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The Role of Head CT Imaging in the Evaluation of Postoperative Neurologic Deficits in Cardiac Surgery Patients

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Abstract

Background—Computed tomography(CT) scans of the head without contrast are routinely obtained to evaluate neurologic deficits after cardiac surgery(CS), but their utility is unknown. We evaluated our experience with this imaging modality to determine its value.

Methods—We retrospectively identified CS patients with postoperative neurologic deficits occurring during the first week after surgery between January 2000 and December 2012. Stroke was defined by neurologist's determination, while a non-focal deficit(NFD) was defined by the presence of seizure, delirium, or cognitive impairment. We defined early non-contrast head CT as occurring within 7 days of surgery. Outcomes included positive findings on CT, in-hospital mortality and length of stay(LOS). Multivariate logistic regression identified predictors of positive findings on head CT.

Results—Within the population of 11,070 postoperative patients, 451 had early non-contrast head CT scans (4%). 202(44.7%) were associated with stroke and 249(55.2%) with NFD. Among stroke patients, 40/202(20%) showed acute infarction, 17/202(8%) showed sub-acute infarction, and 5/202(2%) showed hemorrhage. Among NFD patients, 1/248(0.4%) showed acute infarction, 4/248(1.6%) sub-acute infarction, and 1/248(0.4%) hemorrhage. There was no difference in in-hospital mortality(S:42/201(21%) versus NFD:41/248(16%), p=0.2) or LOS (S:24d versus NFD: 22d, p=0.5). On multivariable logistic regression, only focal deficits and aortic procedures predicted a positive finding on CT scan.

Conclusions—To our knowledge, this is the only modern study to review the utility of early postoperative non-contrast head CT in CS patients. With focal neurologic deficits, this imaging modality was positive for approximately one third of patients, but rarely positive for NFD. Its use in this setting has limited utility.

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Keywords

Cerebral Complications; Intensive Care

Introduction

Neurologic deficits (ND) following cardiac surgery (CS) are a devastating problem, with an incidence that varies widely from 25–79%. Focal deficits occur in as many as 6% of some series.[1–12] Risk factors for postoperative neurologic dysfunction include age, history of cerebrovascular disease, atherosclerosis and diabetes.[1, 5, 7, 8, 13, 14] In addition to patient risk factors, intraoperative events involving microemboli from the bypass circuit, air, intra-cardiac thrombi or debrided tissue, aortic atheroma released during cross-clamping, as well as global hypo-perfusion have all been implicated as etiologies of postoperative neurovascular complications.[3, 7, 8, 12, 15–19]

Although previous studies have examined the etiology, incidence and risk factors associated with neurologic dysfunction after CS, few have examined the sensitivity of diagnostic modalities, in particular non-contrast computed tomography (CT) scans of the head, in the early postoperative period (<7 days postoperative). The purpose of this study was to assess the utility of early non-contrast head CT scans after CS.

Patients and Methods

Patient Data

We retrospectively reviewed our prospectively maintained database to identify patients who developed new postoperative NDs evaluated by a non-contrast CT scan of the head between January 2000 and December 2009. All adult (>16 years) post-operative cardiac surgical patients were eligible, with no exclusions based on procedure type. We examined the records of all patients found to have new postoperative NDs assessed within 7 days of surgery by a non-contrast head CT. Patients whose first head CT occurred more than 7 days postoperatively were excluded from the analysis. All pertinent data (demographic information, comorbidities, operative data and postoperative data) were extracted from the medical record. This study methodology was approved by the Johns Hopkins Medicine Institutional Review Board.

Stratification

Patients were stratified into two categories. Patients with focal ND on a physician's neurologic exam and a physician diagnosis of stroke were classified as having a stroke. Patients who experienced evidence of a seizure, cognitive impairment, agitation or delirium in the absence of a focal deficit, as evidenced by daily rounding reports composed by nurses and nurse practitioners were classified as having a non-focal deficit (NFD). All outcomes compared data utilizing this stratification.

