The Atriocaval Shunt

Facts and Fiction

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During the past 11 years, 31 patients with major juxtahepatic venous injuries were treated with the atriocaval shunt. Penetrating injuries occurred in 27 patients (87%), and injuries from blunt trauma occurred in four patients. Shock was present on admission in 28 patients (90%). Resuscitative thoracotomy for cardiovascular collapse was required in 13 patients (42%). Juxtahepatic venous injuries included the vena cava in 23 patients (74%) and the hepatic veins alone in five patients (16%). One patient had an isolated portal venous injury, and two patients died before their vascular injuries could be delineated. Technical problems related to the shunt occurred in seven patients. Most were related to delays in placement or problems encountered in obtaining vascular control of the suprarenal vena cava. Major hepatic resection was performed in 11 patients (35%). Twenty-five patients died of their injuries. No patient survived who required resuscitative thoracotomy, hepatic resection, or when technical problems with the shunt occurred. Six patients (19%) survived and were discharged from the hospital. All sustained gunshot wounds to the retrohepatic vena cava. Four of the six survivors had serious postoperative complications, but none were related to the shunt. Major juxtahepatic venous injuries are highly lethal. The atriocaval shunt will permit the salvage of some patients where other methods are not possible. Avoidance of delay and alternative shunting techniques that eliminate difficult maneuvers may improve survival in the future.

THERE ARE FEW TECHNICAL MANEUVERS in surgery as dramatic or desperate as the use of the atriocaval shunt in the management of patients with injuries to the major juxtahepatic veins. Invariably, the patient is on the brink of exsanguination and the surgeon is unlikely to attain hemostasis using conventional techniques. These injuries are fortunately rare, but when they are encountered, the surgeon must have a plan for controlling the hemorrhage and repairing the vascular injuries. The usual approach has been with the use of the atriocaval shunt.[1-5] Some surgeons, however, have expressed concern about difficulties or high mortality rates associated with the use of the shunt.[6-9] The atriocaval shunt has been used at this institution to treat many injuries involving the suprahepatic vena cava, retrohepatic vena cava, and hepatic veins which have been encountered. The purpose of this review is to analyze the procedures performed during the past 11 years emphasizing the indications, results, techniques, and pitfalls with the atriocaval shunt in the management of these lethal injuries.

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Clinical Material and Methods

From January 1, 1977 through November 20, 1987, 31 injured patients were treated at Ben Taub General Hospital in Houston, Texas, with the atriocaval shunt. All patients in this series are listed and numbered individually for reference. Table 1 lists all nonsurvivors who required resuscitative thoracotomy, Table 2 lists all nonsurvivors who did not require resuscitative thoracotomy, and Table 3 lists all survivors.

All patients were males with an average age of 30 years (range: 14–64 years). Penetrating injuries occurred in 27 patients (87%), and included 21 with gunshot wounds and six with stab wounds. Blunt trauma was responsible for the injuries of four patients, including two motorcycle accidents, one automobile accident, and one fall.

Prehospital care was administered by the paramedics and emergency medical technicians of the Houston Fire Department. During the study period, average prehospital time was reduced from 40 minutes in 1977 to 25 minutes in 1987. On arrival to the emergency center,

TABLE 1. *Patients Requiring Resuscitative Thoracotomy**

No.	Age (Years)	Mechanism	Time†	INJ‡	Associated Injuries§	Severe Liver Injury	Hepatic Resection	Lowest pH	Lowest Temp	Length of Operation	RBC‖ Units Given
1	41	GSW	15	SHVC	Diaphragm, lung	No	No	NA	30.5	0.75	8
2	23	GSW	30	RHVC	Diaphragm, aorta	No	No	7.09	NA	3.75	49
3	27	GSW	30	RHVC PV	—	Yes	Lobe	6.98	28.6	1.5	15
4	NA	GSW	30	¶	Kidney	Yes	Lobe	6.90	28.5	0.75	13
5	NA	BT	30	RHVC HV	Brain, hilum of lung	No	No	7.23	NA	0.75	7
6	32	GSW	30	RHVC	—	Yes	Lobe	7.12	31.5	1.75	36
7	32	GSW	15	HV	—	Yes	No	NA	NA	0.25	0
8	23	SW	15	RHVC	Stomach	No	No	NA	NA	0.5	1
9	NA	GSW	20	RHVC HV	Diaphragm, lung, colon, small bowel, spleen	Yes	Segment	6.96	31.1	1.0	12
10	NA	GSW	30	HV	Diaphragm, lung	Yes	Lobe	7.10	30.1	1.5	30
11	NA	GSW	20	HV	Diaphragm, lung	Yes	No	7.00	30.5	1.0	10
12	14	BT	10	RHVC HV	Brain	Yes	No	6.87	32.0	1.25	48
13	20	SW	60	SHVC	Diaphragm, lung	No	No	NA	37.6	0.75	10

* All had aortic clamps placed and all exsanguinated in the operating room.
† Time from admission to operating room.
‡ Juxtahepatic vascular injuries.
§ All had liver injuries.
‖ Red blood cell.
¶ Undetermined.

GSW = gunshot wound.
BT = blunt trauma.
SW = stab wound.
SHVC = Suprahepatic vena cava.
RHVC = Retrohepatic vena cava.
PV = Portal vein.
HV = Hepatic vein.

patient resuscitation and subsequent treatment was performed by surgical residents under the supervision of the senior surgical faculty.

Shock, defined as blood pressure less than 80 mmHg, was present in 28 patients (90%) on admission. Patients who had cardiopulmonary arrest within a few minutes of arrival to the emergency center, or while in the emergency center, underwent immediate left anterolateral thoracotomy with cross-clamping of the descending thoracic aorta and were taken expeditiously to the operating

TABLE 2. *Nonsurvivors not Requiring Resuscitative Thoracotomy*

No.	Age (Years)	Mechanism	Time*	INJ†	Associated Injuries‡	Severe Liver Injury	Hepatic Resection	Aortic Clamp	Lowest pH	Lowest Temp	Length of Operation	RBC§ Units Given
14	20	BT	180	RHVC HV	—	Yes	Total	Yes	NA	NA	1.75	12
15	NA	SW	NA	HV	Small bowel, colon	No	No	Yes	NA	NA	NA	NA
16	27	SW	225	RHVC	Diaphragm, lung	No	Lobe	Yes	7.06	28.5	3.0	45
17	41	SW	180	RHVC	Diaphragm	No	No	Yes	NA	NA	NA	30
18	21	BT	20	RHVC HV	—	Yes	Lobe	Yes	6.95	30.5	2.0	35
19	NA	SW	20	RHVC HV	Small bowel, lung	No	Lobe	Yes	NA	30.0	1.75	24
20	45	GSW	10	HV	Renal artery, renal vein, diaphragm, lung	Yes	Lobe	Yes	7.21	34.0	1.5	18
21	26	GSW	30	RHVC	—	No	No	Yes	7.26	32.0	1.0	35
22	59	GSW	‖	PV	Gall bladder	No	Lobe±	No	7.19	34.0	3.75	10
23	24	GSW	45	RHVC	Diaphragm, kidney, renal vein	Yes	No	No	7.20	29.5	2.5	66
24	33	GSW	10	¶	—	Yes	No	Yes	NA	NA	0.5	6
25	64	GSW	‖	SH	—	No	No	Yes	6.93	34.0	1.5	15

* Time from admission to operating room.
† Juxtahepatic vascular injuries.
‡ All had liver injuries.
§ Red blood cell.
‖ Shunt placed at second operation for rebleeding.

