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Prospective Study of Blunt Aortic Injury

Helical CT is Diagnostic and Antihypertensive Therapy Reduces Rupture

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Objective

There were two aims of this study. The first was to evaluate the application of helical computed tomography of the thorax (HCTT) for the diagnosis of blunt aortic injury (BAI). The second was to evaluate the efficacy of β-blockers with or without nitroprusside in preventing aortic rupture.

Summary Background Data

Aortography has been the standard for diagnosing BAI for the past 4 decades. Conventional chest CT has not proven to be of significant value. Helical CT scanning is faster and has higher resolution than conventional CT. Retrospective studies have suggested the efficacy of antihypertensives in preventing aortic rupture.

Methods

A prospective study comparing HCTT to aortography in the diagnosis of BAI was performed. A protocol of β-blockers with or without nitroprusside was also examined for efficacy in preventing rupture before aortic repair and in allowing delayed repair in patients with significant associated injuries.

Results

Over a period of 4 years, 494 patients were studied. BAI was diagnosed in 71 patients. Sensitivity was 100% for HCTT *versus* 92% for aortography. Specificity was 83% for HCTT *versus* 99% for aortography. Accuracy was 86% for HCTT *versus* 97% for aortography. Positive predictive value was 50% for HCTT *versus* 97% for aortography. Negative predictive value was 100% for HCTT *versus* 97% for aortography. No patient had spontaneous rupture in this study.

Conclusions

HCTT is sensitive for diagnosing intimal injuries and pseudoaneurysms. Patients without direct HCTT evidence of BAI require no further evaluation. Aortography can be reserved for indeterminate HCTT scans. Early diagnosis with HCTT and presumptive treatment with the antihypertensive regimen eliminated in-hospital aortic rupture.

Rupture with immediate death remains a major problem in the management of blunt aortic injury (BAI). Parmley et al.'s 1958 report[1] was the first to characterize this injury in detail, and the key conclusion derived from that analysis was that prompt diagnosis was required to avert exsanguination from aortic rupture. Physical examination and chest radiography were the mainstays for diagnosing BAI in that report. Although aortography was not used for diagnosis in the 38 patients who arrived at the hospital in that seminal study (only 2 of whom survived), an addendum to the article described 3 subsequent cases, and it was stated that "retrograde aortography was demonstrated to be the most effective roentgenographic means of delineating the extent of the lesions."[1] Over the intervening 4 decades, aortography has remained the accepted standard for definitive diagnosis.

In the past 10 years, there have been several reports evaluating chest computed tomography (CT) for the diagnosis of BAI.[2-19] Some investigators have been encouraged by their results, but others have been skeptical of any value of chest CT. All of those reports used conventional CT technology; those examinations took several minutes, and

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image resolution was variable because of motion artifacts and volume averaging. Those who found CT helpful used it as an advanced screening tool beyond chest radiography. Mediastinal hematoma detection was generally noted to be fairly good, but aortic pathology was poorly imaged. Therefore, some investigators concluded that patients with mediastinal hematomas should be referred for aortography but those without hematoma could be screened out for further workup. There has been some recent enthusiasm for the application of the newer helical (spiral) CT technology for diagnosing BAI. The scanning time is faster, and image resolution is improved over the previous generation of scanners.

Although early diagnosis prompting emergent thoracotomy and repair has been the most widely supported approach for minimizing the risk of death from aortic rupture, it has been suggested that decreasing aortic wall shear force with antihypertensive medications may further decrease the risk of spontaneous rupture. β-blockers and vasodilators have been used to reduce wall shearing forces by lowering ventricular ejection dynamics (Δ pressure/Δ time).

Although encouraging, the collected experience is retrospective and uncontrolled.[20–24] This approach has also been suggested as a way to delay repair in patients at high risk of operative mortality[25] specifically, patients with closed head injury, pulmonary injury, or significant underlying disease states who may have better outcomes if their confounding pathology could be ameliorated before thoracotomy.

This study was conducted to gather a large, prospective experience with BAI to evaluate the utility of helical scanning for screening and diagnosis, the efficacy of antihypertensive therapy in preventing aortic rupture before urgent repair, and the efficacy of antihypertensives in allowing successful delay of aortic repair in patients with significant associated pathology.

METHODS

This study was prospectively conducted over the 4-year period from November 1993 to October 1997. During that interval, all patients with significant blunt torso trauma were evaluated for injury with helical computed tomography of the thorax (HCTT) and of the abdomen. The scans were obtained to diagnose abdominal, pelvic, and thoracic injuries, in addition to the evaluation for BAI.

In the first year of the study, a comparative, nonrandomized evaluation of HCTT *versus* aortography was undertaken. Patients with scans demonstrating abnormalities of the mediastinum, specifically of the thoracic aorta, were evaluated with aortography after HCTT. After analysis of that initial year's experience,[26] only patients with HCTT findings suggesting BAI were referred for aortography; patients with mediastinal hematomas without direct evidence of aortic injury did not undergo conventional aortography in the subsequent 3 years of the study.

Antihypertensive therapy was initiated at the suspicion of aortic injury. This was occasionally prompted by a clearly abnormal mediastinum on admission chest x-ray but was usually triggered by abnormalities on HCTT. If patients were not hypotensive, they were begun on a treatment protocol of intravenous β-blockers (labetalol or esmolol). The systolic blood pressure was titrated to approximately 100 mmHg, the pulse to <100. Nitroprusside was added if a satisfactory blood pressure could not be achieved with β-blockade alone. Pulmonary artery catheters were placed in patients with proven injuries who required sustained therapy to maintain a mixed venous oxygen saturation of 65%. Patients were selected for urgent thoracotomy and repair if they were considered to be hemodynamically stable without immediately life-threatening associated injuries. Repair was undertaken by femoral-femoral partial cardiopulmonary bypass with pump oxygenator, atriofemoral bypass with centrifugal pump, or full cardiopulmonary bypass (ascending and arch injuries). Patients with significant closed head or pulmonary injuries or cardiac insufficiency were managed in the intensive care unit and did not have aortic repair until their underlying condition improved.

