ABDOMINAL VASCULAR INJURIES: A CONTINUING CHALLENGE

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I. INTRODUCTION

Abdominal vascular injuries are among the most lethal of injuries sustained by trauma patients and their management is fraught with difficulties, presenting numerous challenges for the modern-day trauma surgeon. The majority of these patients arrive at trauma centers in profound shock secondary to massive blood loss which often is unrelenting. Patients sustaining abdominal vascular injuries best exemplify the vicious cycle of shock, acidosis, hypothermia, coagulopathy, and cardiac dysrithmias.(1) Furthermore, many patients present in cardiopulmonary arrest, necessitating drastic life-saving measures, such as emergency department thoracotomy, aortic cross clamping, and open cardiopulmonary resuscitation to achieve any chance of reaching an operating room alive.(2-4) To compound the problem, exposure of the retroperitoneal hemorrhaging vessels is quite difficult and requires extensive dissection and mobilization of the intraabdominal organs. These maneuvers are time-consuming and fraught with pitfalls, as rapid dissection through large retroperitoneal hematomas can lead to iatrogenic injuries in patients who can ill afford further uncontrolled hemorrhage.(1)

Abdominal vascular injuries are rarely isolated. In fact multiple associated injuries are the rule rather than the exception, increasing not the severity, but also the time needed to repair many of these often critical associated injuries. Moreover, abdominal vascular injuries are characterized by massive blood loss, necessitating large quantities of crystalloids, blood, and blood products for intravascular volume replacement. Coupled with the frequent need to cross clamp the aorta or other major intraabdominal vessels, this scenario predisposes these patients to the development of reperfusion injuries and their sequelae.(1-4)

The concept of "bail out", popularized by Stone5 in the early 1980's and later known as "damage control",(6) is usually applied to patients sustaining abdominal vascular injuries. Similarly, these patients often demand heroic abdominal wall closures with prosthetic materials which initiates a cycle of frequent surgical re-interventions adding multiple and additive physiologic insults to an already compromised patient.

The classical dilemma of how to repair vascular injuries under conditions of massive contamination while avoiding graft infections and vessel blow-outs, remains one of the most difficult problems that face modern-day trauma surgeons.(7, 8) Septic processes and multiple system organ failure (MSOF) are frequent complications encountered by these patients, precipitated by profound shock, tissue hypoperfusion, massive blood volume replacement, generalized edema, and prolonged contamination. All these factors clearly conspire to produce high morbidity and mortality rates for patients sustaining these injuries. It is clear that improved outcomes are generally the result of expedient and precise surgical interventions by trauma surgeons with extensive experience in the management of these injuries along with the vast surgical armamentarium needed to effectively deal with them.(5-14)

II. HISTORICAL PERCEPTIVE

Some of the earliest contributions in the development of vascular surgery were made by Eck,(7, 8, 15) a Russian Surgeon who in 1877, was the first to perform a permanent union between two intraabdominal blood vessels when he performed an anastomosis between the portal vein and the inferior vena cava. In 1897, Silberberg,(7, 8, 15) successfully sutured arteries, including the abdominal aorta and in 1899, Dorfler,(7, 8, 15) recommended the use of fine round needles and sutures to repair all layers of the vessel. His technique was successful in 12 of 16 experiments. Similarly, in 1900, Payr,(7, 8, 15) performed arterial anastomosis by invagination using magnesium rings. An other advance was made in 1901 when Clermont,(7, 8, 15) successfully performed an end-to-end anastomosis of a divided inferior vena cava with a continuous fine silk suture.

In 1950, Oubert replaced a thrombosed aortic bifurcation with an arterial homograft, and in 1951, Dubost(7, 8, 15) resected an abdominal aortic aneurysm and restored arterial continuity with a thoracic aortic homograft. Julian, DeBakey, and Szilagyi performed similar operations soon afterward.(7, 8, 15) In 1956, Voorhees(15) pioneered abdominal aortic prosthetic grafts.

III. INCIDENCE

Abdominal vascular injuries are seen much more frequently in busy urban trauma centers than during military conflicts. Some of the most important data dealing with these injuries were collected by DeBakey and Simeone[16] who, in 1946, reported 2,471 arterial injuries from World War II, which included 49 intraabdominal injuries accounting for an incidence of 2%. In 1958, Hughes17 reported 304 arterial injuries from the Korean War, only 7 of which occurred in the iliac arteries, accounting for an incidence of 2.3%. In 1970, Rich[18] reported a series of 1,000 arterial injuries from the Vietnam War, of which 29, or 2.9%, involved the abdominal vessels.

