

# Renal protection in thoracoabdominal aortic aneurysm surgery

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**Abstract** It is indisputable that open thoracoabdominal aortic aneurysm (TAAA) repair remains a highly complex and sophisticated surgical intervention. Despite advancements in the imaging modality, evolution of our understanding of the pathology afflicting the aorta, intraoperative brain and spinal cord monitoring, intraoperative organ protection, postoperative critical care and organ support, monitoring and the close follow-up of affected patients, this type of surgery remains a challenge to the surgeon and the patient. In this review, we will illustrate the recent evidence on renal protection and prediction during TAAA.

**Keywords** Aneurysm · Aortic · Aorta · Aortic operation · Hypothermia · Kidney · Perfusion

## Background

It is indisputable that open thoracoabdominal aortic aneurysm (TAAA) repair remains a highly complex and sophisticated surgical intervention. Despite advancements in the imaging modality, evolution of our understanding of the pathology afflicting the aorta, intraoperative brain and spinal cord monitoring, intraoperative organ protection, postoperative critical care and organ support, monitoring and the close follow-up of affected patients, this type of surgery remains a challenge to the surgeon and the patient. Early mortality from open repair remains significant, ranging from 5 to 19% [1]. Organ protection during TAAA surgery remains

an elusive target and a challenge. In the early days, multiple techniques were described to reduce ischemic damage to downstream organs including the spinal cord and kidneys, however, those techniques were undoubtedly limited and burdened with complications and failure. To be specific, such techniques include decreasing the duration of aortic and visceral artery clamping times with an approach that focused on restoring the renal arteries first, and working backward to complete the aortic repair, using passive shunts [2] to maintain an oxygenated blood supply, and inducing hypothermia to reduce metabolic demand [3]. Nonetheless, in the modern era, spinal cord perfusion can be intrinsically monitored intraoperatively utilizing neuromonitoring devices, motor and somatosensory evoked potentials, and after surgery on intensive care using motor-evoked potentials. This monitoring allows the surgeon to change surgical tactics and strategy to improve blood supply to the spinal cord. However, renal and visceral ischemia remain life-threatening complications of TAAA repair. In this review, we will illustrate the recent evidence on renal protection and prediction during TAAA.

## Preoperative renal function

Renal dysfunction after TAAA repair occurs in as many as 28% of patients, it necessitates postoperative dialysis in 4–11% of cases [4]. Different biomarkers have been described and used to predict renal failure postoperatively [5] but again those are surgeon-dependent and not patient-specific. Girardi et al. [6] have reported that preoperative renal failure (defined as a serum creatinine level > 1.5 mg/dL or need for hemodialysis) on mortality and morbidity following open repair of thoracic and thoracoabdominal aortic aneurysms. They conclude that preoperative renal failure predicts substantially higher rates of operative and late

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mortality and of major adverse events. However, their study is not of novelty as similar groups from around the world had previously reported their large series and concluded the same [4, 7–12].

On the contrary, Safi et al. had previously described the importance of a stronger surrogate marker between the preoperative glomerular filtration rate and mortality following thoracic and thoracoabdominal aortic surgery [5]. They confirmed the risk profile associated with increased mortality and morbidity following TAAA repair stating that clinically evident renal disease (dialysis, history of renal insufficiency, or serum creatinine > 2.0 mg/dL) is a known risk factor for mortality after thoracoabdominal aortic aneurysm repair. However, they hypothesized that the glomerular filtration rate (GFR) would be a more sensitive determinant of renal function than serum creatinine alone.

## Intraoperative renal protection strategies

### Distal perfusion techniques and adjuncts

#### *Passive shunts for renal perfusion during thoracoabdominal repair*

Historically, TAAA repair and renal protection were limited to the method of a shunt that maintained antegrade flow from the descending thoracic aorta to the infrarenal aorta while the aorta was clamped [13]. 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 [13].

#### *Left heart bypass (LHB)*

Left heart bypass (LHB) use is associated with an increased incidence of postoperative renal failure [14] and isothermic visceral and renal perfusion was a concern in some initial studies. Jacobs et al. [15] postulated that this may be due to inadequate renal perfusion pressure. They proposed using catheters equipped with pressure channels to maintain the perfusion pressure at 60 mmHg or higher, particularly in patients with chronic hypertension or chronic renal insufficiency (e.g., 85 mmHg). Kulik and colleagues [4] reported their experience with extent I, II, and III TAAA repairs performed with cardiopulmonary bypass and deep hypothermic (22 °C or lower) circulatory arrest, with a 7% incidence ( $n = 15$ ) of new-onset acute renal failure necessitating dialysis out of 218 patients. More than half of these patients receiving dialysis died secondary to multisystem organ dysfunction, but only 4% of early survivors required temporary dialysis. Yet, in 1996, Coselli et al. introduced the concept

of left heart bypass (LHB) for TAAA repair [16] with substantial improvements regarding morbidity and mortality after TAAA. Their early outcomes following LHB including the operative mortality was 10% in a cohort of 1415 patients with Crawford class II aneurysms. Postoperative complication rates included paraplegia in 7.5%, pulmonary complications in 35.7%, and renal failure in 15.9%, which demonstrated acceptable levels in this high-risk population. This had then shifted the paradigm of how we manage and protect renal function in TAAA repair.

#### *Cardiopulmonary bypass and hypothermia*

In contrast to LHB, partial and total CPB circuits drain deoxygenated blood while returning extracorporeal oxygenated blood to the body. Cardiopulmonary bypass enables various approaches to produce 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 [17]. 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 [18]. 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]. However, there are some disadvantages of cardiopulmonary bypass requiring higher level of heparinisation with increased bleeding associated complications. Therefore, this method of circulatory management is not the preferred method for those with high volume practice.