HCTT Technique and Interpretation

Until September 1997, a Hi-Speed Advantage helical scanner (GE Medical Systems, Milwaukee, WI) was used in conjunction with proprietary software for CT angiography reconstructions. During the final 2 months of the study, a Somatom Plus 4 helical scanner (Siemens AG Medical Systems, Erlanger, Germany) was used. The following protocol was followed. The patients' arms were raised over their head to avoid imaging artifacts. Nasogastric tubes were not removed. Patients received 150 cc of nonionic contrast (300 to 320 mg/cc of iodine) via their best peripheral (preferably left arm) or central venous access. Contrast was power-injected at a rate of 2 cc/sec with a scanning delay of approximately 20 seconds. Scan thickness was 7 mm from the thoracic inlet to the diaphragm with a 1:1 pitch. The helical study was reconstructed every 3.5 mm to provide approximately 50 axial images. Helical acquisition of images took approximately 30 seconds. Computer reconstruction took 11 to 13 minutes after the scan. CT aortography was performed with two-dimensional and three-dimensional reconstruction techniques, previously described in detail.[27] Those reconstructions initially took 45 minutes, but after experience with the initial 10 to 15 patients, this time was reduced to 15 minutes.

Relative to aortic pathology, scans were classified as demonstrating aortic injury, no aortic injury, or indeterminate for aortic injury. This classification was according to the presence or absence of pseudoaneurysm or intimal injury. The severity of intimal injury was determined by estimating the percentage of lumen compromise on the axial scan that best showed the intimal abnormality. Lumen compromise <10% was considered minor, 10% to 25% moderate, and >25% severe. The severity of pseudoaneurysm

Table 1. THE NUMBER OF HCTT AND AORTOGRAMS DONE PER YEAR OF STUDY, AND THE NUMBERS OF VARIOUS FINDINGS ON INITIAL HCTT INTERPRETATION

	Study Year				
	One (%)	Two (%)	Three (%)	Four (%)	Total (%)
HCTT	142	113	120	119	494
Aortogram*	132 (93)	54 (48)	39 (33)	39 (33)	264 (53)
HCTT finding†					
Hematoma‡	114 (80)	93 (82)	104 (87)	99 (83)	410 (83)
Aortic injury	21 (15)	15 (13)	22 (18)	18 (15)	76 (15)
Indeterminate§	18 (13)	20 (18)	10 (8)	17 (14)	65 (13)
Ductus diverticulum§	9 (6)	3 (3)	3 (3)	3 (3)	18 (4)

* Number in parentheses is % of HCTT group who had aortogram.
† Number in parentheses is % of HCTT group with that particular finding.
‡ None without evidence of aortic injury by HCTT had aortic injury on aortography.
§ None found to have aortic injury on aortography.
HCTT = helical computed tomography of the thorax.

was determined by estimating the percentage of increased lumen diameter compared with the distal scan that demonstrated a normal aorta. An increase <10% was considered a small pseudoaneurysm, 10% to 25% a medium pseudoaneurysm, and >25% a large pseudoaneurysm. The extent of injury was determined by the relation to the great vessels, particularly the left subclavian artery (isthmus injuries), and the number of contiguous scans (3 mm/image) on which the abnormality was detected.

Findings on an image were considered indeterminate for pseudoaneurysm if an unexplained local area of high attenuation (similar to the high-attenuating blood vessels) was found adjacent to the course of the aortic lumen. Findings were considered indeterminate for intimal flap if an unexplained area of low attenuation was noted that projected into the lumen on at least one axial scan.

Scans were interpreted at the time of acquisition by radiology residents and staff and by senior surgical residents, trauma fellows, and surgical staff. These initial evaluations always involved at least one radiologist and one surgeon. All scans were subsequently reviewed by board-certified radiologists with expertise in chest CT.

Aortography

Thoracic aortography was performed using standard retrograde femoral techniques. At least two digital arteriographic projections were obtained (usually left anterior oblique and lateral) to include the ascending aorta, the origins of the great vessels, and the distal descending thoracic aorta to the hiatus of the diaphragm. In addition to static images, unsubtracted and subtracted images were reviewed by cine or rapid video playback. A total of 100 to 150 cc of contrast was used for aortography. During the first year of study, angiographers had access to chest x-rays but were blinded to the results of HCTT. In subsequent years, HCTT findings were available to angiographers, and occasionally additional aortography views were obtained based on HCTT findings to define subtle injuries missed on initial oblique and lateral views.

Statistical Analysis

Routine demographics and injury patterns were analyzed. The results of HCTT and aortography were evaluated for diagnostic accuracy. The additional outcomes of aortic rupture and mortality were analyzed. Analysis of variance for continuous variables and chi square analysis for dichotomous variables were used in a statistical comparison of survivors of BAI with nonsurvivors; a level of $p < 0.05$ was considered significant.

Table 2. FINDINGS ON ADMISSION CHEST X-RAYS IN 76 PATIENTS WITH HCTT DIAGNOSIS OF BAI

Finding	Number	Percent
Wide mediastinum	51*	67
Indistinct aortic knob	16	21
Pleural effusion	5	7
Tracheobronchial compression	3	4
Apical pleural cap	3	4
Nasogastric tube deviation	2	3
Normal	20†	26

* Three were false positive HCTT examinations.
† Two were false positive HCTT examinations.
HCTT = helical computed tomography of the thorax; BAI = blunt aortic injury.