Conversely, in civilian series, injuries to abdominal vessels account for 27% to 33% of all vascular injuries treated in urban trauma centers.[7, 8] The incidence of abdominal vascular injuries has been progressively rising over the last few years. Asensio and co-workers[19] recently reported that 302 patients were admitted for abdominal vascular injuries, over a 6-year period, to the LAC+USC Trauma Center, a busy urban trauma center that admits between 7,000 and 7,500 cases per year, Demetriades, Asensio, and co-workers[20] also reported that 67 patients were admitted for penetrating injuries of the abdominal aorta, over a 5-year period, to the same trauma center.

IV. MECHANISMS OF INJURY

Penetrating abdominal trauma is the most common cause of abdominal vascular injuries, accounting for approximately 90% to 95% of all abdominal vascular injuries. Blunt abdominal vascular trauma is much less frequent, with an estimated incidence of approximately 5% to 10%, and is not as frequent.[7, 8, 20-22] Approximately 25% of all patients undergoing laparotomies for gunshot wounds of the abdomen have sustained abdominal vascular injuries, while 10% of those undergoing exploratory laparotomy for stab wounds of the abdomen will have sustained abdominal vascular injuries.[7, 8, 20-22] Penetrating abdominal injuries are usually the result of missile injuries and stab wounds, whereas blunt injuries are the result of motor vehicular collisions and direct impact.

V. ASSOCIATED INJURIES

The abdominal blood vessels, by virtue of their retroperitoneal location and anatomic proximity to other organs are rarely the site of an isolated injured. In fact, it is estimated that approximately two to four associated intraabdominal injuries occur with abdominal vascular injuries.[7, 8, 19, 20-22] Penetrating trauma accounts for the vast majority of associated injuries. Multiple vessels are occasionally injured in patients sustaining abdominal vascular injuries, with a combination of arterial and venous injuries appearing to be the most common of all associated vascular injuries.[19]

VI. ANATOMIC LOCATION OF INJURY

Abdominal vascular injury associated with blunt trauma most commonly occurs in the upper abdominal arteries and veins; however, penetrating injuries are unpredictable as missile trajectories cannot often be predicted. Consequently they may occur within any area of the abdomen usually affecting more than one vessel. Limited data are available on the cumulative effect of multiple vessel injury on mortality. Because of the close proximity between abdominal arteries and veins, arteriovenous fistulas may occur, although they are uncommon.[7, 8]

The abdominal aorta and inferior vena cava may be injured at the suprarenal or infrarenal locations, while the inferior vena cava may be injured at its retrohepatic location, one of the most lethal injuries known to man. The superior mesenteric artery may be injured in any of its four zones, and the superior mesenteric vein may be injured at its infrapancreatic or retropancreatic location. The portal vein may be injured either at its origin at the confluence of the superior mesenteric and splenic veins or it may be injured alone within the confines of the portal triad. The renal artery may be injured in any one of its three parts and the renal veins may be injured either at their confluence with the inferior vena cava or at the renal hilum.[1]

VII. DIAGNOSIS

A. *Clinical Presentation*

The trauma surgeon must be cognizant that any penetrating injuries to the torso from the nipples to the upper thighs, pose a significant risk of abdominal vascular injury. Penetrating injuries directly over the midline harbor a strong potential for aortic or cavil injuries and all penetrating injuries surrounding the periumbilical region harbor the potential for aortic or inferior vena cava bifurcation injury. Missile injuries that traverse the abdominal cavity or pelvis also pose a great risk of inflicting abdominal vascular injuries, and this pattern of injury is often quite lethal. Penetrating injuries in the right upper quadrant can also result in aortic, vena cava, and portal venous injuries.[1]

The clinical presentation of patients who have sustained abdominal vascular injuries is determined by whether they present with a contained retroperitoneal hematoma or free bleeding within the abdominal cavity. Obviously those with a contained retroperitoneal hematoma will be either hemodynamically stable or have some degree of initial hypotension responsive to intravenous fluids, whereas those with free retroperitoneal and intraabdominal hemorrhage will present profoundly hypotensive.[1, 7, 8]

The presence of penetrating abdominal injury associated with massive abdominal distention and shock usually signals the presence of an uncontained intraabdominal hemorrhage secondary to injury of one of the major abdominal vessels. For patients with penetrating pelvic injuries who present with absent femoral pulses, one must suspect the presence of an injury to the ipsilateral iliac artery.[1]

