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[Intervention Review]

Distal aortic perfusion during thoracoabdominal aneurysm repair for prevention of paraplegia

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ABSTRACT

Background

During thoracoabdominal aortic aneurysm (TAAA) surgery, decreased spinal cord perfusion can result in neurological deficits such as paraplegia and paraparesis. Distal aortic perfusion, alone or in combination with other adjuncts, may counter the decrease in spinal cord perfusion and hence reduce the risk of spinal cord injury.

Objectives

To determine the effectiveness of distal aortic perfusion with or without other adjuncts against other adjuncts without use of distal perfusion during TAAA surgery in reducing the risk of developing paraplegia and paraparesis.

Search methods

The Cochrane Peripheral Vascular Diseases Group Specialised Register (last searched 5 January 2012) and CENTRAL (Issue 4, 2011) were searched for publications describing randomised controlled trials of distal aortic perfusion during thoracoabdominal aortic aneurysm surgery. Reference lists of relevant studies were checked.

Selection criteria

Randomised or quasi-randomised controlled clinical trials of distal aortic perfusion during TAAA repair.

Data collection and analysis

Studies identified for potential inclusion were independently assessed for inclusion by at least two authors, with excluded trials arbitrated by the third author.

Main results

There were no randomised controlled trials identified.

Authors' conclusions

Currently, there are no randomised controlled trials to support the role of distal aortic perfusion in TAAA surgery for prevention of neurological injury. However, randomised controlled trials are not always feasible based on ethical grounds. Observational studies suggest that distal aortic perfusion alone or in combination with other adjuncts, that is cerebrospinal fluid (CSF) drainage, reduces the rate of neurologic deficit across all types of TAAA; in particular making a striking difference in the rate of neurologic deficit following type II TAAA repair. In the absence of randomised controlled trials, we recommend a standardised approach to reporting through registry studies to strengthen the evidence base for distal aortic perfusion.

PLAIN LANGUAGE SUMMARY

Distal aortic perfusion during thoracoabdominal aneurysm repair for prevention of paraplegia

Aneurysm of an artery is a localised abnormal dilation with a diameter of the artery at least one and a half times its normal size. Aneurysms in both the thoracic and abdominal aorta are termed thoracoabdominal aortic aneurysms (TAAA). Open surgical repair is effective in ensuring the survival of people with such aneurysms. Complications of paralysis of the legs and lower parts of the body (paraplegia) and partial paralysis affecting the lower limbs (paraparesis) can however develop during surgery and in the postoperative period, following apparently successful surgery. This is the result of inadequate blood flow to the spinal cord and the vulnerability of the spinal cord to ischaemic injury.

Different additional treatments (adjuncts) are used to protect the spinal cord and minimise the chances of these complications. Distal aortic perfusion is one of these. The most commonly used technique is through cannulation of the left atrium to redirect blood flow through a centrifugal pump to the distal aortic region to maintain perfusion to the spinal cord and vital organs such as the kidneys. This is a complex procedure that has its own specific complications. It can be used alone or with other adjuncts that include systemic cooling or regional spinal cord cooling, cerebrospinal fluid (CSF) drainage, re-anastomosis (re-joining) of intercostal arteries, monitoring somatosensory-evoked potentials to indicate spinal cord ischaemia.

Currently, there are no randomised controlled trials (RCTs) to support the role of distal aortic perfusion in TAAA surgery for prevention of neurological injury. Observational studies from experienced surgical centres suggest a potential benefit with the use of distal aortic perfusion as sole adjunct or in combination with CSF drainage. This will need to be validated in future RCTs to compare distal aortic perfusion with another adjunct against other adjuncts without use of distal perfusion during TAAA repair. Randomised controlled trials are not always feasible in this type of surgery based on ethical grounds.

BACKGROUND

Description of the condition

An aneurysm of an artery is a localised abnormal dilation with a diameter of the artery at least 50% greater than its normal size. Aneurysms that coexist in both segments of the thoracic and abdominal aorta are termed thoracoabdominal aortic aneurysms (TAAA). The extent of aortic involvement in TAAA is described by the modified Crawford classification as type I to V (Table 1). TAAA repair is associated with a significant mortality of 3% to 23%, reported in recent literature, with open surgical repair an effective method to ensure survival (Tabayashi 2005). This is verified by the fact that only two patients need to be treated to prevent

one mortality, a number needed to treat (NNT) of two (Miller 2004). The most feared complications are paralysis of the legs and lower parts of the body (paraplegia) and partial paralysis affecting the lower limbs (paraparesis) following apparently successful surgery. The incidence ranges between 5% and 11% (Cambria 2002; Coselli 2000; Estrera 2001; Hollier 1992) of thoracoabdominal surgeries and up to 22% after type II TAAA repairs (Greenberg 2008). The postoperative complication of paraplegia or paraparesis results in severe physical disability and is also associated with decreased life expectancy (Svensson 1991). In the reported series by Svensson et al, the five-year survival rate for patients with spinal cord injury was 44%, compared with 62% for those without spinal cord injury (Svensson 1993). In the last decade, a variety of techniques have emerged for prevention of paraplegia and paraparesis.