Table 3. ASSOCIATED INJURIES IN 76 PATIENTS WITH HCTT DIAGNOSIS OF BAI

Injury	Number	Percent
Closed head	30	39
Closed head with intracranial blood	17	22
Rib fractures	52	68
Lung contusion	32	42
Cardiac contusion	2	3
Diaphragm	5	7
Spleen	10	13
Liver	19	25
Small bowel	2	3
Pelvic fracture	26	34
Femur fracture	20	26
Tibia fracture	19	25
Facial fracture	19	25
Thoracic spine fracture	3	4
Lumbar spine fracture	9	12
None	2	3

HCTT = helical computed tomography of the thorax; BAI = blunt aortic injury.

RESULTS

During the 4-year study period, approximately 8000 HCTTs were performed to evaluate blunt torso injury. There were 494 patients with evidence of mediastinal hematoma, aortic injury, or both on HCTT, and these formed the study population. Seventy-one patients were proven to have BAI. Males made up 71% of the group, females 29%. The average age was 39 ± 17 (range, 13 to 84). Mechanisms of injury were motor vehicle crash (92%), pedestrian struck by a moving vehicle (4%), motorcycle accident (3%), and other (1%). Table 1 hows the number of HCTTs and aortograms performed per year of study and the initial HCTT interpretations. The incidence of BAI in motor vehicle crashes over the 4-year period was 1.2%. The number of HCTTs with abnormal mediastinal findings was similar in each of the years.

The study was designed for patients to have both HCTT and aortography in the first year to assess the safety of more selective use of aortography in subsequent years. Ninety-three percent of patients with abnormal HCTTs had aortograms performed in that first year; the 7% who did not have both studies were deemed to have trivial hematomas on HCTT. During that experience, no patient with hematoma on HCTT without evidence of aortic injury had an abnormal aortogram. Thus, in subsequent years, the threshold for performing aortography was elevated. In the second year of the study, the percentage having aortograms dropped to 48%, which included some patients with large mediastinal hematomas as well as those with definite evidence of aortic injury, those with indeterminate findings of aortic injury, and those with ductus diverticulum. In the last 2 years of the study, the 32% incidence of aortography represented patients with HCTT diagnoses of aortic injury, indeterminate findings of aortic injury, or ductus diverticulum. Over the 4 years, there were no recognized deaths in the hospital, or none known to occur after hospital discharge, from undiagnosed aortic rupture.

The HCTT diagnoses of mediastinal hematoma, aortic injury, ductus diverticulum, and indeterminate findings of aortic injury remained quite similar over the course of the study (see Table 1). The incidence of interpretation of aortic injury was nearly equal to that of indeterminate findings, totaling 15% for aortic injury and 13% for indeterminate scans. However, no patient with indeterminate findings was found to have a BAI by aortogram.

The 65 HCTT initial interpretations of indeterminate findings for aortic injury were reviewed by board-certified radiologists with expertise in CT, and the following determinations were made: possible small intimal defects or small pseudoaneurysms (10), motion artifact (16), volume averaging/beam hardening artifact (7), atherosclerotic vascular disease (17), pneumomediastinum or pneumothorax

Table 4. HELICAL CT CLASSIFICATION OF THE MORPHOLOGY OF BLUNT AORTIC INJURY IN THE 76 PATIENTS INTERPRETED AS HAVING POSITIVE SCANS*

	Intimal Flap			
Pseudoaneurysm	Minor	Moderate	Severe	Total
None	6 (0)†	2 (0)	1 (1)	9 (1)
Small	9 (5)‡	3 (1)	3 (3)	15 (9)
Medium	5 (3)‡	4 (4)	1 (1)	10 (8)
Large	10 (9)	14 (12)	18 (15)	42 (36)
Total	30 (17)	23 (17)	32 (20)	76 (54)

* Numbers in parentheses are those patients within that group which underwent thoracotomy for repair during their hospitalization.
† Three false positive HCTT for aortic injury.
‡ One ductus diverticulum at thoracotomy.
CT = computed tomography.

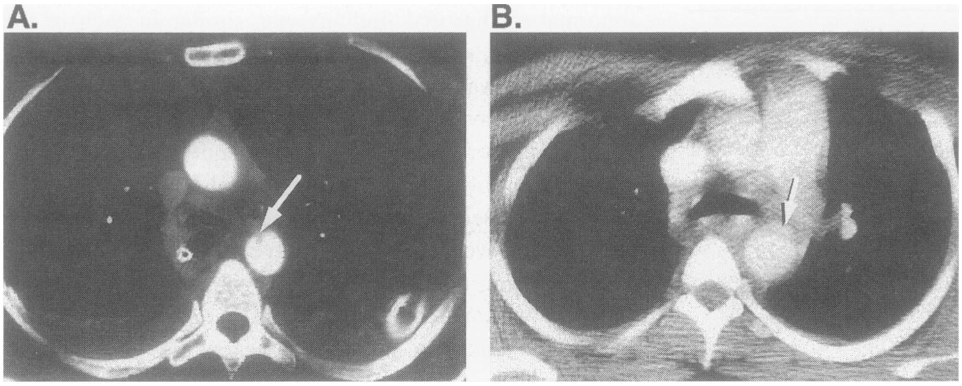

Figure 1. Helical scan demonstrating (A) a minor intimal injury (arrow) in the proximal descending aorta above the level of the pulmonary artery and (B) a small pseudoaneurysm (arrow) at the carina, at the level of the left pulmonary artery.

(6), prominent vascularity (5) and ductus diverticulum (4). All indeterminate findings, with the exception of atherosclerotic vascular disease and ductus diverticulum, were present on only one or two axial images. Motion artifacts can be due to arm, respiratory, or cardiovascular motion, especially of the ascending aorta. Volume averaging/beam hardening artifacts can be related to scatter from calcified nodes, nasogastric tubes, or endotracheal tubes. Prominent vascularity can result from a mediastinal vessel, including the innominate vein, superior intercostal vein (crossing to the left of the arch), or bronchial artery.

The remaining part of this section specifically addresses the 76 patients with HCTT interpretation of aortic injury.

