

REVIEW ARTICLES



Arterial pressure management and carotid endarterectomy

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Acute perioperative changes in arterial pressure occur frequently, particularly in patients with cardiovascular disease or those receiving vasoactive medications, or in relation to certain cardiovascular surgical procedures. Both hypo- and hypertension are common in patients undergoing carotid surgery because of unique patho-physiological and surgical factors. Poor arterial pressure control is associated with increased morbidity and mortality after carotid endarterectomy, but good control of arterial pressure is often difficult to achieve in practice. New guidelines have emphasized the benefits of performing carotid surgery urgently in patients with acute neurological symptoms. This strategy may make perioperative arterial pressure control more challenging. However, few specific data are available to guide individual drug therapy. The incidence, implications, and aetiology of haemodynamic instability associated with carotid surgery are reviewed, and some recommendations made for its management. Close monitoring and titration of therapy are probably the most important considerations rather than specific choice of agents.

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Acute changes in arterial pressure are common during many surgical procedures. A wide variety of causes may contribute,⁶¹ but cardiovascular instability is more common and marked in patients with cardiovascular disease or those receiving vasoactive medications or in those undergoing certain cardiovascular surgical procedures.

Carotid endarterectomy (CEA) is a preventative operation with well-defined indications based on the results of large-scale randomized prospective studies.^{26 42 73 78 110} The aim of surgery is to decrease the subsequent risk of fatal or disabling stroke in patients with significant carotid stenosis, but the benefits are only realized if perioperative morbidity and mortality are low. In addition to perioperative stroke, patients undergoing CEA are at increased risk of other cardiovascular complications because of the relatively high incidence of coexisting coronary artery disease, hypertension, and diabetes mellitus. Arterial pressure is often difficult to control in patients undergoing CEA, yet perioperative haemodynamic instability can directly or indirectly influence morbidity and mortality. Carotid surgery is unique in that one of the principal components of the physiological control mechanism of arterial pressure, the baroreceptors in the carotid sinus, are involved in the disease process itself, and may be affected by the surgical procedure, concurrent

therapy, and by anaesthesia. Patients who have suffered recent transient ischaemic attack (TIA) or stroke have altered baroreceptor sensitivity⁸³ and may therefore be at greater risk of haemodynamic instability (Table 1). Recent evidence has emphasized the high incidence of disabling and non-disabling stroke occurring in the first few days after a TIA, so that urgent surgery is now advocated.⁸⁶ Although vascular surgeons and stroke physicians support CEA being performed early after TIA, this could make perioperative cardiovascular management more difficult because baroreflex function is impaired in the first weeks after TIA or stroke.⁸³ This article reviews the incidence, significance, and causes of haemodynamic instability in patients undergoing CEA, considers the patho-physiological mechanisms involved, and the evidence for specific management strategies.

Perioperative risk factors in patients undergoing CEA

Several factors are associated with poor outcome after CEA, including prior ipsilateral hemispheric neurological symptoms (stroke or TIA), severe contralateral carotid stenosis, or distal internal carotid artery (ICA) or external carotid artery

Table 1 Risk factors for perioperative instability in patients undergoing CEA**Preoperative**Short interval between symptomatic neurological event and the date of surgery⁸⁹Bilateral carotid atheroma⁷⁴Previous contralateral CEA or radical neck surgery⁶Poorly controlled preoperative hypertension¹¹⁷**Intraoperative**Eversion endarterectomy⁶⁹Local anaesthetic block/section of carotid sinus nerve¹⁰⁸

stenosis.^{10 36 44 57 67 88 91} Risk is particularly high in those with acute or unstable neurological symptoms (e.g. very recent stroke or crescendo TIAs),^{11 107} and neurological risk is lower in asymptomatic patients⁸⁸ or those with ocular symptoms only.⁸⁷ Chronic renal failure,⁴⁵ severe coronary artery or peripheral vascular disease,^{65 88} or patients with a combination of medical risk factors are also associated with poor perioperative outcome.^{20 44 65 67 107} Longer term outcome is worse in patients who smoke, and those with diabetes or hyperlipidaemia, but for these and other risk factors, for example, age or gender, the evidence is inconclusive.⁴⁴ Hypertension is common in patients undergoing CEA, with a prevalence of about 65%.^{19 44 113} It is often assumed that untreated hypertension is an independent risk factor for poor outcome after CEA, but what is the evidence for this?