These include systemic cooling or regional spinal cord cooling, cerebrospinal fluid (CSF) drainage, re-anastomosis (re-joining) of intercostal arteries, monitoring somatosensory-evoked potentials, distal aortic perfusion; and a combination of these techniques (Table 2) (Bicknell 2009).

How the intervention might work

Paraplegia and paraparesis occur in the setting of TAAA surgery because of the inherent vulnerability of the spinal cord to ischaemic injury as well as an inadequate blood supply to the spinal cord in the perioperative and postoperative period (Griep 2007). The spinal cord is supplied by one anterior and two posterior spinal arteries. These spinal arteries are in turn supplied by radiculomedullary arteries that arise from intercostal branches of the aorta and lumbar arteries in the thoracolumbar region. Not all intercostal branches contribute to spinal blood flow and the discontinuity of the anterior spinal artery with multiple watershed areas are inherent vulnerabilities for spinal cord ischaemia. The most dominant radiculomedullary artery is named the artery of Adamkiewicz and supplies the lower one-third of the spinal cord (Yoshioka 2006). It is variable in location, originating from a left intercostal or lumbar artery in 68% to 73% of cases and at the level of the ninth to 12th intercostal artery in 62% to 84% (Uotani 2008; Yoshioka 2006). Other factors to consider that could affect blood supply to the spinal cord include previous aortic aneurysm repair and the patencies of collateral circulations via the subclavian, iliac and vertebral arteries.

The principle of distal aortic perfusion is to maintain spinal cord and renal perfusion during the critical period of aortic cross clamping. Distal aortic perfusion can be accomplished through insertion of either a passive shunt, which relies on a pressure gradient, or a bypass by the use of roller pumps, centrifugal pumps or total cardiopulmonary bypass. The major disadvantage of passive shunts, such as the Gott shunt, is that they cannot regulate flow. Atrial-femoral bypass with a centrifugal pump is the most widely accepted technique and has the advantage of avoiding or at least reducing heparinisation (Cambria 1998; Jacobs 1999) as well as the ability to control distal flow. In this technique, the left atrium or pulmonary vein is cannulated and blood is pumped and directed to the distal aorta via the femoral artery, but can also be directed into the distal aorta itself or via a surgically fashioned conduit. Using a centrifugal pump in atrial-femoral bypass is superior to passive shunting by allowing adjustment of blood flow to equilibrate the proximal and distal aortic pressures (Cambria 1998; Robertazzi 1998; Tabayashi 2005). Distal aortic perfusion preserves flow to the spine during the construction of the proximal anastomosis because the technique of sequential clamping is employed. This protection is however brief and does not explain the beneficial effects of distal aortic perfusion because the vast majority of the aneurysm wall and the corresponding intercostals and lumbar arteries are excluded should no re-attachment be performed.

In circumstances where the arteries supplying the anterior spinal artery arise from the excluded segment of the aorta, the spinal cord will remain ischaemic even if the distal aorta is perfused (Tabayashi 2005). However, distal aortic perfusion is continued during the re-implantation of the visceral segment and distal anastomosis creation with some flow to the spine via the collateral network until the restoration of the flow to the iliacs. Potential serious complications associated with distal aortic perfusion include haemorrhage at the cannulation site, embolisation and dissection of the aorta and visceral arteries (Jacobs 1999).

Distal aortic perfusion is often used in combination with other techniques, such as systemic cooling or regional spinal cord cooling, cerebrospinal fluid (CSF) drainage, re-anastomosis of intercostal arteries, and monitoring motor and somatosensory-evoked potentials (Table 2) (Bicknell 2009). Over a 15-year period, Safi et al have reported the use of distal aortic perfusion together with CSF drainage and systemic cooling with a dramatic reduction of neurologic deficit, to less than 2% (Safi 2008). The CSF drainage technique aims to reduce CSF pressure and may counter the increase in CSF production secondary to proximal hypertension from aortic cross clamping (Khan 2003; Robertazzi 1998). Intraoperative monitoring of evoked potentials can serve as an indicator of spinal cord ischaemia and may be used to guide the need for CSF drainage when concomitantly used (Weigang 2005). Intercostal and lumbar vessel re-anastomosis is a technique aimed to preserve spinal cord perfusion where the artery of Adamkiewicz is most likely to be found (T9 to T12). Additional protection of the spinal cord may be achieved by cooling of the epidural space during surgery (Davison 1994). However, the same effect may be reproduced by passive hypothermia, allowing the patient to cool down to 32 °C during the procedure (Griep 2007).

