Perfusion Techniques for Renal Protection during Thoracoabdominal Aortic Surgery

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Abstract: Open thoracoabdominal aortic aneurysm (TAAA) repair includes aortic clamping that interrupts antegrade blood flow to distal organs. Ischemia involving the kidneys can lead to renal failure and poor outcomes. To this end, prevention of ischemic kidney damage has led to several perfusion strategies that protect the kidneys during TAAA surgery. Options for renal perfusion include the use of passive shunts or mechanical circulatory support to deliver oxygenated blood continuously to the kidneys until normal aortic flow is re-established. An alternative approach, renal perfusion with cold crystalloid, has emerged as the preferred option of renal protection at several centers. Although there is considerable variation, several studies have demonstrated that cold crystalloid renal perfusion provides excellent protection, particularly in high-risk patients such as those with renal artery occlusive disease, preoperative renal dysfunction, or a ruptured aneurysm. Notably, recent consensus practice guidelines recommend either cold crystalloid or blood perfusion be considered for renal protection during TAAA repair. In this article, we discuss these various strategies for renal protection during TAAA repair and highlight the related technical aspects. Keywords: aneurysm, aortic, aorta, aortic operation, hypothermia, kidney, perfusion, review. JECT. 2012;44:P31–P37

Open surgery of thoracoabdominal aortic aneurysm (TAAA) repair invariably involves a period of clamping of the descending thoracic aorta that interrupts antegrade blood flow to the distal organs for a minimum of 30 minutes. Although considerable attention focuses on ischemia involving the spinal cord, renal ischemia often leads to renal dysfunction or failure. Current series of TAAA repairs indicate a 20–30% postoperative renal dysfunction rate leading to dialysis in 3–6% of patients (1–5). To attenuate the renal damage caused by ischemia, several selective perfusion strategies to protect the kidneys during aortic occlusion have evolved. In this article, we discuss these various strategies for renal protection during TAAA repair and highlight the related technical aspects.

RENAL PERFUSION STRATEGIES

Passive Shunts for Renal Perfusion during Thoracoabdominal Repair

The first option developed for maintaining renal perfusion while the thoracic aorta was clamped was the use of a passive shunt. One of the earliest accounts described the use of polyethylene as a passive shunt during TAAA repair; the shunt maintained antegrade flow from the descending thoracic aorta to the infrarenal aorta while the aorta was clamped (6). After this initial report, several authors described their experience in using shunts or bypass grafts to accommodate distal aortic and renal perfusion during TAAA repair (7–9). Despite the important advantages of facilitating pulsatile arterial flow to the kidneys, the use of passive shunts has inherent limitations. Foremost, end-organ oxygen delivery is dependent on adequate proximal mean arterial pressure and blood oxygenation. Given the wide availability of mechanical circulatory support, passive shunt use has become infrequent in the current era.

Although today passive shunts are not frequently used to provide distal aortic perfusion during TAAA repair, a few groups continue to use this technique for selective
renal perfusion and have achieved satisfactory results. For example, inline shunting can be delivered through balloon-tipped perfusion catheters connected to a bifurcated side-arm graft sewn just past the proximal aortic graft anastomosis (10,11). After the proximal anastomosis has been completed, the clamp is moved onto the aortic graft below the side-arm to establish selective renal perfusion. Alternatively, to enable selective renal perfusion during the proximal anastomosis, a 14-gauge aortic needle–cannula can be inserted into the descending thoracic aorta above the clamp site and connected to perfusion tubing and a balloon-tipped catheter (12). The concomitant use of intra-abdominal saline–ice slush can be used to add the benefit of renal hypothermia to the passive shunt strategy (11).