¶ Undetermined.
GSW = Gunshot wound.
SW = stab wound.
BT = blunt trauma.
± Lobectomy performed at third operation for hepatic necrosis.

TABLE 3. *Survivors*

No.	Age (Years)	Mech-anism	Shock	Time*	INJ†	Associated Injuries‡	Severe Liver Injury	Aortic Clamp	Lowest pH	Lowest Temp	Length of Operation	RBC§ Units Given	Length of Stay
26	30	GSW	No	540	RHVC	Diaphragm	No	Yes	7.38	35.5	4.0	9	11
27	22	GSW	No	210	RHVC HV	Diaphragm, lung	No	No	7.15	29.0	7.0	40	36
28	28	GSW	Yes	10	RHVC	Skull fracture, extremity	No	No	7.29	33.0	5.5	18	14
29	21	GSW	Yes‖	15	RHVC	Stomach extremity	No	No	NA	NA	NA	34	63
30	23	GSW	Yes	150	RHVC	Spinal cord, extremity, diaphragm, lung	No	Yes	7.18	32.5	4.5	35	103
31	26	GSW	No	15	RHVC HV	Esophagus, stomach, spleen, diaphragm	No	No	7.15	33.1	3.5	43	198

* Time from admission to operating room.
† Juxtahepatic vascular injuries.
‡ All had liver injuries.
§ Red blood cells.
‖ BP 0 on admission.
GSW = gunshot wound.
NA = not available.

room.[10] Eleven patients (35%) underwent resuscitative thoracotomy in the emergency center. In addition, two patients had cardiovascular collapse in the operating room before the induction of anesthesia and required resuscitative thoracotomy. Overall, 13 of 31 patients (42%) required resuscitative thoracotomy.

The length of time from admission to the time the patient arrived in the operating room was determined for 28 patients. There were 21 patients (68%) operated on within 30 minutes of arrival in the emergency center, and eight patients operated on between 45 and 540 minutes after admission. Two patients had rebleeding after repair of injuries without the atriocaval shunt and had shunts placed to control the hemorrhage during reoperation. Both patients had missed injuries, and their times from admission to operation were not determined. For one patient, this time could not be determined with precision.

The diagnosis of injuries requiring an atriocaval shunt was made at the time of operation in all cases. Often, injuries involving the juxtahepatic vasculature were suspected on the basis of the location of missiles in and around the lower thoracic and upper lumbar spines on chest x-rays. At the time of abdominal exploration, profuse venous hemorrhage from behind the right lobe of the liver, into the lesser sac, or posterior to the porta hepatis suggested injury to the retrohepatic vena cava. Hemorrhage near the diaphragm suggested injury to either the suprahepatic vena cava, retrohepatic vena cava, or hepatic veins. Patients with severe parenchymal liver injuries, in whom a Pringle manuever failed to control hemorrhage, were suspected of having injuries to the retrohepatic vena cava or hepatic veins. Unusual presentations occurred in four patients: three had hemorrhage into the right hemithorax and one had a pericardial tamponade.

The incisions used were dependent on the patient's initial condition. Nine patients requiring resuscitative thoracotomy had bilateral anterolateral thoracotomies before midline abdominal incisions. Of the four remaining patients treated with resuscitative thoracotomy, two had left anterolateral thoractomies extended into left thoracoabdominal incisions and two had median sternotomies connected to midline laparotomies. Three patients underwent initial right anterolateral thoracotomies. When the hemorrhage was noted to come through a defect in the diaphragm, midline incisions were performed. On recognition of the nature of the injury, two patients had conversions to bilateral anterolateral thoracotomies and one had an extension into a right thoracoabdominal incision. The remaining 13

TABLE 4. *Juxtahepatic Vascular Injuries in 31 Patients*

Injury	No. of Patients
RHVC only	11
RHVC and HV	8
RHVC and PV	1
SHVC only	3
HV only	5
PV only	1
Undetermined	2
Total	31

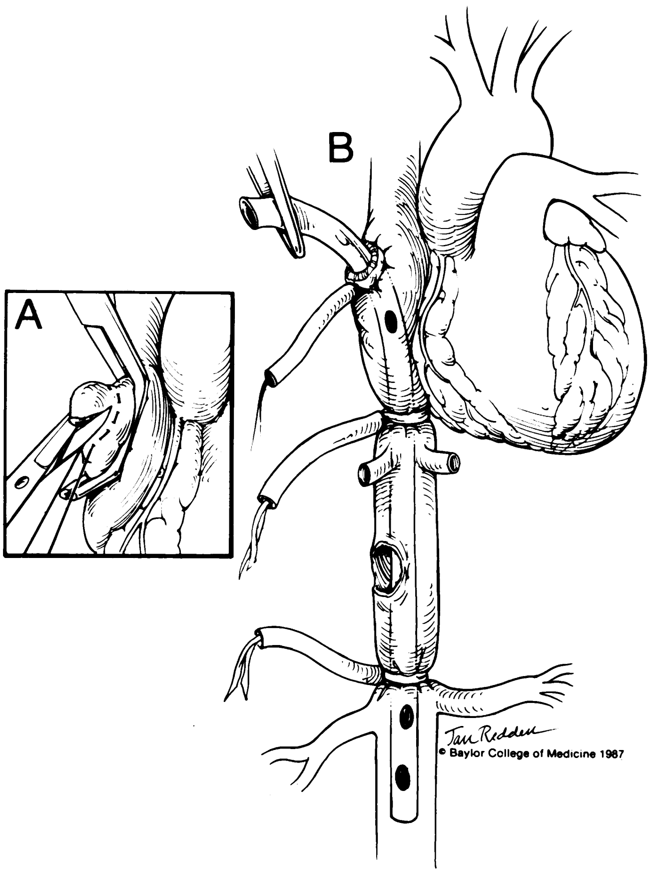
RHVC = Retrohepatic vena cava.
HV = Hepatic vein.
PV = Portal vein.
SHVC = Suprahepatic vena cava.

TABLE 5. *Associated Injuries in 31 Patients*

Injury	No. of Patients
Liver	31
Diaphragm	13
Lung	10
Extremity	5
Stomach	3
Small bowel	3
Colon, spleen, renal vein, brain	2 each
Aorta, renal artery, esophagus, spinal cord	1 each

patients had midline abdominal incisions followed by extension with a median sternotomy.

Injuries for which the shunt was placed are listed in Table 4. Twenty-three patients (74%) had injuries to the inferior vena cava, whereas the hepatic veins were involved in 13 patients (42%). One patient, no. 22, had an intrahepatic portal vein injury that was not controlled with the initial Pringle maneuver as evidenced by persistent hemorrhage from beneath the porta hepatis. Two patients with devastating injuries exsanguinated as the



FIGS. 1A and B. *A.* Properly positioned atriocaval shunt fashioned from a chest tube. *B.* Atrial purse string suture and incision in atrial appendage.

shunt was being placed and did not have the extent of their juxtahepatic vascular injuries delineated.

Associated injuries are listed in Table 5. All patients in the series had hepatic injuries. In 13 patients (42%), the injury to the hepatic parenchyma was judged to be severe, *i.e.,* life-threatening in its own right. One patient had a severe pulmonary hilar injury requiring pneumonectomy. Another patient had an aortic injury at the level of the diaphragm severe enough to require prosthetic graft replacement. Two patients had severe intracranial injuries.

Aortic clamping was used to maintain perfusion to the coronary and cerebral circulation in 25 patients (81%). All 13 patients with resuscitative thoracotomy had the thoracic aorta clamped. Ten of the 12 nonsurvivors (83%) without resuscitative thoracotomy, and two of the six survivors (33%) had the aorta clamped at the diaphragm.