Hypertension and outcome after CEA

Severe preoperative hypertension may in theory predispose to neurological or cardiovascular complications after CEA. However, the data are inconsistent. Although several studies of CEA have shown a relationship between preoperative and postoperative hypertension,^{5 117} and between perioperative hypertension and worse neurological outcome or death,^{5 10 46 67 88} other large studies have found no such associations.^{44 91 113} Some of the negative studies involved subgroup analysis of data from studies showing a positive association.^{36 37} Possible reasons for these inconsistencies include differences in study size, design, period of follow-up, precise definitions used (e.g. by adopting differing thresholds to define hypertension or by using absolute values of arterial pressure), or because the specific studies have used crude (retrospective) indices [i.e. death, myocardial infarction (MI), or stroke] without specifically looking for other complications. Some studies have evaluated data over 20 yr, during which time surgical, anaesthetic, and medical practices have changed. Improvements in medical therapy have changed the long-term and perioperative implications of certain risk factors, for example, thrombolysis, early percutaneous coronary intervention and secondary prevention after MI. Thresholds for active treatment of arterial pressure have decreased, particularly in some patient groups such as diabetics. Some carotid surgery studies have included asymptomatic and symptomatic patients, and overall case mix in North America includes a higher proportion of asymptomatic patients compared with

that in Europe. Most perioperative strokes related to CEA are caused by thromboembolism rather than hypo- or hypertension^{55 116} and most of these are caused by technical surgical error.^{45 80} However, many studies have not accounted for important surgical variables such as the site and severity of carotid stenosis; the presence and degree of contralateral disease; and the surgical technique (eversion *vs* standard endarterectomy, use of shunts, administration of heparin, or its reversal with protamine).

It is now appreciated that the significance of preoperative hypertension is related to the presence of end-organ damage, though some studies have not accounted for this. Hypertension has been historically identified as a risk factor for perioperative myocardial ischaemia, arrhythmias, cardiovascular lability, and poorer perioperative cardiac outcomes.⁵⁴ However, a recent meta-analysis suggests that the actual risk in general surgical patients is statistically (odds ratio 1.35), but probably not clinically, significant.⁵³ Thus in general surgical patients, a systolic arterial pressure (SAP) <180 mm Hg or diastolic arterial pressure (DAP) <110 mm Hg on hospital admission does not increase perioperative risk substantially. In contrast, severe hypertension (SAP >180 mm Hg or DAP >115 mm Hg) predisposes to wide intraoperative swings in arterial pressure, perioperative cardiac arrhythmias, and myocardial ischaemia.^{51 66 77}

Irrespective of baseline arterial pressure, arterial pressure is often labile in patients undergoing CEA. One study reported incidences of systolic hypertension (SAP >220 mm Hg) and hypotension (SAP <90 mm Hg) of 9% and 12%, respectively.¹¹⁷ Patients undergoing CEA are at increased cardiovascular risk compared with general surgical cohorts, because of the high incidence of other risk factors (ischaemic heart disease, heart failure, diabetes mellitus, and chronic obstructive pulmonary disease) in this group.¹⁹ Exaggerated perioperative changes in arterial pressure may compound this risk and, as cardiac complications such as MI and cardiac failure account for 37–50% of the long-term mortality after CEA,^{49 65} it is reasonable to control arterial pressure as closely as possible. Cerebral blood flow in patients with carotid stenosis may depend on collateral circulation and autoregulation of cerebral blood flow may be impaired, particularly in chronically hypertensive patients. Vigorous antihypertensive treatment in these circumstances can predispose to cerebral ischaemia.³²

In patients undergoing CEA, untreated preoperative hypertension is associated with postoperative hypertension.^{5 117} This may predispose to postoperative wound haematoma formation related to increased suture line or venous bleeding, with possible airway obstruction.⁶⁰ It can also predispose to cerebral hyperperfusion syndrome or intracerebral haemorrhage after CEA.

Cerebral hyperperfusion syndrome

Cerebral hyperperfusion syndrome and intracerebral haemorrhage are associated with postoperative hypertension,

Table 2 Risk factors for cerebral hyperperfusion syndrome⁹⁰

Recent ipsilateral ischaemic stroke
Severe ipsilateral or contralateral carotid disease
Markedly increased cerebral perfusion (MCA flow velocity or pulsatility) after flow restoration
Severe postoperative hypertension

although they can occur in patients who are initially normotensive after surgery.⁹⁰ Cerebral hyperperfusion syndrome occurs in ~1% of patients after CEA and classically presents 2–7 days after operation as severe headache, neurological deficits, or seizures leading to intracerebral haemorrhage. The clinical picture is similar to hypertensive encephalopathy, and mortality after intracerebral haemorrhage may be up to 67%.⁹⁰ It has previously been suggested that cerebral hyperperfusion syndrome is caused by increased flow in dilated cerebral arterioles in areas of the brain that were previously hypoperfused,⁴ though more recent workers have proposed that the aetiology is that of an ischaemia–reperfusion injury.^{56–71} There is local loss of autoregulation leading to ipsilateral vasogenic cerebral oedema, usually in the posterior cerebral circulation, though overall cerebral blood flow is not always increased.^{56–71} Risk factors for intracerebral haemorrhage after CEA include recent ipsilateral ischaemic stroke, severe ipsilateral or contralateral carotid disease, markedly increased cerebral perfusion (middle cerebral artery flow velocity or pulsatility) after flow restoration, or severe postoperative hypertension⁹⁰ (Table 2). Cerebral oedema in cerebral hyperperfusion syndrome is treatable and may be reversed by aggressive control of arterial pressure. Therefore, tight control of arterial pressure is warranted in patients with risk factors for cerebral hyperperfusion syndrome, particularly if marked perioperative increases in middle cerebral artery flow velocity or pulsatility occur.