HCTT Diagnosis of Aortic Injury

There were 76 patients who had initial HCTT interpretation of BAI. Admission chest x-ray findings were interpreted by a radiologist blinded to HCTT and angiography results. Those findings are listed in Table 2. Associated injuries are listed in Table 3. Closed head injury was present in 39%, and 57% of those had evidence of intracranial blood. Two thirds of the patients had significant associated chest pathology. One third had pelvic fractures, and 51% had lower extremity fractures. Twenty-two percent required laparotomy (67% of those before aortic repair). Two patients required craniotomy (excluding placement of an intracranial pressure monitor). The anatomic locations of injury were aortic isthmus, 65 (86%), aortic arch, 5 (7%), descending aorta near the diaphragm, 5 (7%), and ascending aorta, 1 (1%). Of the arch injuries, two involved the innominate artery, two the left carotid artery, and one the proximal left subclavian artery.

CT Morphology of Injury

The classification of BAI according to the CT interpretation of degree of intimal injury and the presence and size of pseudoaneurysm is shown in Table 4. Intimal defects were minor in 39%, moderate in 30%, and severe in 30%. Pseudoaneurysms were absent in 12%, small in 20%, medium in 13%, and large in 55%. Figures 1, 2, and 3 show representative axial scans of that morphologic classification. Although 53 of 67 patients (79%) with pseudoaneurysms underwent thoracotomy for repair, only 1 of 9 (11%) without a pseudoaneurysm underwent operation.

Aortography Group

Aortography was performed after HCTT in 63 patients (83%). No patient underwent aortography either before or in lieu of HCTT. Of the 63 patients having aortography, 47 had subsequent thoracotomy (41 urgent thoracotomy and 6 planned delayed thoracotomy). All but two, both in the delayed group, were proven intraoperatively to have aortic injuries and underwent repair. Those two had false-positive

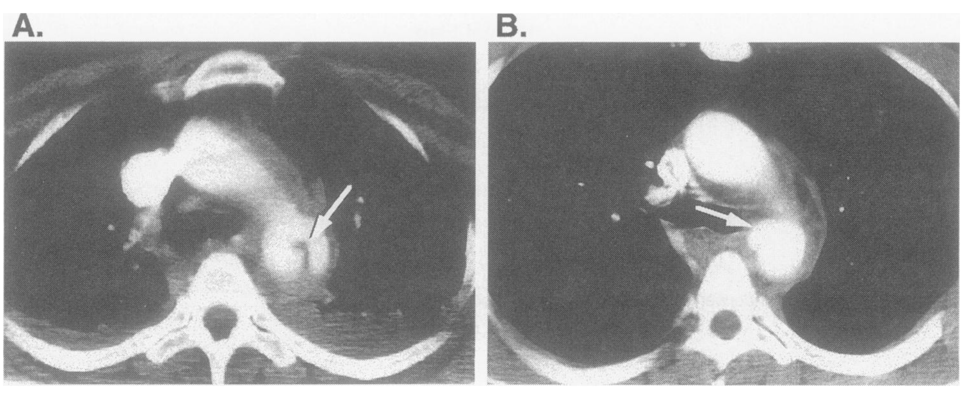

Figure 2. Helical scan demonstrating (A) a moderate intimal injury (arrow) at the carina, proximal to the pulmonary artery but distal to the left subclavian artery, and (B) a medium pseudoaneurysm (arrow) at the carina, distal to the left subclavian artery.

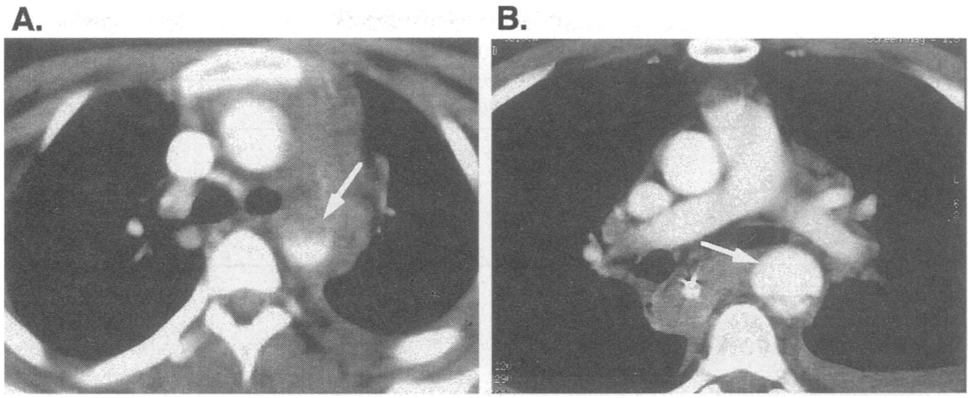

Figure 3. Helical scan demonstrating (A) a severe intimal injury (arrow) at the carina, distal to the left subclavian artery, and (B) a large pseudoaneurysm (arrow) at the level of the pulmonary arterial bifurcation, with associated nasogastric tube deviation secondary to a periaortic hematoma.

HCTTs and were interpreted as having minor intimal defects, with one also having a small pseudoaneurysm; the aortograms were also interpreted as aortic injury. At the time of thoracotomy, they were found to represent ductus diverticula.

Sixteen patients having aortography were managed nonoperatively. There were five deaths in this nonoperative group, and all had aortography findings consistent with the HCTT interpretations. Of the 11 nonoperative patients who survived, 5 had small intimal defects that were missed on initial aortography, but 4 were subsequently noted on aortography after adjusting views based on CT findings; the fifth intimal defect could not be seen after additional projections but was confirmed by intravascular ultrasound. In the absence of HCTT, those aortograms would have been false-negative studies. Four of the five resolved on subsequent HCTT; the fifth remained unchanged at 1 week follow-up, and the patient did not return for further scheduled follow-up. Four of the remaining six nonoperative survivors had angiographic and HCTT findings that correlated; the other two patients had small intimal defects without pseudoaneurysms that were not seen on aortography. They were not observed on follow-up HCTT evaluation at 48 hours and are being considered false-positive HCTTs.