Outcomes

The primary endpoint was the presence of a new radiographic finding on early non-contrast head CT. Such findings included evidence of ischemic infarct, embolic infarct and hemorrhage. Secondary end-points included in-hospital mortality, length of stay (LOS), time to neurologic consult, time to head CT, patient final disposition and the type of radiographic finding associated with the neurologic injury. Sub-group analysis stratified by time to head CT within the 7 day period was also performed. Multivariate logistic regression analysis was utilized to identify clinical variables predictive of a positive imaging study.

Statistical Analysis

Baseline differences in demographic and operative variables among injury classifications were compared using the Student's t-test for normally distributed continuous variables. These variables are presented as the mean and standard deviation (SD). Continuous variables that were not normally distributed were compared with the Wilcoxon rank-sum test and presented with median and interquartile ranges (IQR). Chi-square analysis or Fisher's exact test were utilized for categorical variables. Categorical variables are shown in numbers and percentages. Post-operative outcomes were compared according to neurologic injury stratification utilizing Student's t-test or chi-square analysis as appropriate.

To examine the predictive effect of clinical variables for positive radiographic findings on non-contrast CT scan, we estimated the odds ratio (OR) by constructing multivariable logistic regression models. To construct our model, variables associated with each outcome on exploratory univariate analysis ($p < 0.2$), those with biologic plausibility and those with previous literature support were incorporated in a forwards and backwards stepwise fashion. The likelihood ratio test and Akaike's information criterion were used in a nested model approach to identify covariates which increased the explanatory power of the model. This method favors a more parsimonious model. ORs are presented with 95% confidence intervals (CI). Values of $p < 0.05$ were deemed significant. Analysis was performed utilizing Stata/IC 11.2 software (StataCorp, College Station, TX).

Results

Cohort Characteristics

Of the 11,070 patients operated upon during the study period, 675 (6.1%) developed postoperative neurologic symptoms evaluated by a non-contrast head CT. Of these patients, 451 (67%) patients underwent early CT scans (< 7 days post-operatively) and comprised our patient cohort.

Their mean age was 65 ± 14 years and 274 (61%) were male. 340 (76%) patients had a history of hypertension and 148 (33%) had a history of diabetes. 60 (13%) patients were active smokers at the time of their operation. 140 (31%) isolated coronary artery bypass (CABG) procedures were performed. A redo sternotomy was required in 28 (6%) patients. Mean cardiopulmonary bypass (CPB) time was 140 ± 74 minutes and an intra-aortic balloon pump (IABP) was placed in 81 (18%) patients.

Positive radiographic findings were identified in 75 (17%) early non-contrast head CT scans. Of these, acute strokes occurred in 41 (55%) patients, subacute strokes in 21 (28%) patients, and hemorrhagic strokes in 6 (8.0%) patients. In-hospital mortality was 18%. Median LOS was 16 days (IQR: 9–29 days).

Stratified Cohort Characteristics

Cohort stratification by type of neurologic injury revealed 202 (45%) stroke patients and 249 (55%) NFD patients. Most baseline characteristics were similar between the two groups. However, stroke patients were less likely to have a seizure history (stroke = 0.5% vs NFD = 3.6%, $p = 0.03$) than NFD patients (Table 1).

Outcomes

Stratification by stroke vs NFD showed stroke patients were significantly more likely to have radiographic findings in their non-contrast head CT scans, compared to NFD patients (69/202 [34%] vs 6/249 [2%], $p < 0.001$). There was no difference in in-hospital mortality between the stroke and NFD groups (42/201 [21%] vs 41/248 [17%], $p = 0.24$).

Similarly, no difference was demonstrated in LOS between the stroke and NFD groups (median-15, IQR: 9–32 vs median-16.5, IQR: 10–27.5; $p=0.97$). However, stroke patients were less likely to be discharged to home. Stroke patients were more likely to receive a neurological consult (stroke=95% vs NFD=51%, $p<0.01$) and received a head CT sooner than NFD patients (stroke= 2.59 ± 1.84 vs NFD= 3.24 ± 2.06 , $p<0.01$; Table 2).