Why it is important to do this review

These additional techniques are now widely used with distal aortic perfusion but there is no consensus on the role of each technique regarding the reduction in the rate of paraplegia. Distal aortic perfusion may have a major role but is associated with an increased complexity of the procedure and specific complications, especially when cardiopulmonary bypass is used. The aim of this review was to evaluate the evidence regarding the use of distal aortic perfusion in TAAA repairs with or without additional techniques for prevention of paraplegia or paraparesis.

OBJECTIVES

To determine the effect of distal aortic perfusion with or without additional techniques (systemic cooling or regional spinal cord cooling, CSF drainage, re-anastomosis of intercostal arteries and

monitoring somatosensory-evoked potentials) on rates of paraparesis and paraplegia in patients undergoing elective thoracoabdominal aortic aneurysm (TAAA) repair.

METHODS

Criteria for considering studies for this review

Types of studies

Randomised or quasi-randomised controlled clinical trials of distal aortic perfusion during thoracoabdominal aortic aneurysm (TAAA) repair.

Types of participants

Patients of any age undergoing elective TAAA repair. Patients undergoing elective repair of TAAA caused by dissection were considered. Studies that did not separate cases into those that were elective or emergency were not considered.

Types of interventions

We included studies using distal aortic perfusion with or without additional techniques (systemic cooling or regional spinal cord cooling, CSF drainage, re-anastomosis of intercostal arteries and monitoring somatosensory-evoked potentials) during TAAA repair. The review made a distinction between bypass with a centrifugal pump and passive shunts. This is compared with TAAA repair without the use of additional techniques.

Types of outcome measures

Primary outcomes

To determine the effect of distal aortic perfusion on rates of the following.

1. Postoperative spinal cord deficits:
 - i) paraplegia, temporary or permanent;
 - ii) paraparesis, temporary or permanent.
2. In-hospital mortality:
 - i) intraoperative mortality;
 - ii) postoperative mortality: cardiac failure, oesophageal perforation, intestinal ischaemia, respiratory failure, multi-organ failure, aorta related complications, cerebrovascular accidents and others.

Secondary outcomes

1. Renal failure after TAAA repair:
 - i) temporary dialysis;
 - ii) permanent dialysis.
2. Length of hospital stay (in days) with or without intensive care unit (ICU) admission.

Search methods for identification of studies

Electronic searches

The Cochrane Peripheral Vascular Diseases Group (PVD) Trials Search Co-ordinator (TSC) searched the Specialised Register (last searched 5 January 2012) and the Cochrane Central Register of Controlled Trials (CENTRAL) (Issue 4, 2011), which is part of *The Cochrane Library* (www.thecochranelibrary.com). See [Appendix 1](#) for details of the search strategy used to search CENTRAL. The Specialised Register is maintained by the Trials Search Co-ordinator and is constructed from weekly electronic searches of MEDLINE, EMBASE, CINAHL and AMED, and through handsearching relevant journals. The full list of the databases, journals and conference proceedings which have been searched, as well as the search strategies used, are described in the [Specialised Register](#) section of the Cochrane Peripheral Vascular Diseases Group module in *The Cochrane Library* (www.thecochranelibrary.com).

Search for ongoing trials

The PVD group TSC searched ClinicalTrials.gov (<http://clinicaltrials.gov/>) and Current Controlled Trials (<http://www.controlled-trials.com/>) (5 January 2012) using the terms (perfusion AND aneurysm).

Searching other resources

We also searched reference lists of relevant studies.

Data collection and analysis

Selection of studies

Two authors (CC-TH and GNCK) independently assessed any studies identified for inclusion in the review using the criteria stated above. In cases of disagreement, the third author (MLvD) acted as arbiter.

Data extraction and management

Two authors (CC-TH and GNCK) intended to independently extract data from the studies included in the review using a standard data extraction form. If there were disagreements, the third author (MLvD) intended to act as arbiter. We intended to assess the primary outcomes measures within 30 days of TAAA repair. If different time points were reported we intended to also consider these.