HCTT Without Aortography Group

Thirteen patients (17%) had only HCTT. Six of these patients were nonoperatively managed due to associated injury. Five died of their associated injuries; one of these patients had a small intimal defect that was subsequently interpreted to be a false positive. One surviving patient was managed nonoperatively due to the small size of her intimal defect. The remaining patients underwent thoracotomy (five urgent thoracotomy and two planned delayed thoracotomy), and all had injuries consistent with HCTT interpretations (five large pseudoaneurysms and two moderate pseudoaneurysms).

Overall Results of HCTT and Aortography

Five of the 76 HCTTs (7%) were considered false-positive examinations (2 ductus diverticula at surgery and 3 small intimal defects without pseudoaneurysms not confirmed by aortography or follow-up CT). During the study period, there were no sudden deaths recognized in patients who had negative HCTT examinations. Thus, there appears to have been no false-negative examination. The five small defects missed on routine angiographic views were interpreted as false-negative arteriographic examinations; all of those resolved on follow-up scan without surgical repair. The two aforementioned ductus diverticula seen on HCTT were also misinterpreted as injuries on aortography.

The entire study population (494 patients) with evidence of mediastinal abnormality by HCTT was evaluated with respect to sensitivity, specificity, accuracy, and positive and negative predictive values for aortic injury (Table 5). The absence of false-negative HCTT studies and the presence of five false-negative aortograms produced sensitivity and negative predictive values that were higher for HCTT than aortography. However, the nearly equal number of indeterminate and positive HCTT studies produced specificities and positive predictive values that were inferior for that diagnostic technique.

Table 5. RESULTS OF HCTT AND AORTOGRAPHY FOR THE DIAGNOSIS OF BLUNT AORTIC INJURY IN 494 STUDY PATIENTS

	HCTT	Aortography
True positive	71	56
True negative	353	201
False positive	70	2
Indeterminate	65	
"Aortic injury"	5	
False negative	0	5
Sensivity	100%	92%
Specificity	83%	99%
Accuracy	86%	97%
Positive predictive value	50%	97%
Negative predictive value	100%	97%

HCTT = helical computed tomography of the thorax.

Table 6. COMPARISON OF SURVIVORS TO NONSURVIVORS IN 71 PATIENTS WITH AORTIC INJURY (MEAN ± S.D.)

Parameter	Lived (n = 55)	Died (n = 16)	p value
Age	36 ± 15	47 ± 20	0.02
Injury severity score	31 ± 11	39 ± 13	0.01
Glasgow coma score	14 ± 3	8 ± 5	0.0001
Revised trauma score	11 ± 1	8 ± 3	0.0001

Antihypertensive Therapy

There were 58 patients (76%) who received a β-blocker (n = 36) or a combination of β-blocker and nitroprusside (n = 21); 1 received only nitroprusside. The remaining 18 patients were not candidates because of instability or normotension. Of those receiving antihypertensives, 62% had initiation within 2 hours of hospital admission, 17% within 2 to 5 hours, and 21% beyond 5 hours. There were no complications noted to be associated with these medications.

Operative Management

There were 52 patients with BAI (73%) managed by thoracotomy and aortic repair (excluding 2 with ductus diverticula). Urgent repair was conducted immediately after diagnostic studies in 46 (88%) of those patients. There were seven deaths (15%) in those having urgent repair. Six patients had planned delay in performance of operative repair because of closed head injury (three) or hemodynamic instability combined with pulmonary insufficiency (three). All patients who underwent delayed thoracotomies survived.

Nonoperative Management

Nineteen patients with BAI (27%) were managed nonoperatively (excluding three false-positive HCTTs). The reasons for choosing nonoperative management were minimal injuries (6 patients) and significant associated injury or hemodynamic instability (13 patients). Five of the six patients with minimal injuries had resolution, and one remained stable. Of the 13 compromised patients, 5 had closed head injuries, 4 had pulmonary injuries, 3 were hemodynamically unstable, and 1 had a massive thermal injury. Nine of those 13 died in the hospital from their associated injuries; 4 patients were followed as outpatients. Three of those four injuries remained unchanged on follow-up HCTT (one with moderate intimal injury and two with medium pseudoaneurysms), and the fourth injury resolved.

Mortality

There were 16 deaths among the 71 patients with BAI (23%). A comparison of those who died to those who survived with BAI is shown in Table 6. Of the 52 patients having thoracotomy and repair, 7 died (13%). The seven deaths were caused by postoperative multiple organ dysfunction in three patients with significant associated pulmonary injury, two patients died in the operating room when their false aneurysms ruptured during dissection, one died in the operating room with massive myocardial infarction and arrest, and one died postoperatively from an anoxic brain injury after a prolonged episode of intraoperative ventricular fibrillation.

There were 9 deaths among the 19 patients (47%) with BAI who were managed nonoperatively. Five of the nine died from closed head injury, two from multiple organ dysfunction, one from cardiac failure, and one from massive thermal injury. No patient died from ruptured BAI. The time from injury to death in the nonoperative group was 1 day in 2 patients, 3 days in 2, and 8 days in 2; individual patients died at 9, 12, and 15 days.

DISCUSSION

Most clinical reports of BAI have been retrospective studies conducted over several years. The incidence of spontaneous rupture in patients who arrive at the hospital hemodynamically stable is generally not reported. A recent prospective multicenter study from the American Association for the Surgery of Trauma found that 207 of 274 patients with BAI were stable at the time of hospital admission.[28] Twenty-four (12%) of those stable patients sustained spontaneous aortic rupture before thoracotomy, and all of those patients died. The present report is the second-largest prospective study of proven aortic injury and the largest from a single institution. There were no instances of rupture before thoracotomy or death from associated injury in the 71 patients with BAI in this study, which represents a significant improvement ($p < 0.01$) over the multicenter study. The authors believe that early HCTT diagnosis and institution of antihypertensives accounted for this improvement.