Analysis of the types of radiographic findings, as seen by CT scan, associated with each classification of neurologic injury demonstrated that stroke patients had more acute infarcts (40/199 [20.10%] vs 1/239 [0.42%], $p<0.001$) and more sub-acute infarcts than NFD patients (17/199 [8.54%] vs 4/239 [1.67%], $p=0.001$). There was no significant difference in the number of hemorrhages seen between the two groups (Table 3). Sub-group analysis revealed no significant difference in any radiologic finding by neurologic injury, when stratified by time to CT scan (Table 4).

Multivariable logistic regression analysis to ascertain clinical parameters which would increase the likelihood of positive radiographic findings on initial head CT resulted in a final model consisting of the several variables. In this model however, only focal neurologic deficit (OR: 22.96 [9.22–57.21], $p<0.001$) and aortic procedures (OR: 3.02 [1.19–7.65], $p=0.02$; Table 5) were predictive of a positive head CT finding.

Comment

Of the 11,070 patients operated on during the time period of our study, 451 were evaluated with early non-contrast head CT scans for new NDs for an incidence of 4%. Of these 451 patients, 202 (44.7%) had focal deficits. In this cohort of patients, positive radiographic findings occurred in 69 (34%) examinations. Of these findings, 58% were acute infarctions, 25% were sub-acute infarctions, and 7% showed hemorrhage. In contrast, identifiable lesions were extremely rare in the cohort of patients with NFD, as only 6/249 (2.4%) patients had positive findings on CT scan and little can be concluded regarding the distribution of lesions in this cohort. The presence of radiographic findings was not affected by the timing of the CT scan. Both aortic procedures and a focal neurologic deficit on physical examination were found to be predictive of positive findings on head CT.

Non-contrast head CT is a common radiographic modality used for identifying the etiology of new neurologic findings after cardiac surgery, particularly in patients with focal deficits. [1, 2, 8, 12, 14, 20] As opposed to magnetic resonance imaging (MRI), CT is relatively rapid, cheap, and widely available. [21, 22] In addition, CT is able to identify most significant intracranial pathologies. Though its resolution is lower than that of MRI, specifically in soft tissue contrast, the use of narrow window width helps to increase the detection of more subtle lesions. [22] Non-contrast CT is primarily used to determine the presence of hemorrhagic stroke while simultaneously ruling out neoplasms or other space occupying lesions that may mimic stroke symptoms. [21, 23–25] Although the appearance of the ischemic core after infarction is quite specific on non-contrast CT, this modality has only a 45%–70% sensitivity in the hyper-acute period (<6 h), as the associated early changes can be very subtle. [25, 27–32] Although few data exist which assess the utility of non-contrast head CT in the immediate analysis of a new neurologic dysfunction after cardiac surgery, it is likely that this sensitivity would be similar.

In the non-cardiac surgical population, Lev and colleagues reported that the sensitivity of non-contrast CT in evaluating stroke was 57%–71%. [21] In our study, only a third of patients with focal deficits had positive findings on head CT. One explanation for our low positivity rate may relate to the early timing of the CT scan with respect to the onset of the stroke. Frequently, in non-surgical patients, stroke symptom onset occurs outside of the hospital, and the necessary delay between symptom onset and head CT increases the

sensitivity of the imaging technique, as the injury has time to evolve. Early on, pathologic changes (e.g. edema secondary to failure of cellular ion pumps[21] and cell death) have not had time to progress to a level visualized by non-contrast CT imaging, despite the fact that these patients may have a sufficient injury to present with a focal exam. However, the percentage of radiographic findings did not increase as the time to CT scan was prolonged.