#### *Renal endarterectomy*

Endarterectomy has been used since the 1950s to remove atherosclerotic material near vessel ostia. However, endarterectomy allows the distortion of the aortic wall and as such it render the wall thin and friable. Early work from Crawford group [19] in Houston deduced that endarterectomy of the renal vessels improved renal perfusion and pressure allowing preoperative renal dysfunction to be corrected. Moreover, Svensson et al. [20] demonstrated that renal endarterectomy is associated with significantly less renal failure in patients with pre-existing renal dysfunction. This practice remains surgeon specific without the robustness of evidence data on trial level. This procedure can be used as an adjunct during TAAA surgery to improve patency and perfusion of renal arteries. Moreover, the use of hybrid stent grafts (GORE® Hybrid Vascular Graft) with sutureless anastomosis facilitates reimplantation of renal arteries with downstream stenosis and perfusion during surgery [21].

## Renal perfusates

### Cold crystalloid versus cold blood substrate

Cold crystalloid (lactated Ringer solution) renal perfusion during TAAA repair has been used since the 1970s [20, 22, 23]. Its use does not depend on the concurrent use of left heart bypass (LHB) described above, which is typically limited to more extensive extent II and III TAAA repairs and may be delivered through a separate perfusion circuit in all extents of TAAA repair. Assessing the current aortic guidelines, one would come across a scattered level of evidence that recommend the use of cold blood or cold crystalloid renal perfusion (class IIB, level of evidence B) [24]. Coselli et al. took matters to higher level with their randomized clinical trials [25, 26] on renal and visceral protection for repair of TAAA. In the first trial, they compared postoperative renal dysfunction in patients receiving either normothermic blood or cold crystalloid for renal perfusion. Applying the multivariate analysis, they demonstrated that cold crystalloid perfusion independently protected against renal dysfunction. Subsequently, they compared renal outcomes in patients receiving either cold blood or cold crystalloid for renal perfusion.

They strikingly found no significant difference between patients about renal failure or early death; however, they noted statistically non-significant trend toward less paraplegia in the cold crystalloid group. This area will always remain debatable as clearly the need for protective renal perfusion will probably remain high because many patients with TAAA have pre-existing renal dysfunction, which has clearly been associated with early death and morbidity as described above. There are other substrate including cold crystalloid fluid, cold saline solution, cold blood, and other cold electrolyte solutions provide effective renal protection that have been described in the literature [26], however, they are biased for small samples, surgeon specific biases and unbalanced cohorts. On the contrary, more studies emerged with a different twist to the extensive reported practice of the Houston group mentioned above. Those studies compared the renal perfusion strategy of using cold crystalloid solution enriched with histidine-tryptophan-ketoglutarate with cold Ringer's lactate solution in patients undergoing open TAAA repair. After 1:1 propensity score matching of 42 patients in each group, the observed freedom from acute kidney injury was significantly greater in the histidine-tryptophan-ketoglutarate group (38.1%) than in the Ringer's lactate solution group (9.5%;  $P = 0.002$ , despite longer total renal ischemic time in the former group [27]. Although the evidence supports the use of cold crystalloid, this substrate 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.

### Custodiol or other cold crystalloids

Histidine-tryptophan-ketoglutarate (HTK) crystalloid solution (Custodiol) offers myocardial protection comparable with repeated tepid blood cardioplegia. In its composition which is primarily a crystalloid solution that is high flow and with electrolyte concentration which is similar to the intracellular environment hence, having low sodium, calcium, potassium and magnesium when compared to Ringer's solution. As such these low levels of electrolytes will reduce the cellular swelling, toxicity and damages caused by the ischemic insult during the bypass and cooling [27]. The main evidence of using Custodiol came from transplant surgery, in particular kidney transplantation, where using Custodiol the donor kidney can survive a prolonged period of ischemia longer than 20 h [28].

Current consensus guidelines recommend the use of either cold crystalloid or blood perfusion as renal protection method during TAAA repair (class IIB, level of evidence B) [24] and the most widely used crystalloid solution is the lactated Ringer's solution [25, 26].

Tshomba et al. [27] studied 111 patients in a propensity matched, prospective study using Ringer's solution versus Custodiol in renal protection during TAAA. They concluded that although the ischemic time was longer in Custodiol group and such patients had higher rate of transfusion requirements, the rate of acute kidney injury was reduced by two-third while using Custodiol than Ringer's solution. It was also associated with higher rate of improvement in eGFR, thus Custodiol renal perfusion was found to be the only independent predictor of freedom from acute kidney injury. However, this study has several confounding factors pertaining to its retrospective nature and the analysis could have potentially been biased by factors that may have influenced renal injury after TAAA repair including the role of volume overload during AKI, the loop diuretics whether given, the increased content of mannitol in the implemented lactated Ringer's solution if used, and the role of supplementation with methylprednisolone.

## Conclusion

Renal protection during TAAA has expanded from historic times and the current armamentarium for this entity allows the surgeons some degree of maneuverability. Importantly, recent consensus practice guidelines suggest that "renal protection by either cold crystalloid or blood perfusion may be considered" based on Level B evidence. This Class IIB

recommendation underscores the need for further studies to confirm the efficacy of renal perfusion during open thoracoabdominal aortic repair.

### Compliance with ethical standards

**Conflict of interest** There are no conflicts of interest or sources of support.

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