For patients who have sustained blunt abdominal trauma with or without hypotension, in the presence of gross hematuria, the trauma surgeon must suspect injury to the renal vessels. In short, any patient who presents with a history of a penetrating abdominal wound and a history of hypotension in the field has an intraabdominal vascular injury until proven otherwise.(1, 7, 8)

Clinical findings such as abdominal discomfort and pain as well as physical examination findings consistent with peritoneal irritation or signs of peritonitis may be due either to the abdominal vascular injury or to other abdominal organ injuries frequently associated with intraabdominal vascular injuries.(1-4, 7, 8) The presence or absence of femoral, popliteal, dorsalis pedis, and posterior tibial pulses should be checked in both extremities. The hand-held Doppler should be routinely used to evaluate the flow signal from these vessels if the patient is hemodynamically stable. It should also be used to listen for venous sounds to ascertain whether elevation of the lower extremities or compression of the calf augments venous flow signals.(1-4, 7, 8) The ankle brachial index (ABI) should also be measured.

B. INVESTIGATIONS

Laboratory tests are of limited value in the early diagnosis of abdominal vascular injuries. An initial CBC should be obtained and will generally show a decrease in both hemoglobin and hematocrit levels. An arterial blood gas (ABG) analysis should also be done to check the patients initial pH, detect acidosis and evaluate the status of oxygenation and ventilation. Furthermore, repeat arterial blood gases are also useful adjuncts in evaluating the progress of resuscitation, while lactic acid levels are useful to obtain as a baseline measurement to monitor the progress of resuscitation. As many patients present with profound hypotension, there are few other investigations that can actually be instituted.(1)

The use of ultrasound will prove useful for detecting the presence of intraabdominal fluid, but very little detailed information will be obtained above the retroperitoneum and major abdominal vessels. A plain radiograph of the abdomen may be of diagnostic value, particularly in patients who have sustained penetrating wounds, to help evaluate the location and trajectory of the missile. Intravenous pyelograms (IVP) may be performed either in the emergency department (ED) or operating room (OR) provided that the patient is not hypotensive, to ascertain whether there are two functioning kidneys.(1)

A CT of the abdomen can be obtained in hemodynamically stable patients who have sustained blunt trauma with or without hematuria and may be useful for detecting retroperitoneal hematomas or for visualizing kidneys following blunt injury to the renal vessels. While angiography remains the "Gold Standard", it is generally not applicable in the acute management of these patients, but is a valuable adjunct to diagnose and treat postoperative complications.(1)

VIII.- SURGICAL MANAGEMENT
A. Emergency Department

All trauma patients should be evaluated and resuscitated according to the ATLS protocols. Prompt attention to achieving a secure airway, venous access, placement of a nasogastric tube, and Foley catheter, as well as early volume replacement with Lactated Ringer's solution and blood are the mainstays of early evaluation and successful resuscitation. When it is strongly suspected that a patient may be harboring abdominal vascular injuries it is not advisable to place intravenous lines in the femoral veins. This is because there could be iliac venous or inferior vena cavil injuries that may be actively hemorrhaging which would prevents volume replacement from reaching the right side of the heart.(1-4, 7-8) Similarly, the need for cross clamping the iliac vein or inferior vena cava during an exploratory laparotomy also arise, which will also prevent replacement fluid from reaching the right side of the heart. Therefore, large intravenous catheters should be inserted in the upper extremities. If the need arises, as it usually does in profoundly hypotensive patients, the subclavian or jugular veins should be accessed. Clinical findings consistent with acute hemoperitoneum or peritonitis, as well as absence of the femoral pulses, demand an immediate exploratory laparotomy. Broad spectrum antibiotics such as cefoxitin, which is routinely used in our department, are administered prior to surgical intervention.(1-4, 7-8)

In patients presenting in cardiopulmonary arrest or profound refractory hypotension unresponsive to fluid replacement via rapid infusers, an emergency department thoracotomy will be needed to perform open cardiopulmonary massage and cross-clamping of the descending thoracic aorta. Cross-clamping of the descending thoracic aorta will allow for redistribution of the remaining intravascular volume to improve perfusion of both the carotids and coronary arteries, and will significantly decrease or stop intraabdominal arterial hemorrhage.(1-4, 7, 8, 23, 24)

Emergency department thoracotomy with cross-clamping of the descending thoracic aorta will subject patients to risks such as ischemia distal to the cross clamp, and increased of heat loss secondary to the open thoracic cavity, and predispose the patient to reperfusion injuries. Despite these risks, it is a useful adjunct, and often the only hope for salvaging in exsanguinating patients in whom vascular control cannot be obtained immediately. Needless to say, time is of the most importance and these patients must be rapidly transported to the OR without any further radiographic evaluations or delays.(1-4, 7, 8, 23, 24)

