by simulated TI through hyperextension was addressed. We used standard neck angulation techniques simulating the “sniffing” position demonstrated by a board-certified anesthesiologist. Thus, our observations and conclusions will be limited to the immediate period of induction and extubation. Subjects were followed for periods of up to 2 to 3 weeks to determine clinical status.

Study Design

From June 1994 through December 1996, 160 consecutive patients were screened for the effects of simulated TI by DMRA and flow analysis with the use of a technique previously described.13 Among the 160 subjects screened were individuals who were scheduled for surgery and others who were future surgical candidates, eg, coronary artery bypass graft, cataract surgery, or cholecystectomy candidates.
However, the majority of the individuals were considered high risk and were studied in relation to suspected cerebral vascular disease and symptomatology. The ages ranged from 17 to 89 years, with 44% males and 56% females (Table 1). Phelps Memorial Hospital Investigational Review Board approved the protocol, and informed consent was provided.

DMRA and flow analysis offer the opportunity to measure qualitative and quantitative hemodynamic changes in vivo (real time) that may arise with simulated intubation. Thus, the primary outcome measure was to determine whether simulated TI induces significant hemodynamic changes that would be important in risk stratification and assessment of clinical status.

Materials
All patients were examined with a 1.5-T superconductive magnet (General Electric Signa; ×5). MR angiography was performed in the axial plane, in a neutral position, and during hyperextension, with the two-dimensional time of flight technique (repetition time, 37 milliseconds; minimum echo time flip angle, 65°; RB, 16 kHz; field of view, 24 cm; slice thickness, 1.9 mm; matrix, 256×128; number of excitations, 1). A volume neck coil at the origins of the vertebral and common carotid arteries and the distal portion of the basilar arteries was included. The images were analyzed for stenosis and dissection, and the size of the vertebral arteries was assessed for hypoplasia. Flow analysis was also performed with a volume neck coil, in a neutral position and during hyperextension, with the use of the cine phase-contrast technique with peripheral gating and flow compensation (flow direction, S/I; flip angle, 20°; repetition time, 22 milliseconds; field of view, 24 cm; slice thickness, 5 mm; multiple locations; velocity encoding, 60 cm/s; matrix, 256×128; number of excitations, 2; frequency direction, anteroposterior). Three measurements were performed in one acquisition: the first below the carotid bifurcations, Figure 1. A and B, Site of flow analysis measurements (dotted lines), below and above the carotid bifurcations and in the mid basilar artery (perpendicular to the vessels). RV indicates right vertebral artery; LV, left vertebral artery; RCCA, right common carotid artery; LCCA, left common carotid artery; RICA, right internal carotid artery; LICA, left internal carotid artery; and B, basilar artery. C and D, Normal MR angiography and flow analysis with vertebral arteries of equal size. Avg indicates average; Pek, peak.
TABLE 1. Demographics

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>17–89 (mean, 66 y)</td>
</tr>
<tr>
<td>Males</td>
<td>n=71 (44%)</td>
</tr>
<tr>
<td>Females</td>
<td>n=89 (56%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prior history of stroke</th>
<th>30/120 (25%)</th>
<th>10/40 (25%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes mellitus</td>
<td>5/120 (4%)</td>
<td>2/40 (5%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>31/120 (26%)</td>
<td>11/40 (28%)</td>
</tr>
</tbody>
</table>

TABLE 2. Infarctions Observed on MRI

<table>
<thead>
<tr>
<th>HVA</th>
<th>n</th>
<th>Right</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bilateral</td>
<td>7</td>
</tr>
<tr>
<td>Proximal posterior circulation</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Cerebellar infarction</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Middle posterior circulation</td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Pontine infarction</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Distal posterior circulation</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Thalamic infarction</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Occipital infarction</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Basal ganglionic infarction</td>
<td></td>
<td>13</td>
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</tbody>
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the second above the bifurcations, and the third in the mid aspect of the basilar artery (Figure 1). Scan time was 3 to 4 minutes per acquisition. Image analysis was then performed by choosing the region of interest of the specific artery and downloading the images into the computer. In all cases, flow analysis was performed at the same level with the subject in a neutral position and during hyperextension with the same physical parameters, and the processing was done by the same operator. The error in the differences measured between hyperextension and the neutral position is very low. For each region of interest, computerized data were generated: volume flow rate (milliliters per minute) and velocity (centimeters per second) were charted and graphed (Figure 1C and 1D). Patients were advised to report any new symptoms produced by this positioning.