**Selective Renal Perfusion with Mechanical Circulatory Support**

**Left Heart Bypass Circuits:** An alternative approach to passive shunting uses extracorporeal circulation techniques to provide distal aortic and selective renal perfusion during TAAA surgery. The left heart bypass (LHB) circuit uses a pump to deliver oxygenated blood drained from the left atrium into either the femoral artery or the distal aorta (Figure 1). This maintains blood flow to the kidneys during the proximal portion of the aortic repair. Once the aorta adjacent to the renal arteries is opened, balloon-tipped catheters (9–16 Fr) connected to a Y-limb from the pump return line are directly placed into the origins of the renal arteries to maintain perfusion (13–15). Like passive shunts, LHB circuits deliver isothermic blood to organs. Concerns about high shear rates that could cause hemolysis and coagulopathy should be considered when using high flow rates through small-diameter catheters (9 Fr) (16).

Observational studies performed in the 1980s and 1990s found that renal perfusion with isothermic blood during LHB was associated with an increased incidence of acute

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**Figure 1.** These illustrations show the use of left heart bypass (LHB) and cold renal perfusion during an extent II thoracoabdominal aortic aneurysm repair. (A) The LHB circuit drains oxygenated blood from the left atrium through a cannula placed into the inferior pulmonary vein. A centrifugal pump returns the blood to the distal circulation through a cannula placed in the lower descending thoracic aorta. A clamped Y-limb from the return line terminates in two 9-Fr balloon perfusion catheters; these will be used later in the repair for selective perfusion of the celiac and superior mesenteric arteries. A separate perfusion system using a roller pump is set up to deliver cold crystalloid to the renal arteries through two 9-Fr balloon perfusion catheters. (B) After the proximal anastomosis has been completed, LHB is stopped, and the balloon perfusion catheters are placed in the exposed ostia. Intermittent boluses of cold crystalloid are delivered to the renal arteries while continuous isothermic blood perfusion is delivered to the celiac and superior mesenteric arteries. (C) Continuous visceral perfusion with isothermic blood and intermittent renal boluses of cold crystalloid can continue to be delivered while the renal and visceral arteries are sewn to an opening in the aortic graft. Reproduced with permission from Coselli JS, LeMaire SA. Tips for successful outcomes for descending thoracic and thoracoabdominal aortic aneurysm procedures. *Semin Vasc Surg* 2008;21:13–20. Figures B, G, and H. Copyright Elsevier.
renal failure (ARF) (17,18). Jacobs and colleagues posited that this association was the result of insufficient renal perfusion pressure and proposed using catheters equipped with pressure channels to monitor and maintain perfusion pressure at 60 mmHg or greater (19). In patients with chronic hypertension and/or preoperative renal insufficiency, they recommended maintaining higher pressures (i.e., 85 mmHg). Furthermore, they described using ultrasound-guided flow monitoring to adjust perfusion flow (generally 200–280 mL/min) and preserve adequate urine output throughout aortic clamping (14,19).

A recent study of TAAA repairs performed with LHB examined the effect of an alternative cannulation technique—i.e., through a side-arm graft sewn to the femoral artery—on postoperative outcomes (20). The authors found that preoperative glomerular filtration rate (GFR) was the strongest predictor of postoperative renal dysfunction and death. Although use of the side-arm cannulation technique did not have a significant impact on outcomes, the strong interaction between preoperative GFR and side-arm cannulation suggested a 15–20% reduction in postoperative renal complications when preoperative GFR was less than 60 mL/min/1.73 m². The authors concluded side-arm cannulation was associated with lower postoperative renal complications in high-risk patients (i.e., those with low GFR); because results were unclear in lower-risk patients, the authors recommended a randomized trial.