Aortography has remained the diagnostic benchmark for BAI since Parmley's study. The sensitivity has been considered to be excellent by surgeons and radiologists. A report of 314 aortograms with 47 cases of BAI demonstrated a 100% sensitivity of aortography.[29] However, a substantial experience with transesophageal echocardiography, in which 93 examinations were performed and 11 cases of BAI identified, reported that angiography had only a 78% sensitivity.[30] The sensitivity of aortography in the present study was 92%. In analyzing these HCTT data, and those generated by studies with transesophageal echocardiography, it becomes apparent that most false-negative aortography results are due to small intimal defects without pseudoaneurysms. Nearly all of those cases in this study were nonoperatively managed without adverse consequences. So although the true sensitivity of aortography may not be as high as generally accepted, most of these lesions are probably not clinically significant. Before those lesions are completely ignored, however, long-term studies are necessary to define more carefully and completely the natural history of isolated small intimal flaps: some could become the nidus for later pseudoaneurysm formation or dissection.

The specificity of aortography has always been demonstrated to approach 100%. The few false-positive examinations represent ductus diverticula, atherosclerotic changes, or double densities from surrounding vasculature; indeed, in the current study there were two false-positive angiographic studies due to ductus diverticula. The ductus diverticulum typically occurs just beyond the left subclavian artery (remnant of the fetal ductus arteriosum) on the anteromedial aspect of the aorta. In a report of 314 aortograms, 51 (26%) demonstrated a focal bulge or convexity at the ligamentum arteriosum that the authors believed were due to ductus diverticula.[31] The classic diverticulum has smooth margins and gently sloping symmetric shoulders.[32] Even with this knowledge in mind, most institutions will have an occasional negative thoracotomy due to the difficulty in distinguishing injury from embryologic remnant; the risks are high if a true pseudoaneurysm is missed.

With those excellent sensitivities and specificities in mind, one might question the need for other technologies for diagnosing BAI. The main disadvantages of aortography are its relative invasiveness and the need for mobilizing interventional teams of radiologists and technologists to perform the examination. The authors' experience and that of most centers is that the morbidity of retrograde aortography is quite low, but it does require both an arterial catheterization and advancement of the intraluminal catheter into the area of injury. Mobilizing the interventional radiology team is not a problem during normal working hours but can be time-consuming in off hours.

The appeal of using CT for BAI is twofold. First, it is easier and faster to obtain in most institutions because CT technologists are more readily available than angiography technologists; most established trauma centers have 24-hour in-house CT technologists. With moderate experience, most radiologists and surgeons can become proficient in interpreting these examinations. Second, CT has become routine for the evaluation of head and abdominal injuries. Nonoperative management of abdominal solid viscera injuries (spleen and liver) is undertaken in approximately 50% and 80% of those injuries, respectively; abdominal CT has become indispensable for that approach. Thus, because acquisition is efficient and a high number of patients will be in the CT suite for imaging of other possible injuries, the potential advantages for evaluation of BAI are obvious. However, "potential" indicates theoretical rather than proven advantages.

The authors identified 18 articles dealing with CT diagnosis of BAI.[2–19] Several of the studies are updates of prior institutional experiences. Some experiences have generated enthusiasm for CT by the investigators, but others have found it to be of little value. Investigators from Baltimore,[13,14,17] Chicago,[10] and Milwaukee[15] have suggested that CT is helpful; those from Houston,[6] Louisville,[12] and St. Louis[4] have found no benefit. The main rationale from those supporting chest CT has been that it can decrease the number of patients requiring aortography. The main concern for those opposed to its use is that injuries are missed with conventional chest CT. The primary support for the utility of CT has been screening for mediastinal hematoma. Patients with findings suggestive for aortic injury on chest radiography could be screened by CT. If no mediastinal hematoma were present, supporters of CT argue that BAI is safely ruled out, and patients with hematoma or other mediastinal pathology should have angiography. However, opponents have questioned the safety of that management scheme. Miller et al.[12] reported a sensitivity of only 55% among 11 major thoracic injuries. Durham et al.[4] noted a sensitivity of 88% with CT (one of eight cases of BAI was missed) and concluded that CT could not reliably exclude injury. The total experience with proven aortic injury in the 18 studies of conventional CT was 117 cases.

The results from this study must be analyzed in a separate light from the past studies that used CT for BAI because helical technology is quite different from conventional CT. The major practical differences are in the duration of examination and image resolution. Thoracic image acquisition occurs in 20 to 30 seconds, compared to 15 to 20 minutes with conventional studies, and half as much contrast is needed. The data are continuously acquired as the patient travels through the gantry. Respiratory artifacts are minimized, and the ability to reconstruct overlapping images at small intervals provides image resolution superior to that of previous CT technology.

To obtain optimal images, a well-established, consistent protocol for HCTT must be in place. The technologists must have a standard approach for rapid injection of contrast with a fixed delay after injection. There must be efforts to limit arm and respiratory motion. In the absence of such defined protocols and supervision, HCTT will be neither consistent nor reliable.