B. Intraoperative Management

In the operating room, the patient's torso from neck to mid-thighs is prepared and draped. The area of the mid-thighs is important should the necessity arise to obtain an autogenous saphenous vein graft. The trauma surgeon must confirm that blood has been prepared for immediate trans-

fusion via rapid infusion technology. He must also institute maneuvers to prevent hypothermia which include: placement of a warming blanket on the operating table, covering the patient's lower extremities, as well as a circulating warm air mattress covering the head to prevent heat loss. The ventilator cascade temperature should be increased to 420°C, and that an ample supply of microwave heated irrigation fluids must be available. Furthermore, the availability of auto transfusion apparatus is of great value.(1-4, 7, 8)

Abdominal injuries should be explored through a midline incision extending from the xyphoid to the pubis. Immediate control of life-threatening hemorrhage followed by immediate control of sources of gastrointestinal spillage must be achieved early. The next step in the management of abdominal injuries consists of thorough exploration of the abdominal cavity. Since the abdominal vasculature resides in the retroperitoneum, a thorough exploration of these structures must be performed utilizing a systematic approach of the anatomic zones of the retroperitoneum. Exploration of the retroperitoneum is quite challenging and demands that the trauma surgeon be totally familiar with the complex anatomy of these zones.(1, 7, 8)

The first and most important goal to achieve in the management of abdominal vascular injuries is hemorrhage control. As in all vascular injuries, proximal and distal control of the hemorrhaging blood vessel is ideal; however, in exsanguinating abdominal vascular injuries, achieving this rapidly can be eztremely difficult.(1-4) These patients frequently patients experience severe and profound hypotension, and cross-clamping of the aorta is therefore the first maneuver to stop life-threatening hemorrhage. If the patient arrives profoundly hypotensive or if a cardiopulmonary arrest occurs in the OR, an immediate left anterolateral thoracotomy with aortic cross-clamping must be performed prior to proceeding with laparotomy.(1-4, 23, 24)

When a patient arrives with some degree of hemodynamic stability, but decompensates during laparotomy, the abdominal aorta can be controlled either digitally at the aortic hiatus, by using of an abdominal aortic root compressor or by the placement of a cross clamp. The placement of a cross clamp in this area can be difficult, as the abdominal aorta is surrounded by the crura of the diaphragm which may require transection.(1-4, 23, 24) Once the exsanguinating hemorrhage has been controlled, the trauma surgeon should classify the hemorrhage or hematoma into one of the three zones of the retroperitoneum; namely Zone I, Zone II, or Zone III. All trauma surgeons must be cognizant of the intricate anatomy of these zones. Zone I begins at the aortic hiatus and ends at the sacral promontory; it is located midline and courses on top of the spinal column. This zone is divided into Zone I supramesocolic and Zone I inframesocolic. There are two Zones II: right and left, located in the pericolic gutters. Zone III begins at the sacral promontory and encompasses the pelvis.(1-4, 7-8)

Zone I supramesocolic contains the suprarenal abdominal aorta, the celiac axis and the first two parts of the superior mesenteric artery; zone 1 extending form the origin of the superior mesenteric artery at the aorta to the point where the inferior pancreaticoduodenal artery emerges, zone 2 extending from the inferior pancreaticoduodenal to the origin of the middle colic artery, zone 3 extending form the trunk distal to middle colic artery and zone 4 including the segmental branches the jejunal ileal artery or colic artery. This zone also contains the infrahepatic suprarenal inferior vena cava, the infrarenal inferior vena cava as well as the proximal portion of the superior mesenteric vein. The right and left zones II contain the renal vascular pedicles. Zone III contains both common iliac arteries and veins, as well as their internal and external branches, and the presacral venous plexus. The portal - retrohepatic area is a special area contains the portal vein, hepatic artery, and retrohepatic vena cava.(1-4, 7, 8)

As soon as the trauma surgeon has identified and classified the hemorrhage or hematoma into one of these zones, he must then approach this zone to obtain vascular control and expose the injured blood vessel before definitive repair can be attempted. Each zone requires a different and complex maneuver to expose these vessels.