Assessment of risk of bias in included studies

The authors (CC-TH and GNCK) intended to assess the risk of bias for each study as described in the *Cochrane Handbook for Systematic Reviews of Interventions* version 5.0.2 (Higgins 2009). The authors intended to assess the risk of bias for each of the following domains:

1. randomisation;
2. allocation concealment;
3. blinding (of participants, personnel and outcome assessors);
4. completeness of data;
5. selective outcome reporting;
6. other sources of bias.

The authors intended to evaluate each criterion as 'low risk of bias' or 'high risk of bias'. If these criteria were not discussed, the authors intended to judge the risk of bias as unclear.

Measures of treatment effect

When dealing with dichotomous outcome measures, we intended to calculate a pooled estimate of the treatment effect for each outcome across trials using the odds ratio (OR) (the odds of an outcome among treatment-allocated participants against the corresponding odds among participants in the control group) and the 95% confidence interval (CI). For continuous outcomes, we planned to record either mean change from baseline for each group or the mean post-intervention value and standard deviation for each group. Then, where appropriate, we planned to calculate a pooled estimate of treatment effect by calculating the mean difference and 95% CI.

Unit of analysis issues

Cross-over trials were not included in the review as only a single treatment can be designated to each group. In the case of cluster-randomised trials we planned to apply an appropriate adjustment for clustering as recommended in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2009).

Dealing with missing data

In order to allow an intention-to-treat analysis, we planned to seek data on the number of participants with each outcome event by

allocated treatment group, irrespective of compliance and whether or not the participant was later thought to be ineligible or was otherwise excluded from the treatment or follow up. The review authors planned to request any missing data from the original investigators, if appropriate.

Assessment of heterogeneity

We planned to assess statistical heterogeneity in the meta-analysis using the I^2 statistic (Higgins 2009). We also planned to explore reasons for the heterogeneity. A guide to interpretation is as follows, as described in the *Cochrane Handbook for Systematic Reviews of Interventions* version 5.0.2 (Higgins 2009):

- under 25% is considered low;
- 50% is considered moderate;
- over 75% is considered a high degree of heterogeneity.

The observed importance of I^2 depends on factors including: (i) magnitude and direction of effects and (ii) strength of evidence for heterogeneity, determined by the P value from the χ^2 test or a confidence interval for I^2 (Higgins 2009).

Assessment of reporting biases

We planned to investigate publication bias using funnel plots if we were able to include a sufficient number of studies (at least 10), as recommended by the Cochrane Handbook (Higgins 2009). If we detected asymmetry, we planned to explore causes other than publication bias. Asymmetrical funnel plots can indicate outcome reporting bias (ORB) or heterogeneity. If ORB was suspected, trialists would have been contacted. Outcome reporting bias can be assessed by comparing the methods section of a published trial to the results section if the original protocol is not available.

Data synthesis

We planned to report dichotomous outcomes as a summary weighted pooled odds ratio (OR) with a 95% confidence interval (CI). We planned to report continuous outcomes (for example duration of hospital stay) as a pooled weighted mean with standard deviation (SD).

We planned to use a fixed-effect model in our analysis. If we detected any moderate heterogeneity (I^2 greater than 50%), we planned to re-assess the significance of the treatment effect by using a random-effects model.

Subgroup analysis and investigation of heterogeneity

We intended to assess heterogeneity in a two-step approach. First, we would explore differences of study population, method, setting or outcomes that might jeopardise pooling of the studies. In the case of obvious 'face value' heterogeneity the studies would be

described but not pooled. Second, we would explore the presence of statistical heterogeneity by using the I^2 test (Higgins 2009). In the case of heterogeneity we intended to explain any heterogeneity, for example by comparing the characteristics of participants, interventions and the outcomes measured in the included trials. We planned subgroup analyses to be undertaken for patients stratified by the following factors:

1. different extent of TAAA according to the modified Crawford classification (I to V);
2. the year that the study was published (before and after 2000);
3. bypass with centrifugal pump versus passive shunts.

Sensitivity analysis

If possible, we planned to perform a sensitivity analysis restricted to RCTs where only trials with adequate allocation concealment and blinding were included. We also planned to assess the impact of statistical heterogeneity on the outcome by performing a sensitivity analysis.

RESULTS

Description of studies

See: [Characteristics of excluded studies](#)

Results of the search

The search of the PVD group Specialised Register did not identify any relevant trials. The search of *The Cochrane Library* yielded 103 reports to trials but none were RCTs relevant to the topic.

Included studies

No randomised or controlled clinical trials (CCTs) were eligible for inclusion in the review.

Excluded studies

Three observational studies were excluded. Cross-referencing identified 19 additional observational studies which were also excluded. The 22 excluded studies consisted of 21 retrospective studies and one prospective study. For details see [Characteristics of excluded studies](#).

Risk of bias in included studies

There were no included studies.