Given the established efficacy of hypothermia as a means of protecting organs from ischemic injury, many groups have reported strategies that effect localized renal hypothermia during selective perfusion from LHB circuits (9,13,15,21,22). One approach is to selectively perfuse one of the renal arteries with a bolus of 15°C blood (9). Continuous cold blood (4–8°C) perfusion of both renal arteries, with concomitant systemic warming through femoral perfusion to prevent systemic hypothermia, has also been successful (21,22). In a retrospective study, 359 patients who underwent TAAA repair with LHB received either warm (37°C) or cold (4°C) blood perfusion delivered to the celiac, superior mesenteric, and renal arteries through 9- or 12-Fr balloon perfusion catheters at total flow rates between 300 and 450 mL/min (13). Systemic hypothermia was prevented by the use of a heat exchanger that enabled the return of warm blood to the left common femoral artery. The study found that the two perfusion techniques produced similar results in terms of ARF, which developed in 22% of warm blood recipients and in 23% of cold blood recipients. However, among the 81 patients who developed ARF, hospital mortality was lower in those who received cold perfusion (27%) than in those who received warm perfusion (56%, \(p < .02\)). The authors concluded that the differences in mortality could be putatively explained by the effect of hepatic and gastrointestinal hypothermia in preventing ischemia/reperfusion injury.

We have prospectively studied a technique to deliver intermittent boluses of cold blood to the kidneys during LHB (discussed in detail subsequently in the section describing the evolution of our technique) (15).

Cardiopulmonary Bypass Circuits: Another approach to providing mechanical circulatory support during TAAA repair is the use of cardiopulmonary bypass (CPB). In contrast to LHB, partial and total CPB circuits drain deoxygenated blood while returning extracorporeally oxygenated blood to the body. To provide distal aortic perfusion during TAAA surgery, blood drained from a cannula in the femoral vein passes through an oxygenator and a heat exchanger before being returned to the femoral artery. Selective renal perfusion is delivered through balloon perfusion catheters connected to a Y-limb from the inflow tubing and placed in the ostia of the renal arteries. The heat exchanger of the CPB circuit allows for variable cooling of the blood being returned.

One approach to using partial CPB during TAAA repair uses one main pump for femoral–femoral bypass, a second pump for bilateral renal artery perfusion, and a third pump for celiac and superior mesenteric artery perfusion (23). Flow rates of 150–200 mL/min/branch have been recommended for selective renal perfusion (24). Pressures at the tips of the perfusion catheters can be monitored to guide adjustments in flow and equalize the renal and distal aortic pressures (23). Alternatively, flows can be titrated by using hepatosplanchnic venous oximetry and urine output (24).

Cardiopulmonary bypass enables various approaches to producing a wide range of protective levels of hypothermia. The simplest approach provides mild systemic hypothermia (34°C) during the aortic repair followed by systemic rewarming (24). Continuous selective perfusion of the kidneys with 30–32°C blood can be delivered using a circuit that returns warmed blood to the inferior vena cava (25). Profound hypothermic (15°C) circulatory arrest and selective kidney perfusion through catheters placed in the renal branches are also effective; in a series of 33 patients who underwent extent III and IV TAAA repairs using this approach, only one patient developed renal failure (3). A recent report demonstrated new-onset ARF requiring dialysis in 7% of 218 patients who underwent extent I, II, or III TAAA repairs performed with CPB and hypothermic circulatory arrest (26). Fifty-three percent of the patients who developed ARF had associated multiorgan dysfunction and died. Temporary dialysis was required in approximately 4% of hospital survivors.

Renal Perfusion with Cold Crystalloid

Renal perfusion with cold crystalloid has emerged as a preferred strategy at many centers. Although there are considerable variations in technique, several studies have demonstrated that cold crystalloid perfusion provides excellent
renal protection, particularly in high-risk patients such as those with renal artery occlusive disease, preoperative renal dysfunction, or a ruptured aneurysm. Crawford was an early proponent of cold crystalloid renal perfusion during TAAA repair, and in 70 of his initial 605 TAAA cases, he perfused the left renal artery with 4°C lactated Ringer’s solution (27). Although the target left kidney temperature was 15°C or less, this was only achieved in approximately 50% of cases. An analysis of data regarding 1233 consecutive descending thoracic or TAAA repairs found no overall benefit in using cold crystalloid perfusion; however, there was a reduced risk of renal failure in the subset of patients with visceral artery occlusive disease (17,28). Recommendations from an analysis of Crawford’s complete series of 1509 patients supported selective use of cold crystalloid renal perfusion in patients with renal artery occlusive disease or preoperative renal dysfunction or when aortic clamp time was anticipated to exceed 30–45 minutes (29).