Zone I supramesocolic is generally approached utilizing a maneuver that rotates the left-sided viscera medially. This approach requires transection of the avascular line of Toldt in the left colon, incision of the lienosplenic ligament and rotating the left colon, spleen, tail, and body of the pancreas as well as the stomach medially. This exposes the aorta from its entrance into the abdominal cavity via the aortic hiatus and includes exposure of the origin of the celiac axis, superior mesenteric artery, and the left renal vascular pedicle. Alternatively the left kidney can be mobilized medially, although this is generally not done.(1-4, 7-8) Another maneuver is to perform an extended Kocher maneuver along with transection of the avascular line of Toldt in the right colon, medially mobilizing the right colon, hepatic flexure, duodenum, and head of the pancreas to the level of the superior mesenteric vessels, and incising the retroperitoneal tissue to the left of the inferior vena cava. This maneuver exposes the suprarenal abdominal aorta between the celiac axis and the superior mesenteric artery. The disadvantage of this maneuver is that the exposure obtained is below the level of any wounds of the supraceliac aorta and the hiatus.(1-4, 7-8)

Maneuvers used to expose injuries in Zone I inframesocolic include displacing the transverse colon and mesocolon cephalad, eviscerating the small bowel to the right, and locating the ligament of Treitz, transecting it with the loose tissue alongside the left of the abdominal aorta until the left renal vein is located. This exposes the infrarenal aorta. To expose the infrarenal inferior vena cava, the avascular line of Toldt in the right colon is transected along with a Kocher maneuver sweeping the pancreas and duodenum to the left and incising the retroperitoneal tissues that cover the inferior vena cava.(1-4, 7-8)

Exposure of the right and left zones II is achieved depending on whether the perirenal hematoma or active bleeding is located laterally or medially. If active bleeding is found medially or if there is an expanding hematoma, vascular control of the vessels in the pedicle is preferable. On the right, this is achieved by mobilizing the right colon and hepatic flexure as well as performing a Kocher maneuver, exposing the inferior vena cava infrarenally and continuing the dissection cephalad by incising the tissues directly over the suprarenal infrahepatic inferior vena cava. This is continued until the right renal vein is encountered. Further dissection superiorly and posteriorly to the right renal vein will locate the right renal artery.(1-4, 7, 8)

On the left, the left colon and splenic flexure are mobilized and the small bowel is then eviscerated to the right. The ligament of Treitz is located and the transverse colon and mesocolon are displaced cephalad. This should locate the infrarenal abdominal aorta, and cephalad dissection will locate the left renal vein as it crosses over the abdominal aorta. The left renal artery will also be found superiorly and posteriorly to the left renal vein. Alternatively, if a perirenal hematoma or bleeding is found laterally with no extension into the hilum of the kidney the lateral aspects of Gerota's fascia can be incised and the kidney elevated and displaced medially to locate the hemorrhage.(1-4, 7-8)

Exposure to the vessels in Zone III can be achieved by taking down the avascular line of Toldt in both the right and left colon and displacing them medially. Utilizing a combination of blunt and sharp dissection, the common iliac arteries and veins will then be located. Meticulous attention must be paid to locating the ureter as it crosses the common iliac artery. A vessel loop should be passed around the ureter to retract and dissection is extended in a caudad direction opening the retroperitoneum over the vessels.(1-4, 7-8)

Once exposure and proximal and distal control have been obtained, all the abdominal vascular injuries should be graded according to the American Association for the Surgery Trauma - Organ Injuries Scale for vascular injuries (AAST-OIS)25 (see Table 1). The routine principles of vascular surgery also apply to the management of the abdominal vascular injuries. Adequate exposure, proximal and distal control, debridment of the vessel wall, prevention of the embolization of clots or plaque, irrigation with heparinized saline, the judicious use of Fogarty catheters, meticulous arteriorraphy or venorraphy with monofilament vascular sutures, avoiding narrowing of the vessel during repair, insertion of an autogenous or prosthetic graft when applicable, and intraoperative angiography when feasible, are the mainstays of successful repair.(1-4, 7-8)

The management of vascular injuries in Zone I supramesocolic consists of primary arteriorraphy of the suprarenal abdominal aorta when feasible, and on rare occasions, the insertion of a Dacron or PTFE graft. Injuries to the celiac axis are usually treated with ligation. Injuries to the first two

zones of the superior mesenteric artery should be treated with by primary repair whenever possible but intense vasoconstriction can make this difficult. These injuries can be ligated because theoretically, there are sufficient collaterals to preserve the viability of the small and large bowel; however, profound vasospasm may lead to intense ischemia and bowel necrosis.(1, 19, 26) The first two zones of the superior mesenteric artery can also be repaired either with an autogenous or prosthetic graft while the insertion of a temporary shunt has also been described(26) (Table 2).