Effects of interventions

Results based on controlled trials were not available as no trials were identified by the search. Information regarding the effectiveness of the intervention is based only on observational data.

DISCUSSION

Summary of main results

Over the last two decades, a number of available adjuncts for protection of the spinal cord during thoracoabdominal aortic aneurysm (TAAA) repair have been developed. Distal aortic perfusion is one of the most consistently used adjuncts, often in combination with CSF drainage. The theoretical benefits of distal aortic perfusion are to maintain perfusion to the spinal cord through perfusion of intercostal arteries, provide perfusion to vital visceral organs and to protect the heart from the haemodynamic changes of cross clamping. Although numerous studies have assessed the efficacy of distal aortic perfusion as an adjunct during TAAA repair, we did not find any evidence from RCTs or CCTs.

Overall completeness and applicability of evidence

The review identified the majority of observational studies concerning use of distal aortic perfusion during TAAA repair through electronic searches as well as cross referencing and handsearching. The current evidence arises from observational studies, which limits its applicability; however, these studies do suggest a potential benefit of distal aortic perfusion in-conjunction with CSF drainage or as a lone adjunct in TAAA repairs.

Potential biases in the review process

There were no included studies in this review. Potential biases in the identification and qualitative assessment of the observational studies will be dictated by the authors' judgement of the relevance of the studies to the topic. Disagreements were resolved through discussion with the other co-authors.

Agreements and disagreements with other studies or reviews

In the modified Crawford classification (Table 1) Type II TAAA has been implicated as having the highest risk for neurologic deficits. From observational studies, distal perfusion with and without an adjunct appears to be beneficial in reducing neurological deficit

in type II TAAA repair. Safi et al, in a series of retrospective studies, investigated the efficacy of the adjuncts distal aortic perfusion (BioMedicus centrifugal pump to achieve left heart bypass) in combination with CSF drainage (Safi 1996b; Safi 1997; Safi 1999; Safi 2003). Neurologic deficits for patients operated on with the adjuncts were 2.4% and 16% in the historical cohort, from the era of 'cross clamp and go', across all type of TAAA repair (Safi 2003; Svensson 1993). The reduced incidence of neurologic deficit for type II TAAA was most noticeable, with a rate of 6.6% and 31% in the historical cohort (Safi 2003; Svensson 1993). Schepens et al, in a series of retrospective studies, also examined the efficacy of distal aortic perfusion (Biomedicus centrifugal pump to achieve left heart bypass) in combination with CSF drainage (Schepens 1999; Schepens 2004; Schepens 2007; Schepens 2009). In the era of cross clamping and a graft inclusion technique the incidence of paraplegia and paraparesis was 5.7% and 8% respectively (Schepens 1994). The use of distal aortic perfusion with a CSF drainage adjunct decreased paraplegia and paraparesis rate to 4.4% and 1.7% respectively (Schepens 2009).

Similar reductions in neurological deficits are seen in other large retrospective studies performed over the last two decades. Estrera et al demonstrated a significant reduction of neurologic deficits when both CSF drainage and distal aortic perfusion were used. Overall, neurological deficits were seen in 3.3% of the adjunct cohort and 8.4% of the group without adjuncts ($P = 0.004$) (Estrera 2001). In the type II TAAA subgroup, the incidence was 7.8% in the adjunct group compared to 30.6% in the non-adjunct group ($P < 0.001$) (Estrera 2001). Bavaria et al found that straight cross clamping resulted in a 27% spinal cord injury, whereas the addition of distal aortic bypass resulted in a statistically significant reduction ($P < 0.01$) in neurologic injury to 7% (Bavaria 1995). Distal aortic bypass also reduced the 60-day mortality rate from 22% to 7% ($P < 0.05$) (Bavaria 1995).

As part of a multi-modality approach for prevention of spinal cord ischaemia, distal aortic perfusion is often used in conjunction with other adjuncts such as CSF drainage. Therefore, it is difficult to attribute a subsequent effect of the interventions to one individual manoeuvre. Coselli et al, in a retrospective study with distal aortic perfusion (using centrifugal pump to achieve left heart bypass) as the sole adjunct, demonstrated a significant reduction in the rate of paraplegia and paraparesis in type II TAAA repair (4.5% with adjunct versus 11.2% without adjunct, $P = 0.019$) (Coselli 2003). However, distal aortic perfusion did not produce a significant reduction in Type I TAAA patients (3.1% with adjunct and 4.2% without adjunct, $P = 0.866$). In both type I and II repair with distal aortic perfusion the aortic clamp time was significantly longer than for the cohort without the use of an adjunct (Coselli 2003). This observation can be attributed to the reduction of ischaemia time by distal aortic perfusion thus allowing a longer clamping time.