The device most often used for vascular isolation was a 36 French chest tube. The shunt was usually inserted through the right atrial appendage and secured at the intrapericardial vena cava and suprarenal vena cava with Rumel tourniquets (umbilical tape snares) (Fig. 1). In seven patients, the size of the shunt was not stated, and in one patient, a 28 French chest tube was used. An additional hole, approximately the size of the internal diameter of the chest tube, was cut 20 c from the closest of the drainage holes. In three patients the shunt was placed through a venotomy in the infrarenal vena cava and secured in the same fashion as those inserted through the atrium. In the most recent patient, difficulties encountered in surrounding the suprarenal vena cava resulted in the use of a 9-mm internal diameter plastic endotracheal tube with omission of the lower tourniquet (Fig. 2).

The shunt was successfully placed in 27 of 31 patients (87%). Four patients were exsanguinated as a result of their injuries while the shunt was being secured. Despite the successful placement of the shunt in 27 patients, only 15 patients (48%) lived long enough to have their injuries repaired.

Eleven patients had hepatic resections performed. There were nine anatomic lobectomies (one for exposure of a retrohepatic vena caval injury only) and one left lateral segmentectomy. In patient no. 14, the entire liver was avulsed from the vena cava and hepatic pedicle. After placement of the atriocaval shunt, the liver was lifted from the abdomen for bench repair of vascular injuries; however, the patient died before reimplantation could be performed. In the patient with the isolated portal vein injury (Table 2), the lobectomy was performed at a reoperation for hepatic necrosis and not during the previous procedure for hemorrhage when the shunt was used.

Results

Twenty-five patients (81%) died of their injuries. Of the 25 nonsurvivors, 21 (84%) exsanguinated in the operating room. Four patients who ultimately died left the operating room alive. Two had persistent hemorrhage after repair of their vascular injuries. Patient no. 16 continued to bleed while in the intensive care unit and died of shock and exsanguination. Patient no. 23 initially had successful control of hemorrhage but developed recurrent bleeding a few hours after the original operation. This patient was taken back to the operating room at which time the bleeding was noted to originate from severe bilobar hepatic injuries. He subsequently died in the operating room. Patient no. 25 died of refractory shock 12 hours after surgery despite successful repairs. This patient was 64 years old and had injuries to both the suprahepatic vena cava and the posterior aspect of the intrapericardial vena cava. Patient no. 22 died of multisystem failure and sepsis on the sixth postoperative day.

Unlike previous series,[11] the number of associated injuries, *per se,* did not adversely influence mortality rate. The average number of associated injuries for survivors in this study was 3.3, and the average number of associated injuries for nonsurvivors was 2.5. In contradistinction to the number of associated injuries, the severity of individual associated injuries did affect outcome. All patients with severe hepatic parenchymal injuries and those treated with hepatic resection died. In one of these cases, the patient did not have a severe hepatic injury, but the resection was performed to expose a stab wound in the retrohepatic vena cava. Two patients had severe intracranial injuries that were not likely to be compatible with survival. The patient with the suprarenal aortic injury also did not survive.

The mechanism of injury did influence survival, although not as anticipated. All patients sustaining stab wounds and blunt trauma died. The reason for the deaths in those patients with stab wounds is most likely related to their condition on arrival to the hospital. In three patients, resuscitative thoracotomy was required. The remaining three were in shock on arrival, and two were treated by hepatic resection. It is possible that the added blood loss associated with hepatic resection may have affected the outcome of these latter cases.

The patient's condition on admission to the emergency center correlated with survival. All patient's requiring resuscitative thoracotomy died. Furthermore, all patients who died were in shock on admission. Twenty-three of the 25 patients (92%) who required aortic clamping died. Technical problems with the use of the shunt occurred in seven patients (Table 6). The majority were related to delays in decision making or

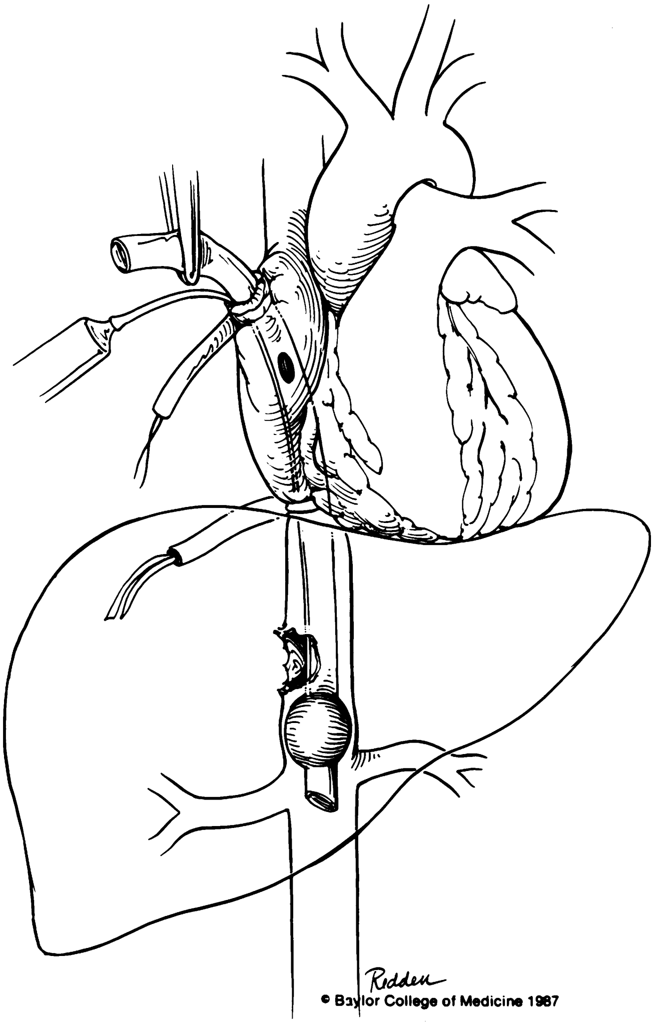


FIG. 2. Properly positioned atriocaval shunt fashioned from an endotrachael tube. Modified from Yellin AE. Arch Surg 1971; 102:566–573.

difficulties encountered in placement of the lower Rumel tourniquet. All seven of these patients died.

Six patients (19%) survived and were discharged from the hospital in satisfactory condition. The survivors had several characteristics in common. Each sustained a

TABLE 6. *Technical Difficulties with the Use of the Shunt in Seven Patients*

Problem	No. of Patients
Late placement	3
Lower tourniquet below renal veins	2
Injury to SRVC during tourniquet placement	2
Atrial drainage hole too close to chest tube fenestrations	1
Total	8*

* One patient with the tourniquet below the renal veins also had an iatrogenic injury to the SRVC.

SRVC = Suprarenal vena cava.

TABLE 7. *Postoperative Complications in Six Survivors*

Complication	No. of Patients
Abscess	
Intra-abdominal	3
Intrahepatic	1
Respiratory failure	3
Postoperative hemorrhage	2
Colocutaneous fistula	1
Small bowel obstruction	1

gunshot wound that injured the retrohepatic vena cava. No survivors required either resuscitative thoracotomy or hepatic resection. Of the three survivors who were in shock on admission, two were operated on within 15 minutes of their arrival. The three patients who were not in shock on admission survived.