The management of injuries to zone I inframesocolic involves many of the same techniques as those used in zone I supramesocolic. Zones 3 and 4 of the superior mesenteric artery should also repaired, although the main jejunal and colic branches of zone 4 may be individually ligated.(1, 19, 26) Injuries to the inferior mesenteric artery are treated usually by ligation. The management of injuries to the infrahepatic suprarenal inferior vena cava, and the infrarenal inferior vena cava consists of lateral venorraphy whenever feasible. If through and through injuries are found in these vessels, both anterior and posterior aspects of the vessel must be repaired. This can prove to be quite challenging.(1, 19)

Although the infrahepatic suprarenal inferior vena cava has no venous tributaries it is quite difficult to mobilize. In general, these repairs are accomplished by extending the injury in the anterior wall and repairing the posterior wall from within. The vessel can be mobilized by rotating the right kidney from left to right outside of the renal fossa; however, this maneuver is quite treacherous and not recommended.(1, 19) When there has been massive destruction of the infrahepatic suprarenal inferior vena cava, ligation can be considered; however, the associated survival rates are low, generally being less than 5%. Occasionally, prosthetic grafts have been utilized in this position. The management of injuries to the infrarenal inferior vena cava usually involve lateral venorraphy. In the presence of through and through injuries, primary repair can be accomplished either by extending the laceration or by rotating the vessel; however, this can be challenging and involves ligating many of its fragile lumbar veins. We recommend performing the repair from within the vessel. When massive destruction has occurred, the infrarenal inferior vena cava can be ligated. which is generally well tolerated. Injuries to the superior mesenteric vein should be primarily repaired, although ligation can be performed, but with serious sequelae to the circulation of the small and large bowel.(1, 19)

Injuries to the right or left Zones II can be challenging to repair . Injuries to the renal artery can be primarily repaired or resected and grafted utilizing either an autogenous or prosthetic graft. Alternatively an aortorenal bypass can be performed utilizing a distal site in the anterior wall of the abdominal aorta. Repairs to the renal arteries are quite difficult. In fact ligation of the renal artery is often performed with subsequent nephrectomy. Injuries to the renal veins can also be repaired with primary venorraphy or ligation. An

injury to the right renal vein that cannot be successfully repaired requires ligation and will demand that a nephrectomy be performed secondary to the lack of venous collaterals. Ligation of the left renal vein is generally well tolerated provided that it is performed proximally and close to the inferior vena cava as they are venous collaterals similar to the gonadal and renolumbar veins, which handle the venous outflow.(1, 19)

Injuries to Zone III can also be quite challenging to manage, as they are often associated with colonic and genitourinary injuries resulting in significant contamination. Injuries to the common iliac arteries can be primarily repaired via arteriorrhaphy, while resection and primary anastomosis are occasionally performed. Autogenous and prosthetic grafts can also be utilized to repair the common iliac arteries. Internal iliac artery injuries are generally treated with by ligation. Injuries to the external iliac artery can be primarily repaired via arteriorraphy and occasionally, by resection and primary anastomosis. Iliofemoral bypasses can be performed with autogenous or prosthetic grafts, although it is uncommon to find a saphenous vein of adequate size to perform an iliofemoral repair.(1, 19)

When there has been massive destruction of either the common or internal iliac arteries ligation may be needed. Arterial flow can be restored utilizing a cross over femorofemoral or axillofemoral bypass. The disadvantages of these bypasses are the need to involve uninjured vessels and a high incidence of thrombosis. Injuries to common, external and internal iliacs veins can be treated with by ligation, which is frequently well tolerated, or by lateral venorraphy. Occasionally, access to an injured right external iliac vein may demand transection of the ipsilateral right iliac artery as the vessel lies below the artery.(1, 19)

Whenever a trauma surgeon performs an abdominal vascular repair serious consideration must be given to "second look" operations to assess for bowel viability as contamination from gastrointestinal or genitourinary injuries pose a great risk for the development of infections in prosthetic grafts inserted to bypass injured vessels. Whenever possible, all grafts, whether autogenous or prosthetic, should be reperitonealized. Similarly, for all vascular repairs adjacent to gastrointestinal suture lines, an effort should be made to interpose viable tissue, generally omentum, between the suture lines to prevent vascular-enteric fistulas or anastomotic dehiscence and blow-outs.(1, 19, 26)

IX. MORTALITY

Abdominal vascular injuries are associated with a high mortality rate. Mortality can be analyzed on a temporal basis and subdivided into early and late mortality. Most early deaths are caused by exsanguination and it is well known that patients presenting in shock have extremely high mortality rates.(1-4) Asensio(2-4) reported that the incidence of exsanguination for penetrating abdominal aortic injuries in both the suprarenal and infrarenal locations was 55%. A review of series in the literature, by Asensio(2-4) revealed that the incidence of exsanguination from penetrating injuries to the superior mesenteric artery was 25%. In a separate study, Asensio(2-4) reported a 37% incidence of exsanguination for both penetrating and blunt injuries to the superior mesenteric artery injuries. According to another review of the literature by Asensio(2-4) the incidence of exsanguination from both penetrating and blunt trauma to the inferior vena cava was 33%, while in collective review of the literature revealed a 30% incidence of exsanguination for blunt and penetrating injuries to the portal vein.