The introduction of the modified Crawford's classification of TAAAs have lead to re-classification of type III TAAA and the cre-

ation of the Type V TAAA group, designed to aid analysis and further stratify risks for neurologic complications (Safi 1999). Type V TAAA repair was associated with a low risk of neurologic deficit, with the rate of neurologic deficit similar to type IV aneurysms (Achouh 2007; Safi 2003). The re-classification may be responsible for type III TAAA becoming a risk factor for neurologic deficit (Estrera 2001). Controversy remains on the use of distal aortic perfusion and additional adjuncts in type IV TAAA repair. The incidence of neurologic deficit with type IV TAAA repair remains low, 0% to 4.8% (Bicknell 2009; Patel 2011; Wahlgren 2005). For this reason distal aortic perfusion and adjuncts have been sparingly applied in this group (Patel 2011; Wahlgren 2005). A retrospective study of suprarenal aneurysm and type IV TAAA repair undertaken with only the clamp-and-sew technique demonstrated a 2% incidence of paraplegia (Richards 2010). Achouh et al applied distal aortic perfusion with adjuncts (CSF drainage, somatosensory evoked potentials, intercostal reattachments) in type IV TAAA repairs and the incidence of spinal cord ischaemia (2.7%) was comparable to studies where adjuncts were not routinely used (Achouh 2007; Patel 2011).

Due to the heterogeneity in the methodological design of the observational studies, it was not appropriate to pool these data for meta-analysis. Observational studies have a high risk of bias, for example a biased selection of participants, recall bias due to poor reporting in medical records and ascertainment bias (Higgins 2009). It is difficult to conclude from observational data alone that the potential benefits of the intervention are not the result of selection bias or other confounders. Although some studies have used historical controls from studies prior to the introduction of modern distal aortic perfusion techniques, any direct comparison between the two groups must be done with caution. Familiarity with the procedure with increased experience of the operators may be one of many confounders that lead to a reduction in overall mortality and morbidity in TAAA repairs.

Studies in TAAA repairs are faced with many inherent challenges, including low patient volume and variability in techniques between institutions and surgeons. Current observational evidence is derived from experienced centres in which data are collected prospectively over decades of practice. Multi-centre collaboration, with a standardised approach to reporting, may be a solution to strengthen the evidence base for distal aortic perfusion techniques. Consistent reporting of key risk factors for the development of neurological deficits, such as the type of TAAA, presence of acute or chronic dissection, contained rupture, renal dysfunction and type of adjunct utilised, are essential for continued improvement in TAAA repair (Safi 2003).

In the absence of RCTs, we are unable to fully evaluate the role of distal aortic perfusion during TAAA surgery. Results from experienced centres through cumulative retrospective studies have shown that distal aortic perfusion, alone or in conjunction with CSF drainage, reduces the incidence of neurological deficits. However, this must be interpreted with caution due to the lack of RCTs.

There may be an ethical dilemma in designing RCTs as distal aortic perfusion has been incorporated into routine practice at major centres for over two decades and accumulated data from observational studies have consistently described reductions in morbidity.

AUTHORS' CONCLUSIONS

Implications for practice

We were unable to identify any randomised or controlled clinical trials to support the use of distal aortic perfusion with or without additional adjuncts in patients undergoing TAAA repair. Current evidence from observational studies suggests that distal aortic perfusion, alone or with other adjuncts, may reduce the rate of paraplegia after TAAA repair; with type II TAAA repairs resulting in the most significant reduction in morbidity. The evolving multimodalities approach to TAAA repair means that distal aortic perfusion is rarely employed as a sole adjunct for the prevention of neurological injury.