Four of the six survivors had serious postoperative complications (Table 7). Three patients had intra-abdominal abscesses that required surgical drainage. In one patient, a colocutaneous fistula developed several weeks after drainage of an intra-abdominal abscess. This patient ultimately required treatment with proximal fecal diversion. One patient, no. 29, in whom an intrahepatic abscess developed, had an anterior defect in the retrohepatic vena cava tamponaded by approximating the hepatic parenchyma over the vascular injury. This was done after a successful suture repair of a posterior hole in the retrohepatic vena cava to avoid extensive hepatic dissection. The intrahepatic abscess was treated satisfactorily by percutaneous drainage. Three patients had respiratory failure and required prolonged endotracheal intubation and ventilation. Two patients had postoperative hemorrhage and required prompt reoperation. One patient had a partial small bowel obstruction that was treated conservatively. Only a single survivor had an uncomplicated recovery. The length of hospital stay for survivors ranged from 11 to 198 days with an alarming average of 71 days. No survivors had long-term sequelae as a result of the shunt.

Discussion

The first clinical use of the atriocaval shunt was by Shrock et al. in 1968.[1] From dissections of human cadavers, they made the observation that there were no venous tributaries other than the hepatic veins, right adrenal vein, and inferior phrenic veins that entered the inferior vena cava above the level of the renal veins. With this vital information, they devised a technique for maintaining venous return from the renal veins and the infrarenal vena cava to the right atrium, and producing a relatively bloodless field with the addition of a Pringle maneuver. They reported the use of this technique in a child who sustained blunt trauma to the liver with injury to the hepatic vein. Although the child did not survive, the report stimulated great interest in other major trauma centers. Bricker and co-workers, from this institution, reported the first patient to survive a repair of injuries to the hepatic vein and retrohepatic vena cava with the use of the atriocaval shunt in 1970.[12] One year later, Bricker et al. reported a second survivor whose extensive injury to the retrohepatic vena cava was also treated with the atriocaval shunt.[2] Other successful cases were reported by Brown et al.,[13] Yellin et al.,[3] Fullen et al.,[4] and Turpin et al.[5] These early successes added enthusiam for the use of the shunt; however, as Walt pointed out by in 1978, not everyone had been able to achieve the results reported by others.[6] Kudsk et al. reported a decade of experience with this technique at San Francisco General Hospital in 1982.[11] The shunt was placed in 18 injured patients, and there were four long-term survivors. One additional patient lived for 45 days. Despite this cautiously optimistic report, pessimism still remained. In 1986, Pachter et al. reported six consecutive patients with juxtahepatic venous injuries managed without the shunt, and five of the six survived.[9] He clearly demonstrated that the use of the atriocaval shunt was not a prerequisite for the successful management of all patients with these injuries.

Until recently, reports of patients surviving blunt trauma requiring the atriocaval shunt have been rare.[14] In 1987, Rovito published a remarkable series in which four of nine patients sustaining blunt trauma to the liver or juxtahepatic veins survived after treatment with the atriocaval shunt.[15] It was this report, to a large extent, that stimulated an interest in reviewing our own techniques and results.

Evaluation of the Current Series

There is no question that the mortality rate for injuries to the retrohepatic vena cava, suprahepatic vena cava, and hepatic veins, despite the aggressive use of the atriocaval shunt, remains exceptionally high. In view of Pachter's superb results in managing these injuries without the shunt, one is forced to ask the question as to whether the atriocaval shunt was responsible for the high mortality rate in the current series. Several observations make that conclusion unlikely. The fact that 42% of the patients in this series required resuscitative thoracotomy suggests that prehospital or preoperative blood loss and shock are major contributing factors. Survival rates for patients sustaining either blunt or penetrating abdominal trauma requiring resuscitative thoracotomy at this institution have usually been in the range of 3%.[10] If these patients are excluded from survival statistics, then six of 18 patients (33%) would have survived. Nevertheless, the mortality rate still remains high even when resuscitative thoracotomy is not required.

In the past, prehospital delay has been cited as being in part responsible for the significant mortality associated with injuries to the vena cava.[16] It was believed that these delays resulted in a large percentage of patients presenting to the hospital in shock. During the current study, the average prehospital delay dropped from 40 minutes to 25 minutes; at the same time the percentage of patients with vena caval injuries presenting in shock rose from 44% to 55%. This implies that more patients with severe hemorrhage and shock are reaching the hospital alive than before, an obvious characteristic of this series. This conclusion is further supported by operative observations from the three groups of patients in Tables 1, 2, and 3. The most critically ill, those requiring resuscitative thoracotomy, had on the average a lower pH, lower core temperatures, shorter operations, and less blood administered than did those who died but did not require resuscitative thoracotomy, or the survivors (Table 8). The same statement also can be made in comparing the latter two groups. This strongly suggests that nonsurvivors died so precipitously from pre-existing shock and hemorrhage that they did not live long enough to be given as much blood during the operation as did the survivors. A technique for gaining hemostasis would be most unlikely to produce this result.

Another factor that may bias these results is the fact that not all juxtahepatic vascular injuries treated at this institution have required the use of a shunt. During the study period, 15 additional patients were treated for injuries to the retrohepatic vena cava without an atriocaval shunt. Seven of the 15 patients survived. The overall survival rate for all patients sustaining retrohepatic vena caval injuries during the study period was 37%. Similar data are not available for patients with hepatic venous injuries because many of these patients are treated with more conservative techniques such as parenchymal suture.[17] The use of the shunt at this institution is reserved for patients with more severe injuries who cannot be treated using simpler techniques. Finally, there were no instances in this series where the application of the atriocaval shunt was believed to be directly or in part responsible for any deaths. Therefore, in the opinion of the authors, it was the extent of the patient's injuries, the rate of their hemorrhage, and the severity of their shock that resulted in a high mortality rate rather than the use of the atriocaval shunt.

TABLE 8. *Intraoperative Averages of Physiologic Parameters, Length of Operation, and Red Blood Cell Replacement in 31 Patients According to Preoperative Status and Outcome*

Preoperative Status and Outcome	Lowest pH	Lowest Temperature (C)	Length of Operation (hours)	RBC Units Given
Resuscitative thoracotomy and died (N = 13)	7.03	31.2	1.2	18.4
Without resuscitative thoracotomy and died (N = 12)	7.11	31.6	1.9	27
Survived (N = 6)	7.23	32.6	4.9	30

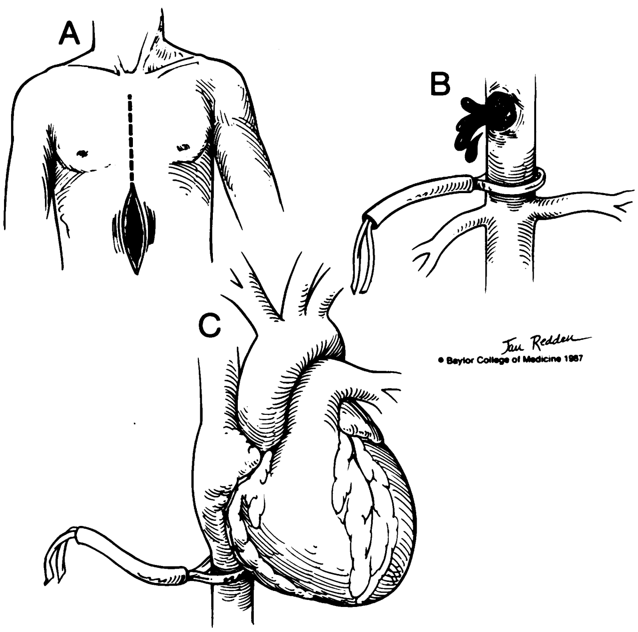
Decision Making

Recognizing the need to use the atriocaval shunt is not always easy. This can lead to disastrous delays as massive blood loss continues. The following operative findings imply that the shunt may be needed. With secure occlusion of the hepatic pedicle (Pringle manuever), profuse venous hemorrhage: (1) from the posterior aspect of the right lobe of the liver, usually through the caudate lobe; (2) into the lesser sac in the absence of a portal venous injury; (3) at the diaphragm anteriorly; (4) from deep within the hepatic parenchyma; or (5) from beneath the porta hepatis indicates that injury to the retrohepatic vena cava, suprahepatic vena cava, or the hepatic veins exists. Unusual presentations may also occur, including hemorrhage into the right hemithorax and pericardial tamponade.