Unlike non-contrast scans, contrast enhanced CT scans allow anatomic visualization of vascular stenosis and occlusions, and increase sensitivity to over 70% in hyper-acute infarcts.[24, 25] Additionally, if performed early enough in the setting of an acute infarct, they are useful in determining the benefit of thrombolytic therapy. Unfortunately, although sensitivity is improved, the addition of contrast carries risks including acute tubular necrosis that may lead to the need for dialysis. Although the risk of contrast-induced nephropathy ranges from 5–6% in the chronic kidney disease literature, the specific risk in cardiac surgery patients is unknown. However, upwards of 30% of postoperative cardiac patients experience at least a 25% decrease in their glomerular filtration rate due to surgery alone. [33–35] The contraindication to thrombolytic therapy in this population, coupled with the risk of contrast-induced nephrotoxicity, mitigate against the routine use of contrast enhanced CT in this cohort.

In patients with a focal exam, 2.5% were found to have an intracerebral hemorrhage. This finding is clinically relevant, as it argues against one of the primary treatment modalities for patients with ischemic stroke, which is permissive hypertension.[36–38] In cerebral hemorrhage, this therapy is contraindicated. Secondly, a significant number of postoperative cardiac patients need anticoagulation due to the presence of atrial fibrillation, mechanical valve placement, or deep vein thrombosis. Knowledge of either an intracerebral bleed or infarct size (a risk factor for hemorrhagic conversion) might alter therapy in this population. Therefore, a non-enhanced CT scan in the face of a patient with a focal deficit may be appropriate, despite its low yield.

As opposed to scans in patients with focal deficits, very few non-contrast studies were positive in patients with NFD. One explanation for this may be that given the neurologic recovery seen in this patient population, as witnessed by the discharge rate to home of close to 50%, the cause of the neurologic abnormality may have been metabolic and reversible. However, if an ischemic event did occur, it most probably was a watershed infarct characterized by hypo-perfusion to those areas of the brain that receive their blood supply from the most distal aspect of a named arterial supply, with the territory at risk being collaterally perfused. In a report by Gottesman et al, CT scans were relatively insensitive in detecting regions of watershed infarction.[39] Furthermore, although emboli are believed to be the cause of many neurologic complications after cardiac surgery, it is primarily microemboli which are thought to be responsible for the diffuse cerebral dysfunction seen in many cases of NFD.[3, 7, 8, 12, 16, 18, 19, 40] These microemboli may be associated with a very subtle anatomic injury that may not be apparent on CT imaging. Additionally, our data suggest that hemorrhage in this population is extremely rare (<1%). Therefore, although the therapeutic benefit of permissive hypertension is unproven in this patient population, if increased afterload can be tolerated, incremental elevations in blood pressure should be implemented in all of these patients, along with collaborative input from neurology, speech/language pathology and physical therapy where appropriate, and early imaging is unnecessary.

NDs are frequently devastating complications of CS. When considering all degrees of impairment, rates are reported to range from 25–79%, with stroke comprising up to 6.1%[1, 7, 8, 10, 11] of these patients, commensurate with our findings. Although often transient, the immediate and long-term sequelae of these post-operative NDs are shown by their

associated mortality, LOS and final disposition. In our study, mortality and LOS were similar in patients who exhibited a ND severe enough to trigger early imaging, regardless of focality. Median LOS in the stroke and NFD groups were 15 and 16.5 respectively, compared to a mean LOS of 12 days in patients without NDs. Nevertheless, focality impacted disposition significantly, with stroke patients discharged to home approximately 25% of the time, as opposed to 50% in the non-focal deficit group.

Though many studies have shown multiple predisposing risk factors for ND including age, cerebrovascular disease history, diabetes, hypertension and the requirement of an IABP[5, 7, 8, 11–14, 16], none of these proved to be predictive for a positive early non-contrast head CT. Only focality and aortic procedures were associated with a positive finding on non-contrast CT.

The data presented in this study suggest that the routine use of non-contrast head CT scan for non-focal NDs presenting in the early-postoperative period after CS is an inefficient, low-yield use of this imaging modality. In the setting of a focal deficit, CT scanning appears to help direct patient care in 33% of patients, diagnosing infarcts, hemorrhage and lesions at risk for hemorrhage. However, CT scanning after NFD rarely yields actionable information. These patients may be better served by forgoing any imaging studies. Post-operative patients are frequently unstable and require added resources for transport to the radiology/CT area of the hospital where the degree of medical support is minimal, compared to the ICU. Additionally, diagnostic tests with such low yield contribute significantly to healthcare costs with marginal benefit.