The techniques for using cold crystalloid renal perfusion during aortic surgery vary considerably. For example, although most groups use lactated Ringer’s solution (5,10,17,30), 9% NaCl solution is used at some centers (31–33). In addition, different centers use various additives in the perfusion solution, including mannitol (12–72 g/L) (5,10,30,33,34), methylprednisolone (500–1000 mg/L) (10,33,34), and heparin (1000–2000 U/L) (32,34). Most groups report delivering the solution through balloon-tipped perfusion catheters (6–9 Fr), although a 12-Fr venous cannula can also be used (10,11,14,31,33). The solution can be delivered through a roller pump, gravity infusion, or syringe injection. An initial bolus of 200–300 mL per kidney can be followed by subsequent boluses every 10–30 minutes or by continuous infusion at 20 mL/min until normal antegrade blood flow is reinstated (11,12,16,30,32). Regardless of the technique, cold crystalloid is only delivered as long as the patient is not too cold or volume-overloaded. Left kidney temperature may be monitored by placing a probe into the parenchyma; although the usual target renal temperature is 15°C or less throughout the ischemic period, recent data suggest that temperatures 28°C or less provide excellent protection (5,15,17).

Recent studies continue to support using cold crystalloid perfusion to provide renal protection during aneurysm repair. Significant outcome improvements have been described when renal cooling was used during repair of ruptured juxtarenal aortic aneurysms (a situation very similar to ruptured TAAA) (31). Specifically, 9% NaCl cooled to 4°C was delivered by gravity infusion through 6- or 9-Fr balloon perfusion catheters placed into the renal artery ostia. After an initial bolus of 300 mL, a continuous infusion was maintained at approximately 20 mL/min. When 10 patients who underwent surgery without renal cooling were compared with 11 recipients of cold renal perfusion, significantly lower rates of postoperative renal insufficiency, multiple organ failure, and mortality were reported in the latter group.

**EVOLUTION OF OUR APPROACH TO RENAL PERFUSION**

Our group’s approach to renal perfusion has evolved substantially over the past decade, primarily driven by the results of two randomized single-center trials evaluating the relative efficacy of three renal perfusion strategies. Before these studies, we used either selective renal perfusion with isothermic blood from a LHB circuit (particularly in extent I and II repairs) or cold crystalloid renal perfusion (particularly in extent III and IV repairs). Because it was unclear as to which method (if either) provided the best renal protection, in the initial comparison, we sought to directly compare these two techniques (35). Thirty patients undergoing extent II TAAA repair performed with LHB were randomly assigned to either receive renal perfusion with cold lactated Ringer’s solution (n = 14) or isothermic blood (n = 16). The incidence of postoperative renal dysfunction—defined as a 50% or greater increase in serum creatinine level from baseline—was significantly lower in the cold lactated Ringer’s solution group (three of 14 [21%]) than in the isothermic blood group (10 of 16 [63%]; p = .03). Only one patient (6%), who was in the isothermic blood group, developed postoperative ARF and required dialysis.