Hypoplasia

Asymmetry in the size of the vertebral arteries is well documented, yet hypoplasia is not clearly defined. Consequently, we defined hypoplasia by two parameters: (1) when the vertebral diameter was two thirds less than the opposite artery and (2) when the flow was less than 50 mL/min (normal vertebral artery blood flow = 61 to 115 mL/min).

Statistical Analysis

Each subject served as his or her own control. Student’s t test (two tailed) was used to measure continuous variables, and the χ² test for independence was used to assess the relationship between hypoplasia and MRI outcomes. Values are reported as mean ± SD. A value of P<0.05 was regarded as statistically significant.

Results

The cohort consisted of 89 females (56%) and 71 males (44%) (Table 1). Age ranged from 17 to 89 years (mean age, 66 years). Hypoplastic vertebral arteries (HVAs) with flow less than 50 mL/min were present in 40 subjects (25%). Hypertension was present in 31 of 120 subjects (26%) and was present in the HVA cohort in 11 of 40 (28%). Diabetes mellitus was present in 5 of 120 subjects (4%) and in the HVA cohort in 2 of 40 (5%). A history of prior stroke was present in 30 of 120 subjects (25%) and in the HVA cohort in 2 of 40 (5%).

Table 2 identifies infarctions observed on MRI. The overall majority of these events were clinically silent. During the present study no overt ischemic symptoms developed during these maneuvers or in the follow-up periods.

HVAs with flow less than 50 mL/min were present in 40 patients (25%) (Figure 2). Males and females were equally represented. Left side (n=16), right side (n=17), and bilateral (n=7) involvement were noted. Compensatory increased blood flow in the contralateral vertebral artery was usually seen with hypertension. Nine of these individuals displayed severe or occluded carotids, whereas 31 had mild carotid atherosclerosis. This difference approached statistical significance in relation to MRI infarctional changes (tₐ = 1.42, P=0.194). With a larger sample size, this would be significant.

There were six cases of unsuspected carotid artery occlusion (three right and three left). One individual also had HVAs. Two vertebral artery occlusions were identified, but not in the HVA cohort. There was no evidence of dissection. Flow reversal was identified in five cases (Figure 2D).

Table 3 identifies flow abnormalities detected on DMRA, which were significant only in the HVA group (77% versus 38%) (P<0.01). The proximal posterior circulation demonstrated cerebellar infarction (n=13), the middle circulation revealed pontine infarction (n=14), and the distal posterior circulation revealed thalamic (n=15), occipital (n=13), and basal ganglionic (n=13) infarctions. Anterior cortical infarctions (frontal/parietal) were also noted (n=25). Six individuals in the HVA cohort did not have brain MRI. Of the 99 non-HVA subjects, 36 (36%) displayed posterior circulation infarcts. Of the 34 HVA patients, 23 (68%) displayed both posterior and anterior infarctions on MRI, whereas 37 of the 99 non-HVA subjects displayed evidence of both infarctions (37%). This difference was statistically significant (χ² = 9.37, P<0.01).

Anterior circulation changes were seen equally in the HVA cohort (25/34; 74%) and in the non-HVA group (74/99; 75%). This was not significant. Basilar artery flow reduction occurred in one third (33%) of the HVA cohort compared with less than 20% of the non-HVA cohort. This was an interesting trend but was not statistically significant (P=0.08). We have previously used a basilar artery perfusion index formulation [12] that has not been validated. This ratio of posterior blood flow [Basilar Artery/(Basilar Artery + 2 Internal Carotid Arteries)] revealed that the basilar artery quotient was disproportionately reduced in 24 patients with HVA (60%), whereas this occurred in only
Figure 2. A and B, Hypoplastic right vertebral artery. C and D, Slow flow and reversal of flow. E and F, Basilar artery flow reduction. Abbreviations are as in Figure 1.
TABLE 3. Flow Abnormalities

<table>
<thead>
<tr>
<th>Abnormality</th>
<th>n</th>
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<tbody>
<tr>
<td>Carotid occlusion</td>
<td>6</td>
</tr>
<tr>
<td>Vertebral occlusion</td>
<td>2</td>
</tr>
<tr>
<td>Slow flow</td>
<td>12</td>
</tr>
<tr>
<td>Reversal of flow</td>
<td>5</td>
</tr>
<tr>
<td>HVA</td>
<td>40</td>
</tr>
</tbody>
</table>

45 patients in the non-HVA cohort (38%) (Figure 2E and 2F). This difference is statistically significant ($\chi^2 = 6.19$, $P < 0.05$).