Asensio19 conducted a study at the LAC+USC Medical Center, spanning 72 months, on a series of 302 patients who sustained abdominal vascular injuries. To date, this is the largest series reported in the literature. There were 266 patients (88%) admitted with penetrating injuries 216 (81%) of whom had sustained gunshot wounds, 46 (17%) stab wounds, and only 4 (2%) shotgun wounds. There were 36 (12%) admitted with blunt injuries, 23 (64%) who had been involved in motor vehicular collisions, 11 (31%) who had been pedestrians struck by vehicles, and 2 (5%) who had sustained falls from great heights. The operative findings revealed that 275 of the 302 patients (91%) had retroperitoneal hematomas, 137 located in Zone I (55 supramesocolic and 82 inframesocolic), 49 in Zone II and 89 in Zone III. In addition, 39 patients had multiple zones of involvement.

There was collective a total of 504 vessels injured in these 302 patients, making an average of 1.67 vessels injured per patient. There were 238 (47%) arterial injuries and 266 (53%) venous injuries. The most frequently injured artery was the aorta, seen in 60 patients (25%). While the most frequently injured vein was the inferior vena cava, seen in 77 patients (31%), followed by the superior mesenteric vein, seen in 33 patients (13%).

Asensio19 reported an overall mortality rate following abdominal vascular injuries of 54%. In the same series19, 15% of the patients who had sustained abdominal vascular injuries succumbed without any vascular control. In this series, 43 patients (14%) underwent Emergency department thoracotomy with 1 survivor (2%) and 88 (29%) underwent this procedure in the operating room with 9 survivors (10%). Attesting to my critical value of these patients, if those submitted to Emergency department thoracotomy were excluded from the mortality analysis the overall mortality would drop significantly to 39%.

Increased mortality rates were also noted when more than one vessel was injured. For Asensio19 reported that 160 patients with one vessel injured had a mortality rate 45%, 102 with two vessels injured had a mortality rate of 60%, 33 patients with three vessels injured had a mortality of 73% and 5 patients with 4-6 vessels injured had a uniform 100% mortality rate. In this series, exsanguination accounted for 83% of the overall mortality. (19)

X.- COMPLICATIONS

Abdominal vascular injuries are associated with very high rates of morbidity. Abdominal compartment syndrome is quite common in the presence of abdominal vascular injuries, while other important complications include thrombosis, dehiscence of suture lines and infection. Vessel occlusion is not uncommon when repairs have been performed on vasoconstricted vessels, such as the renal artery or superior mesenteric artery.(1-4, 19, 26) Systemic hypovolemia and intestinal hypervolemia syndrome are common when the portal vein, superior mesenteric vein or suprarenal inferior vena cava have been ligated, as there is little venous outflow from the enteric circulation and limited time for the development of venous collaterals. Aortoenteric fistulas may develop if no viable tissue is interposed between an aortic and enteric repair, most frequently the stomach,(1, 7, 8) and less frequently aortoduodenal fistulas in the third portion of the duodenum

The cycle of hypothermia, acidosis, coagulopathy and cardiac disrhythmias is frequently seen in abdominal vascular injuries. Limb ischemia and compartment syndromes can occur in patients when there has been a delay in the restoration of arterial blood flow. The same complication can occur in patients who do not tolerate ligation of the inferior vena cava or iliac veins,(1, 7, 8) due to poor venous collaterals.

Asensio19 reported 128 major complications in his series of 302 patients with abdominal vascular injuries. The mean ICU of stay was 4 days (range 1-67), and the mean hospital length of stay was 9 days (range 1-45).

XI.- RECENT ADVANCES

Asensio and colleagues in a multi-institutional study conducted in the United States involving 34 trauma centers over a period of 10 years looked at the American experience with the management of superior mesenteric artery injuries. These injuries are rare, often lethal and incur very high morbidity and mortality. The purposes of this study were to review a multi-institutional experience with these injuries; to analyze Fullen's classification based on anatomic zone and ischemia grade for its predicted value; to correlate the American Association for the Surgery of Trauma-Organ Injury Scale (AAST-OIS) for abdominal vascular injury with mortality; and to identify independent risk factors predictive of mortality, describing current trends for the management of this injury. Outcome variables were analyzed by univariate analysis. The data was also submitted to multivariate analysis, stepwise logistic regression was used to identify a set of risk factors significantly associated with mortality.