Because the benefits of local hypothermia exceeded those of isothermic blood perfusion, we wondered whether combining hypothermia with blood perfusion would enhance protection. Therefore, in our second trial, we examined the intuitive benefits of delivering blood while establishing and maintaining renal hypothermia (15). In this study, 172 patients undergoing extent II or III TAAA procedures with LHB were randomly assigned to receive intermittent renal perfusion with either cold blood or cold lactated Ringer’s solution. The incidence of ARF requiring dialysis was 3% in both groups and there was no difference in the incidence of postoperative renal dysfunction. Changes in urinary markers of renal injury—including retinol binding protein, α-1 microglobulin, microalbumin, N-acetyl-β-D-glucosaminidase, and intestinal alkaline phosphatase—were similar in the two groups. Surprisingly, there was a higher incidence of paraplegia or paraparesis in the cold blood group (five of 86 [6%]) compared with the cold crystalloid group (zero of 86); this difference nearly reached statistical significance (p = .06). Although the total intercostal ischemic time was longer in the cold blood group than in the cold crystalloid group, the unprotected (i.e., time without LHB) intercostal ischemic times were similar in the two groups. Ultimately, we were unable to identify a clear
explanation for the difference in spinal cord complications. The study did, however, confirm the efficacy of renal hypothermia in preventing renal complications and also helped define the degree of hypothermia needed to provide effective protection. The target left kidney temperature during cold renal perfusion (15°C or less) was achieved in only 41% of patients. In nearly all patients (97%), left kidney temperature was reduced to 28°C or less. We found that the incidence of renal dysfunction was similar among those in whom the 15°C threshold was attained and in those in whom this target was not reached, supporting the concept that moderate levels of renal hypothermia can provide sufficient renal protection during TAAA surgery.

Our current approach to renal protection is based on these studies (36,37). We routinely use intermittent cold crystalloid perfusion (provided that we have direct access to the renal artery ostia) in patients undergoing TAAA repair. The perfusate is prepared by adding mannitol (12.5 g/L) and methylprednisolone (125 mg/L) to lactated Ringer’s solution, which is then cooled to 4°C and administered by a roller head pump and ¼-inch perfusion tubing that terminates in a bifurcation connected to two 9-Fr Pruitt balloon perfusion catheters (LeMaitre Vascular Inc., Burlington, MA). In most patients undergoing extent I or II TAAA repair, we use LHB to provide distal aortic perfusion (including to the renal arteries) during the proximal anastomosis between the aorta and the graft (Figure 1A). After completing the proximal anastomosis, LHB is stopped and the remainder of the aneurysm is opened longitudinally. In patients undergoing extent III or IV TAAA repairs, during which we rarely use LHB, the entire aneurysm is opened immediately after aortic clamping. In most cases, the abdominal portion of the aortotomy provides exposure of the renal artery origins, which are then evaluated for occlusive disease and dissection. When there is significant stenosis resulting from atherosclerosis or dissection, an endarterectomy or balloon-expanded stent deployment is performed (38). Perfusion catheters are then introduced into the renal arteries (Figure 1B); in patients with aortic dissection extending into a renal artery, we ensure that the catheter is placed into the true lumen. To prevent arterial rupture, balloons are inserted just beyond the ostium and inflated just enough to avoid displacement. An initial bolus of 200–300 mL per kidney of cold solution is administered. This is followed by 200- to 300-mL infusions (100–150 mL per kidney) delivered intermittently every 10–15 minutes until arterial flow is re-established. Importantly, the amount and frequency of the cold boluses are adjusted to maintain systemic temperature greater than 32°C and to avoid fluid overload. We generally deliver approximately 1 L of cold crystalloid during the operation. We only place a temperature probe into the left renal parenchyma if necessary for a research protocol. After the completion of aortic repair, the operative field is irrigated with warm saline to reverse systemic cooling; the patient’s nasopharyngeal temperature generally rises to 33°C by the end of the procedure.

We have evaluated the outcomes in 434 consecutive patients who underwent open TAAA repair after completion of the second randomized trial in late 2006 (Table 1). Left heart bypass was used during the majority of extent I and II TAAA repairs but rarely in extent III TAAA procedures. Cold crystalloid perfusion of the renal arteries was used in nearly all patients who underwent extent II, III, or IV repairs. Because access to the renal artery ostia is often limited during extent I repairs, cold renal perfusion was used in only 54% of these procedures. The overall operative mortality rate was 7%, and the overall incidence of acute renal dysfunction was 15%. Ten percent of patients needed transient postoperative dialysis, and only 6% required dialysis after discharge.