The surgeon should attempt to palpate the region of the injury to determine the size of the defect. Excessive time should not be spent in this endeavor as significant blood loss may continue. If the lesion is palpable and small, it may be prudent to continue dissection to expose the defect and repair it without a shunt. If the defect is large (greater than 1.0–2.0 cm in diameter) the use of the atriocaval shunt is highly desirable unless clamp control can be easily achieved.

The importance of the Pringle maneuver cannot be overemphasized. Not only does this technique control blood loss, it also plays a pivotal role in decision making. Obviously, if the hemorrhage is controlled with a Pringle maneuver, a shunt is not necessary.

Even with the best intentions, pernicious delay may occur. This can result from difficultly in making a diagnosis or from inexperience and a reluctance to expand the scope of the operation. This is understandable since injuries requiring the atriocaval shunt are rare. During the study period, 268 vena caval injuries were treated, and only 9% required the use of the shunt. Furthermore, during the same period, 1782 hepatic injuries were treated, and the shunt was required in only 1.8% of these cases. The decision to place the shunt, with the subsequent finding that it may not have been necessary, should not be harshly criticized.



FIGS. 3A–C. *A.* Preferred thoracic incision for patients not requiring resuscitative thoracotomy. *B.* Proper position for lower tourniquet is around suprarenal vena cava in abdomen. *C.* Proper position for upper tourniquet is around intrapericardial inferior vena cava.

Maintaining hemostasis, before and during placement of the shunt, is crucial to survival. In most cases, particularly those associated with severe hepatic injuries, posterior compression of the liver with laparotomy pads in addition to a Pringle manuever will be satisfactory.

Adequate exposure is also mandatory. In patients who have not required emergency thoracotomy, extension of the midline abdominal incision into a complete median sternotomy affords ideal exposure. Radial division of the diaphragm to the adventitia of the inferior vena cava is often necessary. Great care must be taken when completing this incision because the tough diaphragmatic fascia at the vena caval hiatus yields suddenly to expose the delicate inferior vena cava beneath. For patients with initial anterolateral thoracotomy, division of the lower portion of the sternum will also facilitate exposure although closure may be awkward. Achieving adequate exposure and maintaining hemostasis are not always compatible. This is especially true when attempting to surround the suprarenal vena cava for placement of a Rumel tourniquet. Posterior compression of the liver increases the difficulty of exposing the suprarenal vena cava. This dilemma has led to minor injuries of the suprarenal vena cava that required repair in two patients in the current series.

Once the decision has been made to use the atriocaval shunt, many options regarding size, style, and route of insertion are available. The ideal size of the shunt has yet to be determined. It should be large enough to permit adequate venous flow under low pressure conditions and yet not so large as to be cumbersome. Thirty-six French chest tubes were often used in this series, although smaller ones have been successfully used. The advantages of chest tubes are their availability and flexibility. They can be inserted from either the atrial or vena caval approach and are available at all times and in all hospitals. The main disadvantage of the chest tube is the need to control the suprarenal vena cava with a Rumel tourniquet. Cannulation through the right atrial appendage is preferable since this is a readily accessible and easily controlled route with the aid of the curved Glover or Satinsky clamp (Fig. 1 inset). Cannulation of the infrarenal vena cava may be desirable for surgeons uncomfortable with atrial cannulation or in patients with an existing anterolateral thoracotomy because the external end of the shunt may rub annoyingly against the exposed upper costal margin.

Their are two styles of shunts: straight tubes and those with inflatable balloons at one end or both. Specially constructed balloon tipped shunts have been used experimentally[18,19] and clinically.[8,20,21] These catheters, depending on design, may be inserted from either only the atrial or infrarenal approach. Two balloon shunts were designed for insertion *via* the femoral vein.[20,21] This approach offers the advantage of not requiring an incision in a large venous structure, but suffers from the drawback of requiring an additional incision and dissection. A potential shortcoming of special devices that are seldomly used is that they may be difficult to find expeditiously in a large operating room suite. The use of an endotracheal tube, first described by Yellin et al.,[3] and used so successfully by Rovito,[15] is an attractive alternative. It is instantly available from the anesthesiologist and comes sterilely packaged.

Technique

The atriocaval shunt increases the complexity of the operation, and critical maneuvers must occur simultaneously. It is essential that a single individual direct these operations. A median sternotomy is the perferred thoracic incision (Fig. 3A). The control of hemorrhage with posterior compression of the liver and a Pringle maneuver is vital and must be performed as soon as the diagnosis is suspected. This will enable the anesthesiologist to correct existing volume deficits and metabolic derrangements before proceeding. It may be desirable at this point to remove previously applied aortic clamps or at least move them to below the level of the renal arteries.

The next step is to prepare the shunt. For chest tubes, a hole is cut 20 cm from the nearest drainage hole. If an endotracheal tube is used, the distance should be somewhat less, 17–18 cm from the nearest hole past the balloon. Care must be taken not to damage the inflation lumen of the balloon.

The end of the shunt that will be outside of the heart or vena cava is securely clamped. Although many have made the recommendation to use this end as an intravenous infusion site, adaptors may be difficult to find and the technique adds unnecessary complexity. Also, complications such as air embolism may occur. Control of the suprarenal vena cava with a Rumel tourniquet should be obtained (Fig. 3B). This treacherous step is omitted if a transatrial endotracheal tube is used. Next, a Rumel tourniquet is placed around the intrapericardial inferior vena cava (Fig. 3C). A partially occluding clamp is then applied on either the right atrial appendage or infrarenal vena cava and a purse string suture is placed. After making an incision encompassed by the purse string, the clamp is removed and the tube is inserted and directed toward the liver. When passing the tube from