Although conventional CT definition has for practical purposes been limited to determining the presence or absence of mediastinal hematoma, HCTT now allows evaluation of the wall of the aorta. This study demonstrated several major advances over conventional chest CT. In the

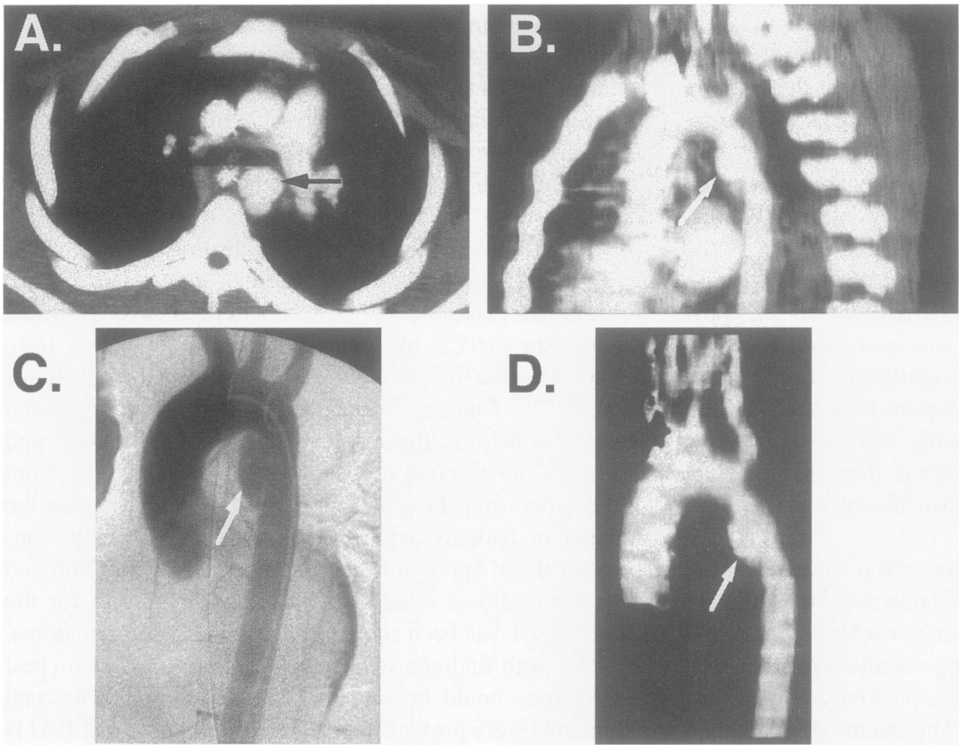

Figure 4. A large pseudoaneurysm of the thoracic aorta beginning in the area of the isthmus. (A) Axial image of CT scan demonstrating large pseudoaneurysm (arrow). (B) Two-dimensional reconstruction of helical scan demonstrating large pseudoaneurysm. (C) Retrograde aortogram demonstrating large pseudoaneurysm. (D) Three-dimensional helical CT demonstrating large pseudoaneurysm.

first year of the study, it was shown that in evaluation of 114 HCTT-proven mediastinal hematomas, further evaluation by aortography demonstrated no cases of BAI unless there was direct HCTT evidence of injury to the aorta. In the third and fourth years of the study, the number of aortograms was reduced 200% (90 to 30) without a missed injury. Thus, if used only for screening, HCTT would provide a significant advance.

The main problem with HCTT in this study was its low specificity. There were essentially the same number of scans that were positive for aortic injury as there were indeterminate studies. All the patients with indeterminate scans had aortograms, however, and none were found to have BAI. Most of these were limited to one or two images and essentially represent noise. However, despite increasing comfort with the interpretation of aortic injuries on HCTT, the authors have continued to refer patients with indeterminate studies for aortography at a constant rate over time.

The authors found HCTT to be quite sensitive for BAI, and they have a high level of confidence because this experience contained a large number of cases of BAI rather than simply a large number of scans. The sensitivity appears greater than that of aortography. Intimal injuries are more accurately (five missed on aortography) and more clearly visualized with HCTT. The experience over time suggested that most pseudoaneurysms were better illustrated on axial images than on aortography. Although only five recent cases were operated on without aortography, the comfort level of cardiothoracic surgeons at the authors' institution has increased to a large degree. It is probable that most pseudoaneurysms will not require aortographic evaluation in the future. However, corroborating experiences from other institutions will be necessary. The extent of aortic injury is occasionally inadequately determined by aortography. It has been reported that in 12.5% of injuries, aortograms failed to secure the diagnosis of multiple tears at the level of the arch.[33] HCTT may be found to identify more accurately the minority of injuries that are more extensive and complex and to allow for a more thoroughly planned operative approach relative to proximal control and the need for bypass.

The two-dimensional and three-dimensional CT angiography reconstructions provide images similar to those of conventional aortography (Fig. 4), so the extent of injury is illustrated in a format to which clinicians are accustomed. However, the data used for reconstruction are obtained from the axial images, and in fact some resolution can be diminished with reconstruction. As experience with viewing the axial images increases, the reliance on reconstructions becomes less important.

The use of antihypertensives in the management of BAI was first described by researchers from the Massachusetts General Hospital.[20] They based their approach on the observation that antihypertensives were successful in the management of dissecting aortic aneurysms by reducing shearing forces. In the initial report, a wide variety of antihypertensives were used in 19 of 44 patients with BAI managed during the 1970s. A more recent study from that institution reported that 34 of 51 patients (67%) received β-blockers or antihypertensive drugs from 1977 to 1990.[21] Seven of those patients were intentionally delayed for repair for 4 days to 4 months, and none ruptured while awaiting repair. A similar report from Toronto reported planned delayed repair in 44 of 59 injuries (75%).[22] Antihypertensives were used to maintain a mean arterial pressure of 80 mmHg. Two of the 44 died from aortic rupture (at 24 hours and 3 days). Another study from the Massachusetts General Hospital was the first to report the use of antihypertensives at initial suspicion of BAI to minimize the occurrence of rupture before repair.[24]