TECHNICAL CONSIDERATIONS

It is important to highlight the potential technical pitfalls and relevant anatomic considerations related to renal perfusion techniques during TAAA repair. Inserting

<table>
<thead>
<tr>
<th>Techniques and Outcomes</th>
<th>All Patients (n = 434)</th>
<th>Extent I (n = 108)</th>
<th>Extent II (n = 137)</th>
<th>Extent III (n = 81)</th>
<th>Extent IV (n = 108)</th>
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<tr>
<td>Renal perfusion technique</td>
<td></td>
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<tr>
<td>Left heart bypass</td>
<td>226 (52%)</td>
<td>90 (83%)</td>
<td>6 (7%)</td>
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<tr>
<td>Cold crystalloid perfusion</td>
<td>379 (87%)</td>
<td>58 (54%)</td>
<td>136 (99%)</td>
<td>78 (96%)</td>
<td>107 (99%)</td>
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<tr>
<td>Outcomes</td>
<td></td>
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<tr>
<td>Operative mortality</td>
<td>32 (7%)</td>
<td>6 (6%)</td>
<td>9 (7%)</td>
<td>9 (11%)</td>
<td>8 (7%)</td>
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<tr>
<td>Acute renal dysfunction</td>
<td>63 (15%)</td>
<td>17 (16%)</td>
<td>22 (16%)</td>
<td>13 (16%)</td>
<td>11 (10%)</td>
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<td>ARF requiring dialysis</td>
<td>43 (10%)</td>
<td>12 (11%)</td>
<td>16 (12%)</td>
<td>9 (11%)</td>
<td>6 (6%)</td>
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<tr>
<td>ARF, on dialysis at discharge</td>
<td>24 (6%)</td>
<td>4 (4%)</td>
<td>10 (7%)</td>
<td>5 (6%)</td>
<td>5 (5%)</td>
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ARF, acute renal failure.
perfusion catheters into the renal arteries can be challenging in patients with a small arterial orifice, branch vessel dissection, or atherosclerotic occlusive disease. When the orifice of a renal artery is too small to accommodate a 9-Fr catheter, a 6-Fr catheter can be used to deliver cold perfusate (31). Gentle dilatation of the stenotic renal artery orifice with a fine clamp before inserting the perfusion catheter has been described (39). Great care to avoid creating an arterial dissection and/or perforation while inserting perfusion catheters is paramount. Similarly, over-inflation of catheter balloons can rupture the arterial wall. The risk of branch-vessel perforation or rupture is particularly high after endarterectomy. Right renal artery perforation is particularly vexing to identify, because bleeding occurs into the right retroperitoneum. Unexplained hypovolemia after blood flow is restored to the viscera should prompt thorough evaluation of the mesentery and retroperitoneal anatomy to rule out branch-vessel rupture. When a perforation is small and accessible, primary repair is recommended; however, severe arterial injuries may require bypass with synthetic or vein grafts. Although uncommon, severe bleeding from a ruptured right renal artery can necessitate ligation to achieve adequate hemorrhage control.

Cold crystalloid perfusion increases the risk of volume overload and systemic hypothermia, which can induce arrhythmias and coagulopathy. Hence, careful attention to temperature and volume status is vital. Boluses of cold crystalloid are delivered judiciously to prevent nasopharyngeal temperature from falling below 32°C. Discussing these issues in advance (i.e., during the preoperative “time-out” briefing) and maintaining clear communication with the perfusion and anesthesia teams during the procedure are paramount.

SUMMARY

Several renal perfusion techniques are available to surgeons; using these to protect the kidneys while the aorta is clamped during TAAA repair is an essential component of a broader strategy for preventing ischemic complications and improving patient outcomes. Importantly, recent consensus practice guidelines suggest that “renal protection by either cold crystalloid or blood perfusion may be considered” based on Level B evidence (40). This Class IIb recommendation underscores the need for further studies to confirm the efficacy of renal perfusion during open thoracoabdominal aortic repair.

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