Limitations

Several limitations of this study can be identified. First, this is a retrospective review and is therefore subject to limitations in data recording which may introduce bias. Second, this study evaluates CT scan data for the first 7 days post-operation, with no long term follow up. Therefore, it is unable to address issues of lesion progression on consecutive CT scans, neurologic recovery or chronic disability beyond final disposition. Third, postoperative neurologic findings were not verified by a common neurologist, but rather by one of a team of neurologists, and therefore, variable diagnostic acumen may have played a role in patient characterization.

Conclusion

To our knowledge, this is the first study examining the utility of non-contrast head CT analysis after CS. In this retrospective review of our experience with non-contrast head CT for the evaluation of new ND after CS in the early post-operative period, less than 3% of scans were positive in patients with a non-focal deficit. This is significantly different from patients experiencing a focal deficit, where the non-contrast scan was positive in 34% of patients. Given that CT scanning is so rarely helpful in patients with a NFD, its clinical benefit should be weighed against its cost, both in risks to the patient as well as the resources used to obtain the study. Further investigation is warranted to better understand which patients should be imaged and which imaging modality would be most useful in the setting of early postoperative NDs after CS.

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Abbreviations

CABG	coronary artery bypass graft
CI	confidence interval
CPB	cardiopulmonary bypass time
CS	cardiac surgery
CT	computed tomography
IABP	intra-aortic balloon pump
IQR	interquartile range
LOS	length of stay
MRI	magnetic resonance imaging
ND	neurologic deficits
NFD	non-focal deficit
OR	odds ratio
SD	standard deviation
VAD	ventricular assist device

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Table 1

Demographic, Comorbidity and Operative Characteristics by Injury Classification

Variable ^a	S (n=202)	NFD (n=249)	p-value ^b
<i>Demographics and Comorbidities</i>			
Age, years	65.76 ± 12.52	64.25 ± 14.54	0.24
Male sex	115/201 (57.21%)	159/248 (64.11%)	0.14
Height, cm	169.76 ± 13.10	169.65 ± 10.94	0.92
Weight, kg	80.16 ± 20.05	80.91 ± 19.10	0.69
Body mass index, kg/m ²	27.37 ± 5.70	28.15 ± 6.49	0.19
Diabetes	68/201 (33.83%)	80/247 (32.39%)	0.75
Hypertension	157/201 (78.11%)	183/247 (74.09%)	0.32
Hypercholesterolemia	107/201 (53.23%)	130/247 (52.63%)	0.90
Peripheral vascular disease	37/201 (18.41%)	37/248 (14.92%)	0.32
Current Tobacco use	23/201 (11.44%)	37/247 (14.98%)	0.27
Myocardial infarction	74/201 (36.82%)	85/247 (34.41%)	0.60
Cerebrovascular disease	34/201 (16.92%)	40/248 (16.13%)	0.82
Syncope	3/202 (1.49%)	6/249 (2.41%)	0.74
Seizure	1/202 (0.50%)	9/249 (3.61%)	0.03
Headache	3/202 (1.49%)	2/249 (0.80%)	0.66
Head trauma	1/202 (0.50%)	0/249 (0%)	0.45
Depression	14/202 (6.93%)	28/249 (11.24%)	0.12
Creatinine, mg/dl	1.35 ± 1.28	1.33 ± 1.18	0.87
<i>Operative Statistics</i>			
Procedure Type			
CABG	64/201 (31.84%)	76/248 (30.65%)	
AVR	16/201 (7.96%)	27/248 (10.89%)	
VAD or Transplant	16/201 (7.96%)	22/248 (8.87%)	
Aortic procedure	33/201 (16.42%)	30/248 (12.10%)	
Mitral valve	17/201 (8.46%)	21/248 (8.47%)	
Combined valve	46/201 (22.89%)	55/248 (22.18%)	
Other	9/201 (4.48%)	17/248 (6.85%)	0.71 ^c
CPB time, mins	141.56 ± 75.43	138.22 ± 72.03	0.64
Cross-clamp time, mins	76.53 ± 46.65	73.94 ± 50.30	0.58
IABP placement	37/201 (18.41%)	44/244 (18.03%)	0.92