Implications for research

This review highlights the gaps in evidence for the use of distal aortic perfusion during TAAA repair. Future research is needed to validate this procedure. Prospective randomised controlled trials are difficult to perform in TAAA surgery due to low patient volumes and the fact that distal aortic perfusion is already an established technique in many centres. Potential obstacles to multi-centre trials will need to overcome the variability in management strategies between different surgeons and institutions. In the absence of RCTs, there needs to be a standardised approach to reporting through registry studies to strengthen the observational evidence base for distal aortic perfusion.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Achouh 2007	Retrospective study of 444 patients with descending thoracic and thoracoabdominal aortic repair. Somatosensory evoked potentials (SSEP) were used in addition to distal aortic perfusion (Bio-Medicus pump with an inline heat exchanger), visceral perfusion, CSF drainage and re-attachment of patent lower intercostal arteries (T8 to T12)
Bavaria 1995	A retrospective study of 156 patients undergoing elective and emergent operations of the thoracic aorta. Techniques used during proximal aortic repair include (1) straight cross clamping of the distal ascending aorta, (2) hypothermic circulatory arrest, and (3) hypothermic circulatory arrest with retrograde cerebral perfusion. Techniques used during distal aortic repair include (1) straight aortic cross clamping and (2) distal aortic perfusion
Chiesa 2004	Retrospective study of 353 procedures for TAAA (178 cases) and thoracic aortic aneurysm (175 cases) . Group one, 157 patients, distal aortic perfusion and CSF drainage were used selectively and in group two, 196 patients, the adjuncts were used routinely
Conrad 2011	Retrospective study of consecutive patients undergoing repair of non-ruptured type I, II and III TAAA. Patients with type IV TAAA and isolated descending thoracic aneurysms were excluded. There were 52 patients in the adjunct group receiving distal aortic perfusion (DAP) through arterial-femoral bypass to support cord collateral circulation and selective intercostal reconstruction based on motor evoked potential (MEP) monitoring. This was compared with propensity-matched 127 patients treated with the clamp and sew technique
Coselli 1999	Retrospective study of 710 patients with type I or II TAAA. Left heart bypass was used in 312 patients. This group was retrospectively compared with 398 patients who had operations without bypass adjunct
Coselli 2002b	Retrospective study of 1773 patients underwent TAAA repair. Adjuncts used include segmental intercostal or lumbar arteries re-attachment (61%); left heart bypass (38.7%) and CSF drainage (9.8%)
Coselli 2003	Retrospective study of 1250 consecutive patients underwent type I or type II TAAA repair. Left heart bypass was used in (53.3%) patients. This group was retrospectively compared with (46.7%) patients who had undergone surgery without the use of left heart bypass
Coselli 2004	Retrospective study of 387 consecutive patients underwent surgical repair of descending thoracic aortic aneurysms using either the 'clamp-and-sew' technique in 341 patients and distal aortic perfusion in 46 patients
Estrera 2001	Retrospective study of 654 cases of the TAAA and thoracic aortic aneurysm. The adjuncts cerebrospinal fluid drainage and distal aortic perfusion were used in 428 of cases
Jacobs 1997	Prospective study of 33 consecutive patients underwent TAAA repair. In type I TAAA repair distal aortic perfusion was performed. In type II, III and IV the additional selective perfusion of the coeliac trunk, superior mesenteric and both renal arteries were performed with connection to the extracorporeal

(Continued)

	circulation
Kouchoukos 2003	Retrospective study of 211 patients underwent TAAA and thoracic aortic aneurysm repair. Profound hypothermia, distal perfusion, and intravenous methylprednisolone and thiopental
Morishita 1997	Retrospective study of 27 patients who underwent TAAA and descending thoracic aneurysm repairs, with heparin-bonded partial cardiopulmonary bypass to support distal aortic circulation during aortic cross clamping, 4 being excluded from the study. 20 patients underwent conventional partial cardiopulmonary bypass were defined as the control group
Quinones-Baldrich 2004	Retrospective study of 50 patients underwent repair of TAAA (47 patients) and thoracic aortic aneurysm (3 patients). Adjuncts used include invasive monitoring, modest anticoagulation, permissive hypothermia, intercostal arteries re-implantation, CSF drainage and distal aortic perfusion
Safi 1996a	Retrospective study of 136 patients underwent type I and type II TAAA repair. 94 patients had received distal aortic perfusion and CSF drainage
Safi 1996b	Retrospective study of 94 patients with TAAA. All patients underwent intraoperative distal aortic perfusion and perioperative CSF drainage
Safi 1997	Retrospective study of 343 patient underwent open TAAA repair and 53 for descending thoracic aneurysm. Simple cross clamp was used for 94 patients and combination of CSF drainage and distal aortic perfusion were for 186 patients. Either distal aortic perfusion or CSF drainage alone was used for 46 and 17 patients, respectively
Safi 1999	Retrospective study of 508 patients underwent open TAAA and thoracic aortic aneurysm repair. 255 patients received the adjuncts of cerebrospinal fluid drainage and distal aortic perfusion
Safi 2003	Retrospective study of 1004 patients underwent open TAAA and thoracic aortic aneurysm repair. Adjuncts of distal aortic perfusion and CSF drainage with moderate hypothermia were used in 741 of patients and 426 of patients underwent intercostal artery re-attachment
Schepens 1999	Retrospective study of 258 patients underwent open TAAA repair. Adjuncts used include simple cross clamping, left heart bypass, intercostal or lumbar artery re-implantation, CSF drainage, administration of a renal cooling solution, permissive mild hypothermia
Schepens 2004	Retrospective study of 402 consecutive patients underwent open TAAA repair. Adjuncts used include simple cross clamping, left heart bypass or extracorporeal circulation, somatosensory evoked potentials, motor evoked potentials and CSF drainage
Schepens 2007	Retrospective study of 500 consecutive open TAAA repairs. Adjuncts used include simple cross clamping, left heart bypass combined with staged clamping, together with evoked potential monitoring (somatosensory potentials and motor evoked potentials), moderate hypothermia and re-implantation of intercostal and lumbar vessels
Schepens 2009	Retrospective study of 571 patients underwent open TAAA repair. Adjuncts used include simple cross clamping, left heart bypass or extracorporeal circulation, somatosensory evoked potentials, motor evoked potentials and CSF drainage