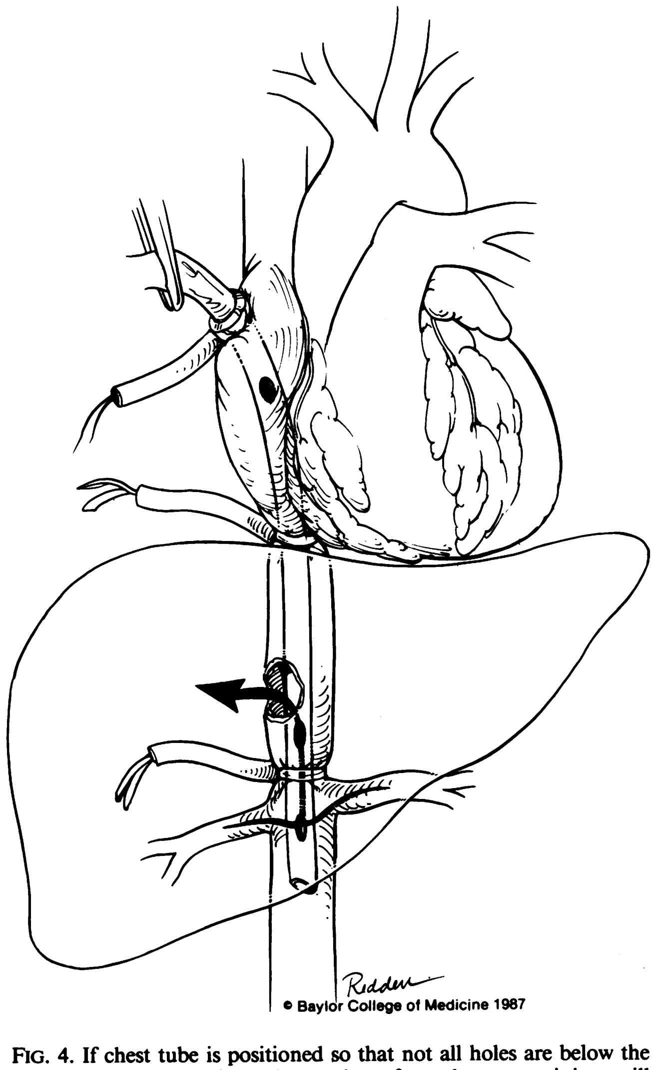


FIG. 4. If chest tube is positioned so that not all holes are below the lower tourniquet, persistent hemorrhage from the venous injury will occur.

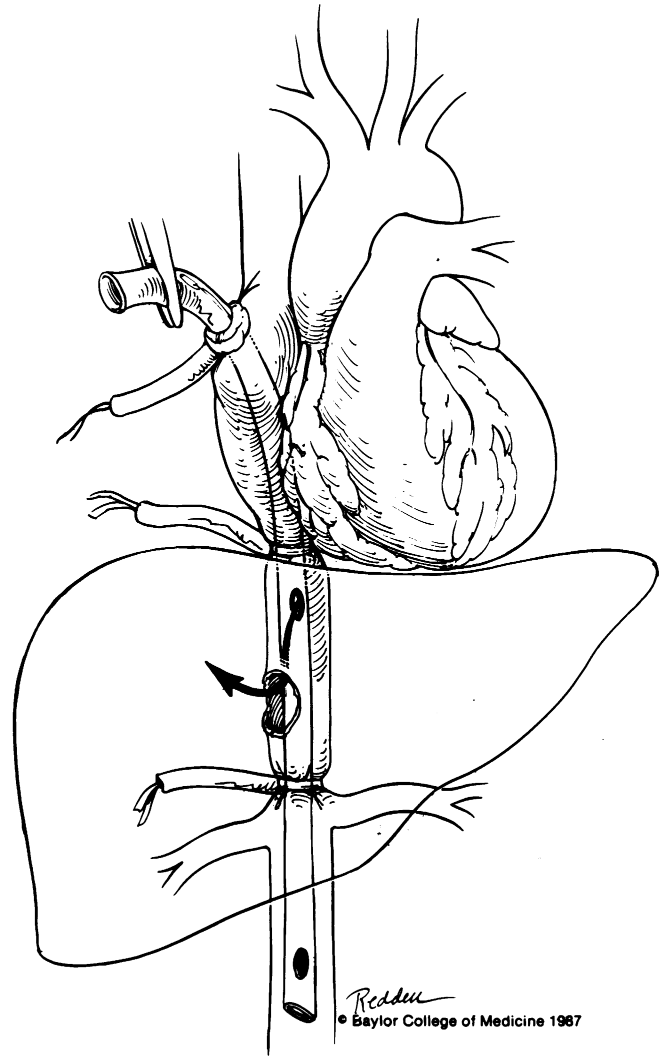


FIG. 5. If atrial drainage hole is positioned below the intrapericardial tourniquet, hemorrhage will continue and venous drainage from the lower body will not reach the heart.

above, care must be taken not to insert the shunt into the hepatic or renal veins. The surgeon controlling the operation should palpate the retrohepatic vena cava and guide the tube into the correct location. The purse string should then be secured with a Rumel tourniquet and all tourniquets secured or balloons inflated. The position of the shunt should be evaluated by palpation above and below both Rumel tourniquets to ensure that all the holes in the shunt are outside of the area of vascular isolation.

Due to the fact that the hepatic veins and isolated segment of the vena cava may drain residual blood, and that the right adrenal vein, inferior phrenic veins, and perhaps aberrant tributaries may be within the area of vascular isolation, some bleeding usually persists from the vascular injury. The amount of blood loss that occurs, although potentially significant, is trivial com-

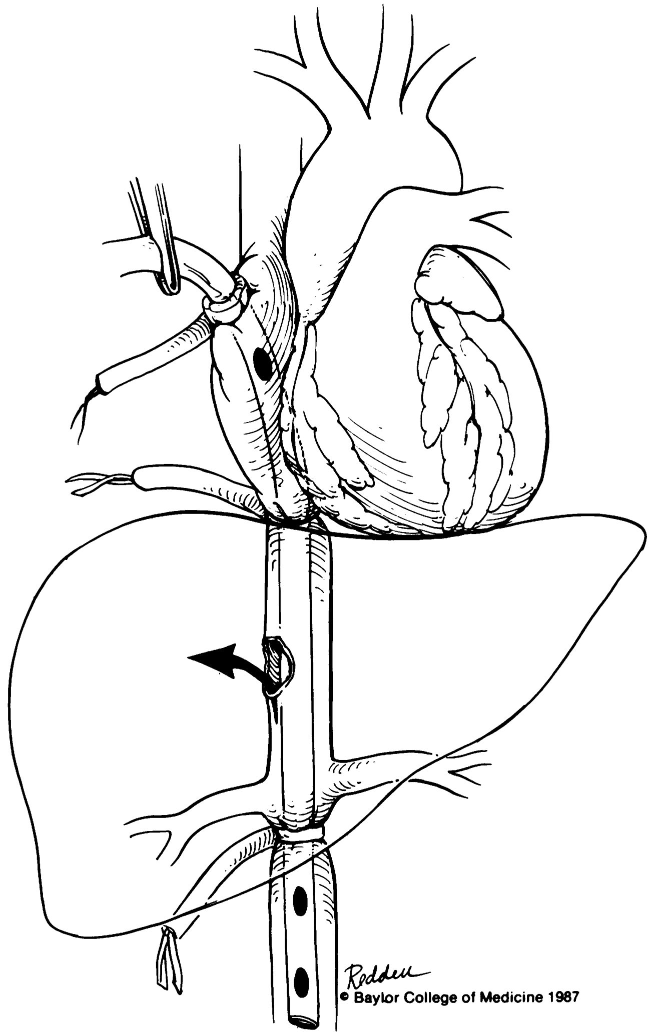


FIG. 6. If lower tourniquet is positioned below the renal veins, vascular isolation does not exist.

pared with the torrential hemorrhage seen from uncontrolled injuries of the large veins.

Technical Pitfalls

Despite the apparent simplicity of the technique, many problems with the use of the shunt can be encountered. If the initial hole in the chest tube is too close to the drainage holes, one of the fenestrations of the chest tube or the atrial drainage hole will be between the Rumel tourniquets, resulting in persistent massive hemorrhage from the site of the injury (Figs. 4 and 5). The only solution to this problem is to withdraw the shunt and correctly prepare another one. If the lower Rumel tourniquet is placed below the renal veins, vascular isolation will not exist (Fig. 6). Injury to the suprarenal vena cava may occur during attempts to surround it when exposure of the area is difficult. Excessive traction on the suprarenal vena cava may cause tearing of the lumbar veins at the origins of the renal veins. During insertion, the shunt may engage a laceration of the retrohepatic vena cava or suprahepatic vena cava causing additional damage (Fig. 7). If the vascular isolation achieved is perfect, a rare circumstance indeed, it is possible that a considerable amount of air may enter the hepatic veins and isolated vena caval segment. When this occurs, the lower Rumel tourniquet or Pringle maneuver should be released before completing the vascular suture line to ensure evacuation of the air.