There were 250 patient enrolled, with a mean Revised Trauma Score (RTS) of 6.44 and a mean Injury Severity Score (ISS) of 25. Surgical management consisted of ligation in 175 of 244 patients (72%), primary repair in 53 of 244 patients (22%), autogenous grafts were used in 10 of 244 (4%), and prosthetic grafts consisting of PTFE in 6 of 244 patients (2%). The overall mortality of this injury remains high. Ninety-seven of 250 patients (39%) died from this injury.

Mortality was then correlated versus Fullen's zones: zone I, 39 of 51 patients died for a 76.5% mortality; zone II, 15 of 34 patients, accounting for 44.1% mortality rate; zone III, 11 of 40 patients succumbed for a mortality of 27.5% and 25 of 108 patients sustaining injuries in zone IV died for a mortality rate of 23.1%. Similarly, mortality versus Fullen's ischemia grade was correlated, 22 of 34 patients incurred this type of ischemia grade and incurred mortality of 64.7%.

Mortality versus AAST-OIS for abdominal vascular injury revealed grade I injuries to have a mortality of 16.4%, grade II 25.5%, grade III 40%, grade IV 53.6%, and grade V 89.5%. Logistic regression analysis identified as independent risk factors for mortality the following: transfusion of greater than 10 units of packed RBCs, intraoperative acidosis, dysrhythmias, injury to Fullen's zone I or II and multisystem organ failure.

From this study the authors concluded that Fullen's anatomic zones, ischemia grade, and AAST-OIS abdominal

Table I: American Association for the Surgery of Trauma-Organ Injury Scale for Abdominal Vascular Injury.

Grade I:	Unnamed superior mesenteric artery or superior mesenteric vein branches. Unnamed inferior mesenteric artery or inferior mesenteric vein branches. Phrenic artery/vein. Lumbar artery/vein. Gonadal artery/vein. Ovarian artery/vein. Other nonnamed small arterial or venous structures requiring ligation.
Grade II:	Right, left or common hepatic artery. Splenic artery/vein. Right or left gastric arteries. Gastroduodenal artery. Inferior mesenteric artery, trunk, or inferior mesenteric vein, trunk. Primary named branches of the mesenteric artery (such as, ileocolic artery) or mesenteric vein. Other named abdominal vessels requiring ligation/repair.
Grade III:	Superior mesenteric vein, trunk. Renal artery/vein. Iliac artery/vein. Hypogastric artery/vein. Vena cava, infrarenal.
Grade IV:	Superior mesenteric artery, trunk. Celiac axis proper. Vena cava, suprarenal and infrahepatic. Aorta, infrarenal.
Grade V:	Portal vein. Extraparenchymal hepatic vein. Vena cava, retrohepatic or suprahepatic, aorta, suprarenal, subdiaphragmatic.

This classification system is applicable for extraparenchymal vascular injuries. If the vessel injury is within 2 cm of the organ parenchyma, refer to the specific organ injury scale. Increase one grade for multiple grade III or IV injuries involving > 50% vessel circumference laceration for grades IV or V.

Table II: Fullen's Anatomic Classification of Superior Mesenteric Artery Injury by Zone and by Grade

Zone	Segment of Superior Mesenteric Artery	Grade	Ischemic Category	Bowel Segments Affected
I	Trunk proximal to first major branch (inferior pancreaticoduodenal)	I	Maximal	Jejunum, ileum, right colon
II	Trunk between inferior Pancreaticoduodenal and middle colic	II	Moderate	Major segment, small bowel and/or right colon
III	Trunk distal to middle colic	III	Minimal	Minor segment or segments, small bowel or right colon
IV	Segmental branches, jejunal, ileal or colic	IV	None	No ischemic bowel

vascular injury grade correlate well with mortality. Furthermore, injuries to Fullen's zones I and II, Fullen's maximal ischemia grade, and AAST-OIS injury grades IV and V, along with high intraoperative transfusion requirements, the presence of acidosis and dysrhythmias are significant predictors of mortality for patients incurring these injuries. All of these predictive factors for mortality should be taken into account in the surgical management of these injuries and early institution of damage control/bail out should be entertained, along with a planned "second look" procedure.

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