The use of antihypertensives was initiated in Memphis by Pate in the 1970s. Of 112 patients with BAI managed more than 30 years ending in 1993, 40 received antihypertensives.[23] Ten patients from that series had planned delay of surgery due to associated injuries, with the delay being from 3 days to 6 months. That institutional experience led to the prospective evaluation of antihypertensives in this report. Approximately 75% of the 71 patients with BAI received β-blockers with or without nitroprusside. The authors believe that the absence of in-hospital ruptures in both the delayed operation and nonoperative management cohorts confirms the results reported in the previously mentioned retrospective reports. There are two important considerations. First, when initiated at the suspicion of BAI, the risk of rupture before urgent repair can be minimized. Second, repair in patients who have serious associated brain and pulmonary injuries or cardiac instability can be delayed to provide time for stabilization. The authors suspect that better survival results with judicious delay in these selected patients. Six of the 52 patients (12%) in this study who had operative repair were delayed because of associated injuries, and all of those survived. It is likely that 10% to 20% of patients will have better outcomes with a planned approach of delayed repair. The authors chose to initiate therapy with β-blockers to maintain a systolic blood pressure around 100 mmHg and a pulse <100; in elderly patients, higher systolic pressures (110 to 120 mmHg) are targeted, and the use of pulmonary artery catheters for mixed venous saturation monitoring is routine. Before this study, one patient with a history of hypertension had his systolic pressure maintained at 100 mmHg. He died from multiple organ failure, believed to be directly related to hypoperfusion; pulmonary artery monitoring was not initially used. Because vasodilators can produce tachycardia, increasing shearing force, they are used only in conjunction with β-blockade when β-blockade is unsatisfactory in controlling blood pressure.

CONCLUSIONS

Patients with HCTT evidence of mediastinal hematoma and no direct evidence of aortic injury require no further evaluation. HCTT is sensitive in defining injuries to the thoracic aorta, specifically intimal injuries and pseudoaneurysms. Minor intimal injuries can probably be observed and followed, although caution should be used until further data are generated. Pseudoaneurysms on HCTT are well defined and those in the isthmus can generally be repaired without aortography. There are a nearly equal number of findings indeterminate for injury as for definite evidence of aortic injury. Although indeterminate findings were not associated with aortic injury, those patients should have aortography pending further technologic advances. Strict technical protocols for performing HCTT must be consistently used to obtain high-quality scans. Initiation of β-blockade with or without vasodilators at the suspicion for BAI minimizes the incidence of rupture before aortic repair and permits safe delay of repair in patients with significant associated injuries.

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Discussion

DR. J. DAVID RICHARDSON (Louisville, Kentucky): Drs. Nunn, Wells, Copeland, Members, and Guests. It is indeed a pleasure to discuss what I think will be a landmark paper.

Before this paper and the recent one from the AAST, I think the only paper that really sequentially looked at a large number of patients with CT followed by angiography was one that Dr. Frank Miller and I completed at the University of Louisville using conventional CT scanning. And in that methodology, we really found that conventional scanning was wanting.

I think the authors have shown with helical scanning, that that's an entirely different entity and that most likely this will replace angiography in many centers as the initial screening tool.

I do have a couple of questions about your methodology on the use of the helical CT. First, how does it work with branch injuries? Where do you see it being used in the evaluation of those patients? Do they need angiography, and how does that go?

The second question refers to the interaction of your radiologists. We are radiology deficient — particularly in the middle of the night — particularly with people who are experts on the CT scans, and I'm curious how much of this is a phenomena of having very interested CT radiologists. And, was your interpretation in that 100% sensitivity-dependent on having radiologists present, or was that more or less amateurs such as first-year residents and surgeons?

Third, we have been impressed that the things we see on angiography often under-call what we see at operation, and I wondered if you see that with the CT reconstruction?

Finally, a word of caution about the antihypertensive therapy. I think that's a very dangerous thing in the way it's being used around the country, where people are basically trying to convert this into an elective operation. I think that's occurring in many centers. I think we need to be careful with that. What are your comments about this?

Thank you. [Applause]

DR. LORING W. RUE, III (Birmingham, Alabama): Thank you, Dr. Nunn, Dr. Copeland, Members, and Guests. Two major questions have been addressed by Dr. Fabian and colleagues — first, the role of rapid high resolution helical CT in the diagnosis of blunt aortic injury — and second, the role of pharmacologic agents to reduce the risk of spontaneous rupture in patients with injury. Both are appealing to those of us in trauma surgery who routinely care for those patients.

Although aortography has been the diagnostic gold standard for years, it's invasive, expensive, time-and-resource intensive, and still subject to limitations of false positive studies. In many trauma centers in this country, abdominal CT is used routinely to evaluate patients, and confirmation of CT to evaluate the abnormal mediastinum would be heartily welcomed.

Now the authors' protocol in using helical CT has yielded at least similar sensitivity as aortogram and has enabled the reduction of the use of this more invasive technique to 33% among high-risk patients with commendable results.

Equally of interest is the pharmacologic regimen used to reduce aortic wall stress. The authors report no such patients with spontaneous rupture to be contrasted with the 12% instance in the recently reported AAST study.

Further, the ability to delay repair in these severely injured patients until they are globally improved is a definite plus.

My first question: patients with severe head injury, nearly 40% in your series, are one group of patients for whom you would advocate pharmacologic intervention and delayed repair. At many trauma centers a strategy is used of maintaining cerebral perfusion pressure, often though the use of vaso-active drugs is followed. Could you help us balance the double-edged sword of minimizing systemic blood pressure for the aorta while maximizing perfusion to the brain?

And in a related vein: half the deaths in the nonoperative group were from severe head injuries. Were these patients directed to nonoperative management from the outset, or did they migrate to that group due to death before planned delayed operation?

The manuscript indicates 20% required laparotomy with two-thirds undergoing abdominal surgery before aortic repair. Could you comment on the one-third who did not follow the conventional dogma of abdominal operation before thoracic? I ask this because some form of circulatory assist, perhaps using heparin, was typically employed in your repair.

Finally, could you comment on the learning curve for surgeons' interpretation of helical CT, as your manuscript suggests? Much like the use of abdominal CT, the surgeons' evaluation of the images is of paramount importance. Did 3-D reconstruction con-