^aContinuous data presented as mean ± SD and categorical data as number (%)^bp-values based on Student's *t*-test, chi-square or Fisher's exact test as appropriate^cp-value for all procedure types combined

Table 2

Post-operative Outcome Variables by Injury Classification

Variable ^a	S (n=202)	NFD (n=249)	p-value ^b
Radiographic findings	69/202 (34.16%)	6/249 (2.41%)	<0.01
In-hospital mortality	42/201 (20.90%)	41/248 (16.53%)	0.24
LOS, days	15 [9–32]	16.5 [10–27.5]	0.97
Neurologic consult	191/201 (95.02%)	127/248 (51.21%)	<0.01
Time to Head CT, days	2.59 ± 1.84	3.24 ± 2.06	<0.01
Disposition			
Home	55/198 (27.78%)	114/239 (47.70%)	<0.01
Rehab/Nursing home/Sub-acute facility	96/198 (48.48%)	84/239 (35.15%)	<0.01
Other	47/198 (23.74%)	41/239 (17.15%)	0.09

^aContinuous data presented as median [IQR] or mean ± SD, and categoric data as number (%)

^bp-values based on Student's *t*-test, Wilcoxon rank-sum test, chi-square or Fisher's exact test as appropriate

Table 3

Radiographic Findings by Injury Classification

Variable ^a	S (n=202)	NFD (n=249)	p-value ^b
Acute infarct	40/199 (20.10%)	1/239 (0.42%)	<0.001
Subacute infarct	17/199 (8.54%)	4/239 (1.67%)	0.001
Hemorrhage	5/200 (2.50%)	1/239 (0.42%)	0.097

^a Categorical data presented as number (%)

^b p-values based on Fisher's exact test

Table 4

Radiographic Findings by Injury Classification Stratified by Timing of CT scan

Variable ^a	S (n=202)			NFD (n=245)		
	< POD 4	POD 4	p-value ^b	< POD 4	POD 4	p-value ^b
Acute infarct	29/145 (20%)	11/54 (20%)	0.95	0/138 (0%)	1/98 (1%)	0.42
Subacute infarct	11/145 (8%)	6/54 (11%)	0.41	2/138 (1%)	2/98 (2%)	1.0
Hemorrhage	3/146 (2%)	2/54 (4%)	0.61	0/138 (0%)	1/98 (1%)	0.42

^a Categorical data presented as number (%)^b p-values based on Chi-square or Fisher's exact test as appropriate

Table 5

Multivariate Analysis to Predict New Findings on Early Head CT Scan

Variable	Odds Ratio	95% CI	<i>p</i> -value ^a
Focal Neurologic Exam	22.96	9.22–57.21	<0.01
Age	0.998	0.97–1.02	0.87
Cerebrovascular Disease	1.58	0.73–3.40	0.24
Seizure History	2.04	0.19–21.89	0.56
Current Tobacco Usage	1.76	0.74–4.20	0.20
Procedure			
CABG		1 (Reference)	
AVR	1.95	0.66–5.77	0.23
VAD or Transplant	3.04	0.86–10.68	0.08
Aortic Procedure	3.02	1.19–7.65	0.02
Mitral Valve	1.32	0.43–4.09	0.63
Combined Valve	0.66	0.26–1.69	0.39
Other	0.46	0.05–4.19	0.49
CPB time	1.001	0.997–1.01	0.62
IABP	1.80	0.82–3.99	0.15

^a *p*-values based on Multivariate Logistic Regression Analysis