The Pringle maneuver may be inadequately applied or become dislodged during required manipulations, and significant bleeding will persist. Another potential reason for failure of the Pringle maneuver is the existence of accessory or aberrant left hepatic arteries in about 25% of patients. These may not be included in the usual manuever. If inadequate hemostasis is encountered despite a well-positioned shunt and a secure Pringle maneuver, this possibility should be considered.

Alternatives and Controversies

The significant mortality rate associated with juxtahepatic vascular injuries treated with the atriocaval

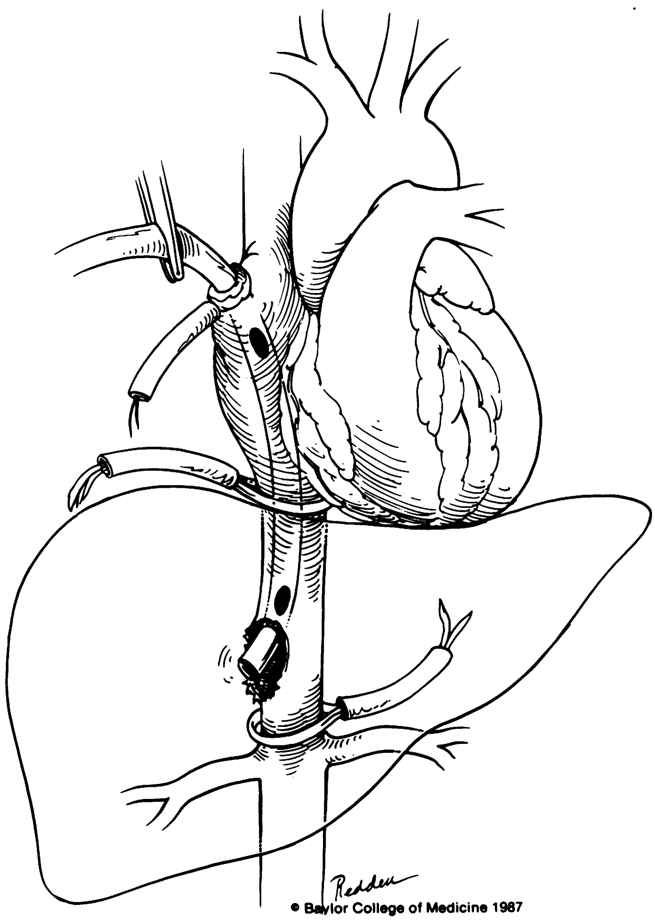


FIG. 7. During insertion, the surgeon should direct the shunt into the proper position and prevent the shunt from extending the venous injury.

shunt has provided a stimulus to find alternative techniques. One option is to use the hepatic parenchyma with intact capsule to tamponade the low pressure venous bleeding. This was successfully used in one patient in this series who would have otherwise required division of the liver to the level of the vena cava. This is not a unique recommendation, and others have used this method with success.[22] This technique is ideally suited for wounds where there is little destruction of the hepatic parenchyma. Great care must be taken in placing the sutures accurately and tying them gently. Another option is to achieve vascular isolation with occluding clamps on the vena cava above and below the liver after applying a Pringle maneuver and a clamp on the aorta. This concept was initially described by Heaney et al. and used by them in elective cases of hepatic resection.[23] The same approach has also been used for the treatment of trauma to the juxtahepatic vasculature in children.[24] In a similar fashion, occlusive balloon catheters have been used both experimentally,[25,26] and clinically.[2,26] Unfortunately, it has been our experience, as well as that of others,[3] that severely injured patients with significant hemorrhage and shock do not tolerate occlusive vascular isolation well.

Another alternative, appropriate for small injuries of the suprahepatic vena cava or retrohepatic vena cava that can be controlled with a finger, is to sew beneath the finger with a needle large enough to make the pass with one motion, and then apply gentle traction to the suture to aid in hemostasis. The remainder of the suture line is then completed while accepting the blood loss. Minor injuries of the retrohepatic vena cava exiting through or posterior to the caudate lobe may be controlled by dividing the left or right triangular ligament and rotating the lobe to the midline. Lobar rotation will aid in exposure of the injury as well as partially or completely occluding the retrohepatic vena cava. Patients may not tolerate this maneuver well, but if the injury is small, it may be the most expeditious way to control hemorrhage and repair the injury. In unusual circumstances, injuries may be exposed enough to grasp with a thumb forceps and secure with a partially occluding clamp.

A unique and bold approach is that of Pachter and co-workers.[9] After expressing disappointment of having only two of four survivors with the shunt, they developed a direct transhepatic approach. The essentials of this technique include: (1) the maintenance of posterior compression of the liver for hemostasis while correcting volume deficits; (2) the use of a Pringle maneuver for as long as is required to repair the injury; and (3) division of as much liver as is necessary, using finger fracture, to expose the injury and gain direct control. In a remarkable series of 10 patients with juxtahepatic vascular injuries, the first four were managed with a shunt and two survived. The next six consecutive patients were managed without a shunt and five of the six survived. The authors agree heartily with Pachter's emphasis on restoring lost volume, maintaining hemostasis, and an adequate duration of the Pringle manuever; however, this achievement may be a greater tribute to the skill of the surgeons involved than testimonial to the technique.

Conclusions

Extensive injuries to the juxtahepatic veins remain lethal injuries. The high mortality rate is due to profuse hemorrhage and severe shock produced by these injuries before the time vascular control can be attempted. The atriocaval shunt is not a perfect solution to the problem and difficulties with its use may occur; however, when the decision to use the shunt is made rapidly and hemostasis is maintained with vigilance, patients with otherwise irreparable injuries may survive. Hepatic resection should be assiduously avoided, and is not necessary only for exposure of the injury. Alternative shunting techniques, *e.g.*, use of a transatrial endotracheal tube, may help to overcome technical problems and improve survival in the future.

Acknowledgment

We thank Marian Torres for her invaluable technical assistance and clerical help.

References

1. Schrock T, Blaisdell FW, Mathewson C Jr. Management of blunt trauma to the liver and hepatic veins. Arch Surg 1968; 96:698–704.
2. Bricker DL, Morton JR, Okies JE, et al. Surgical management of injuries to the vena cava: changing patterns of injury and newer techniques of repair. J Trauma 1971; 11:725–735.
3. Yellin AE, Chaffee CB, Donovan AJ. Vascular isolation in treatment of juxtahepatic venous injuries. Arch Surg 1971; 102:566–573.
4. Fullen WD, McDonough JJ, Popp MJ, et al. Sternal splitting approach for major hepatic or retrohepatic vena cava injury. J Trauma 1974; 4:903–911.
5. Turpin I, State D, Schwartz A. Injuries to the inferior vena cava and their management. Am J Surg 1977; 134:25–32.
6. Walt AJ. The mythology of hepatic trauma—or Babel revisited. Am J Surg 1978; 135:12–18.
7. Coln D, Crighton J, Schorn L. Successful management of hepatic vein injury from blunt trauma in children. Am J Surg 1980; 140:858–864.
8. Millikan, JS, Moore EE, Cogbill TH, et al. Inferior vena cava injuries—a continuing challenge. J Trauma 1983; 23:207–212.
9. Pachter HL, Spencer FC, Hofstetter SR, et al. The management of juxtahepatic venous injuries without an atriocaval shunt. Surgery 1986; 99:569–575.
10. Feliciano DV, Bitondo CG, Cruse PA. Liberal use of emergency center thoracotomy. Am J Surg 1986; 152:654–659.
11. Kudsk KA, Sheldon GF, Lim RC Jr. Atrial-caval shunting (ACS) after trauma. J Trauma 1982; 22:81–85.
12. Bricker DL, Wukasch DC. Successful management of an injury to the suprarenal inferior vena cava. Surg Clin North Am 1970; 50:999–1002.
13. Brown RS, Boyd DR, Matsuda T, et al. Temporary internal vascu-