DATA AND ANALYSES

This review has no analyses.

ADDITIONAL TABLES

Table 1. Crawford classification of thoracoabdominal aortic aneurysms

Modified Crawford classification (Crawford 1974; Safi 1999)	Extent of involvement
Type I aneurysm	Begin above the sixth intercostal space and extend down to the origins of the coeliac trunk and superior mesenteric arteries but above the level of the renal arteries
Type II aneurysm	Begin above the sixth intercostal space and extend into the infrarenal aorta, often to the level of the aortic bifurcation
Type III aneurysm	Begin below the sixth intercostal space to below the renal arteries
Type IV aneurysm	Involvement of the entire abdominal aorta from the level of the diaphragm (12th intercostal space) to the bifurcation (total abdominal aortic aneurysm)
Type V aneurysm	Begin below the sixth intercostal space to just above the renal arteries

Table 2. Techniques to prevent spinal cord deficits during TAAA repair

Maintenance of spinal cord perfusion
Distal aortic perfusion <ul style="list-style-type: none">• Passive shunt• Atrial-femoral bypass with centrifugal pump Cerebrospinal fluid drainage Intercostal and/or lumbar artery re-anastomosis
Neuroprotective measures
Systemic hypothermia Regional hypothermia <ul style="list-style-type: none">• Epidural infusion• Intrathecal infusion
Intraoperative monitoring for spinal cord ischaemia
Motor evoked potential (MEP) Somatosensory evoked potential (SSEP)

APPENDICES

Appendix I. CENTRAL search strategy PVD Group

#1	MeSH descriptor Aortic Aneurysm, Abdominal explode all trees	503
#2	(thoracic or thoracoabd*) near3 (aneurysm* or balloon* or dilat* or bulg* or ruptur*)	100
#3	TAAA	9
#4	MeSH descriptor Aorta, Abdominal explode all trees with qualifier: SU	174
#5	MeSH descriptor Aorta, Thoracic explode all trees with qualifier: SU	33
#6	MeSH descriptor Spinal Cord explode all trees with qualifier: BS	11
#7	distal near3 aort*	34
#8	MeSH descriptor Paraplegia explode all trees with qualifiers: CO,PC	33
#9	(#1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8)	801
#10	MeSH descriptor Perfusion explode all trees	697
#11	perfus*	5950
#12	bypass or shunt* or pump*	15793
#13	(#10 OR #11 OR #12)	20856
#14	(#9 AND #13)	103

HISTORY

Protocol first published: Issue 1, 2010

Review first published: Issue 3, 2012

Date	Event	Description
15 December 2009	Amended	Contact details of authors amended

CONTRIBUTIONS OF AUTHORS

Charlie Chia-Tsong Hsu (CC-TH), Gigi Nga Chi Kwan (GNCK) and John A Rophael (JAR) drafted the review. Mieke L van Driel (MLvD) provided support with the methodological aspects of the review. All authors contributed to drafting of the review and agreed on the final version.

DECLARATIONS OF INTEREST

None known

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DIFFERENCES BETWEEN PROTOCOL AND REVIEW

In order to reflect the objective of the review we have reordered the primary and secondary objectives. In addition we have removed the secondary outcome 'Major post-operative haemorrhage. Major haemorrhage is considered if it is fatal or leads to a decrease in the haemoglobin level of 20 mg/L or requiring transfusion of at least two units of blood' because on reflection it is not uncommon to receive two or three units of blood products during TAAA repair.

INDEX TERMS

Medical Subject Headings (MeSH)

Aortic Aneurysm, Abdominal [*surgery]; Aortic Aneurysm, Thoracic [*surgery]; Paraparesis [*prevention & control]; Paraplegia [*prevention & control]; Spinal Cord [*blood supply]; Spinal Cord Ischemia [*prevention & control]

MeSH check words

Humans