Discussion

Risk stratification relying solely on history of hypertension, diabetes, cardiac disease, hypercholesterolemia, prior stroke, or heart attack is insensitive and insufficient to predict in vivo events. Transient changes in blood flow during hyperextension have been identified in a specific cohort that displays a higher incidence of infarction of the posterior circulation. Despite the absence of acute ischemia or stroke, the aforementioned association with hyperextension for 12 minutes raises many questions. It is well known that individuals are placed in the hyperextended position with various other procedures during surgery; consequently, if this position is maintained for more than 12 minutes, could this induce a POS? Perhaps it is worthwhile to abandon surrogate markers that relate to the status and degree of atherosclerosis. Our results argue that DMRA represents a novel, in vivo challenge test that is more sensitive than other techniques in demonstrating enhanced susceptibility to TI. It is not known whether these reversible flow changes become irreversible on the basis of duration of positioning or local inflammation, but this may be a logical conclusion. The striking vascular changes seen in the cohort with HVA raise the question of whether the mechanism of injury may be acute, as noted in the figures, as well as delayed, with intimal damage and secondary changes that evolve over hours or days. The fact that 80% of POS is noted in the postoperative period at a mean of 10 days after the operation may represent this delayed effect. It is noteworthy that the HVA cohort displayed a significantly higher incidence of posterior and combined infarctions, suggesting that this is an independent harbinger of stroke. The magnitude of these data, seen in only 25% of the study population, suggests that this could be a public health concern since HVA has been estimated to occur in 40% of the population.

Patients with prior stroke merit special attention since investigators have documented that the presence of preoperative findings of cerebral vascular disease augments the risk 5- to 10-fold for stroke and myocardial infarction.

The HVA cohort displays a unique vulnerability to simulated TI, with significant mechanical compression at the atlanto-axial and atlanto-occipital junctions. This is not influenced by age or medication. The presence of an HVA imposes specific physiological stresses, ie, changes in regional hypovolemia, slow flow, reversible flow, and altered perfusion in the absence of neurological symptoms. The high incidence of posterior circulation silent infarctions and absence of ischemic symptomatology during simulated TI suggest that a threshold exists and portend that an “in vivo” accident is imminent if this position is maintained too long or if neck position during the operation and during the postoperative period is neglected. Investigators have previously demonstrated that intimal injuries as well as atherosclerotic changes can have a dynamic pathophysiology leading to tears, rupture, vasocclusion, local thrombosis, or occlusion. Local areas of injured intima may attract granulocytes that lead to local inflammatory reactions and subsequent platelet clumping, resulting in luminal constriction and even thrombosis. While the emergence of neurological symptoms such as seizures, hemiparesis, and aphasia after surgery is often attributed to intraoperative embolism or a local complication of surgery, ie, hypoxia, we speculate on the basis of our data that a significant number of POS are due to neck angulation difficulties. This suggests that the prior slow flow or reversible flow could develop into irreversible flow. However, our study is limited to the immediate real-time period with no long-term follow-up. Thus, in the setting of general anesthesia, physicians and nurses should be aware that neck positioning is crucial and should be monitored not only in the operating room but also in the recovery room.

In conclusion, sustained hyperextension simulating TI for up to 12 minutes appears to be safe and unaccompanied by ischemic symptoms. The use of DMRA as a novel surveillance technique indicates that significant blood flow abnormalities occur in a cohort with HVA. This group demonstrated a higher incidence of silent posterior circulation infarctions, suggesting that they are at disproportionate risk for future ischemic insults. Subjects with a high degree of carotid stenosis or occlusion with hypoplasia are also at increased risk. The presence of these biological markers for augmented stroke risk should result in special attention focused on neck position during intubation, surgery, and the postoperative period and should also provide a future strategy for modifying neck positions during activities of daily living.

Acknowledgment

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References