lar shunt for retrohepatic vena cava injury. J Trauma 1971; 11:736–737.
14. Misra B, Wagner R, Boneval H. Injuries of hepatic veins and retro-hepatic vena cava. Am Surg 1983; 49:55–60.
15. Rovito PF. Atrial caval shunting in blunt hepatic vascular injury. Ann Surg 1987; 205:318–321.
16. Graham JM, Mattox KL, Beall AC, et al. Traumatic injuries of the inferior vena cava. Arch Surg 1978; 113:413–418.
17. Feliciano DV, Mattox KL, Jordan GL Jr, et al. Management of 1000 consecutive cases of hepatic trauma (1979–1984). Ann Surg 1986; 204:438–444.
18. Davis EA, Falk G, Yarnoz M, et al. An improved technique for the repair of the intrahepatic inferior vena cava and hepatic veins. J Trauma 1971; 11:738–741.
19. Aaron WS, Mays ET. Isolation of the retrohepatic vena cava by balloon catheter: an experimental assessment. Rev Surg 1975; 32:222–225.
20. Pilcher DB, Harman PK, Moore EE. Retrohepatic vena cava balloon shunt introduced via the sapheno-femoral junction. J Trauma 1977; 17:837–841.
21. Testas P, Benichou J, Benhamou M, et al. Vascular exclusion in surgery of the liver. Am J Surg 1977; 133:692–696.
22. Lucas CE, Ledgerwood AM. Prospective evaluation of hemostatic techniques for liver injuries. J Trauma 1976; 16:442–451.
23. Heaney JP, Stanton WK, Halbert DS, et al. An improved technic for vascular isolation of the liver: experimental study and case reports. Ann Surg 1966; 163:237–241.
24. Williams CD, Brenowitz JB. Sequential aortic and inferior vena caval clamping for control of suprarenal vena caval injuries: case report. J Trauma 1977; 17:164–167.
25. Doty DB, Berman IR. Control of hepatic venous bleeding by transvenous balloon catheter. Surg Gynecol Obstet 1970; 131:449–452.
26. Copping JW Jr, Schaub GA, Hoshal VL. Control of massive hemorrhage from vena cava and liver injuries. Arch Surg 1972; 104:104–106.

Discussion

DR. J. DAVID RICHARDSON (Louisville, Kentucky): This paper represents another excellent contribution and presentation from the Houston group on the management of a difficult topic in trauma, and I certainly would recommend the manuscript by Drs. Feliciano, Burch, and Mattox to your attention. They have done an excellent job of outlining some of the real pitfalls that these patients present.

At issue is whether or not the atriocaval shunt is really necessary for juxtahepatic caval injuries or whether these injuries really could be repaired with similar results without the use of a shunt. With the use of an atriocaval shunt, we have treated 24 patients with retrohepatic or juxtahepatic caval injuries at the University of Louisville. Unlike the Houston group, 16 of our cases were due to blunt trauma, and only six were due to penetrating trauma.

Seven of these 24 patients were able to leave the operating suite alive. Three subsequently died of sepsis, coagulopathy or various other problems, and there were four long-term survivors. These results are not altogether dissimilar from those presented from Houston. Two of the four survivors had blunt trauma unlike the Houston group's series and two of our patients had penetrating injuries. In two of these cases in which I personally participated, the caval injuries were fairly small, and quite honestly, they could possibly have been repaired by direct suture technique or conventional techniques without the use of a shunt. However, I agree with the point the authors made, that is, once these injuries are recognized, you need to commit fairly promptly to either using the shunt or not, and we did choose that technique with success.

We have come to believe that prompt placement of the shunt, as has been indicated by the authors, before the development of coagulopathy is the key to its successful use, and, therefore, we try to move forward with prompt shunt placement as soon as we recognize the severely bleeding venous injury in the retrohepatic position that does not promptly respond to a Pringle maneuver.

Technically, we have found the endotracheal tube to be useful in that it obviates the need to encircle the inferior vena cava with its attendant technical complications. I think it is maybe a little bit tougher to cut that more proximal hole, but at least you don't have to deal with the distal cava in quite the same manner.

In our residency program, we have made liberal use of the fresh dissection lab which we developed in conjunction with the department of anatomy, and I think, quite simply, if you are going to try to teach residents to do that, you really can't do it with a bleeding, dying patient, and that the forethought of having gone through this a couple of times in the dissection lab is certainly one that I would commend to those of you who are involved in resident education or who might be an occasional operator in this area yourself.

In summary, we believe that the atriocaval shunt does have a place in these most difficult injuries, but that the very nature of the injuries themselves will always make the survival ability of these patients lower than would ordinarily be satisfactory. We will continue to use the shunt in these selected patients, however.

DR. LEON PACHTER (New York, New York): I would like to congratulate the Baylor group on their superb contribution to the management of juxta hepatic venous injuries employing an atriocaval shunt.

A recent review of 66 cases treated at major trauma centers in which atriocaval shunts were used revealed that only 15 patients survived for a mortality of 77%.

The authors were able to salvage 6 of 18 patients for a mortality of 67%, when patients with resuscitative thoracotomy were excluded. The lethal nature of this injury is quite evident.

Why has the mortality with atriocaval shunting been so high? First and foremost is the devastating nature of the injury itself, but in most series, failure of the atriocaval shunt was probably related to three key factors. First, delay in early recognition of the injury. Second, delay in shunt-insertion until all other methods have been exhausted to control hemorrhage. At this point, a coagulopathy exists and no matter what the surgeon does, the patient will most probably die. To insert a shunt at this time only will result in a bad name for the procedure. Three, lack of experienced personnel for expeditious shunt insertion. If these three factors are avoided as they were by the authors, then the devastating nature of the injury itself must be implicated as the eventual cause of death.

Given this fact, what then is the optimal method of managing these injuries? Atriocaval shunting no doubt will be the method of choice, but alternatives do exist.

We managed six consecutive patients at Bellevue Hospital without a shunt, employing the technique of prolonged portal triad occlusion up to 60 minutes and rapid finger fracture of normal hepatic parenchyma to get down to the site of vascular injury for primary repair. Five patients survived.

Clearly, there exists a group of patients that can be managed without a shunt.

In their manuscript, the authors themselves report 15 patients with retrohepatic caval injuries who were managed without a shunt. Seven of the 15 survived for a salvage rate of nearly 50%. The survival in this group of patients without a shunt is clearly somewhat better than the 67% reported in patients in whom a shunt was used.

I would appreciate the authors' commenting on the two groups and elucidating for us the criteria for either using an atriocaval shunt or not.

As no one institution has enough patients for statistically significant data, a larger series will be needed to set up guidelines as to which patients require a shunt and which patient can be managed without it.

I enjoyed the manuscript, and I am sure that it will be a landmark paper in the field of hepatic trauma.

DR. JOHN OCHSNER (New Orleans, Louisiana): Dr. Feliciano has shown us that this is really a devastating lesion, having an 81% mortality.