Despite the inconsistencies in the literature, most anaesthetists and surgeons looking after vascular patients agree that close monitoring and control of arterial pressure is important in patients undergoing CEA. Most also appreciate that marked swings in heart rate and arterial pressure are common, even in the absence of pre-existing hypertension. However, good arterial pressure control is important because surgery in the presence of a tight carotid stenosis presents two potential problems. First, before carotid cross-clamping, a relatively high arterial pressure may be needed to provide adequate distal cerebral perfusion across the carotid stenosis in order to prevent ‘watershed’ cerebral ischaemia. Secondly, once the endarterectomy is performed and the stenosis removed, there is a risk that cerebral vessels previously ‘protected’ by the stenosis are exposed to a relatively high pressure. It is also clear that hypertension is associated with increased perioperative risks in patients presenting for CEA compared with other types of surgery. Why should this be?

Pathophysiology of haemodynamic instability during CEA

The arterial baroreflex

Cardiovascular function is controlled within the brainstem and influenced by input from a number of peripheral receptors, including sensory afferent fibres from non-encapsulated visceral nerve endings in the aortic arch and carotid sinus at the carotid bifurcation (arterial baroreceptors), atrial and ventricular walls (cardiac baroreceptors), and arterial chemoreceptors in the carotid and aortic bodies, which synapse in the nucleus tractus solitarius.¹⁷ The arterial baroreflex is the reflex alteration in sympathetic and parasympathetic cardiovascular activity in response to acute changes in arterial pressure, detected by baroreceptors in the carotid body and aortic arch. It is responsible for acute modulation of arterial pressure and is altered in different disease states: for example, chronic hypertension, carotid artery disease, and cerebrovascular disease, all of which are prevalent in patients presenting for CEA. Carotid baroreceptor denervation causes increased arterial pressure variability, because of decreased vagal and sympathetic baroreflex sensitivity, although this does not lead to chronic hypertension as other baroreceptors are able to maintain normal chronic arterial pressure.¹¹¹ Baroreflex function is inevitably disturbed in patients undergoing CEA. There are several separate potential causes of this.

Altered baroreceptor function in patients undergoing CEA

Acute changes in arterial pressure and heart rate during CEA were initially believed to be caused by surgical manipulation of the carotid sinus,¹² although other theories, including alterations in the renin–angiotensin system,¹⁰³ vasopressin concentrations,⁶² or central catecholaminergic activity,^{2–47} have also been postulated. However, it is now clear that carotid atheroma itself reduces cerebral perfusion pressure and impairs baroreceptor reflexes and cerebrovascular reactivity, even in asymptomatic patients.³⁸ Impaired baroreflex and cerebrovascular reactivity are predictors of long-term outcome.¹⁰⁰ Carotid atheroma is also associated with atheromatous disease in other parts of the arterial tree, but because of the effects of carotid atheroma on arterial baroreflex sensitivity, perioperative haemodynamic instability is more likely.¹²

Surgery to the carotid arteries is associated with baroreceptor dysfunction. Surgical removal of a carotid plaque causes immediate partial disruption of baroreceptor activity leading to hypertension and increased arterial pressure instability. This may last for several hours or days after surgery⁹⁹ and may be caused by stripping of sensory nerve endings from the arterial lumen. It may explain why carotid sinus nerve block during surgery has variable

effects on perioperative arterial pressure control.^{3 39} The human baroreceptor system, in common with other physiological mechanisms, incorporates an element of redundancy, so that overall functioning may be unimpaired if one site alone is diseased. Patients with significant contralateral carotid atheroma suffer more intraoperative and postoperative hypertensive episodes than those with normal contralateral carotid arteries because of bilateral baroreceptor dysfunction and reduced baroreflex reserve.⁷⁴ In further support of this, baroreceptor 'failure' has been reported after staged bilateral CEA in an elderly patient.⁶ Equally, recovering baroreceptor function after CEA may account for the improved arterial pressure control sometimes observed in the late postoperative period.⁵⁰

In addition to the direct effects of surgery, several other factors contribute to baroreflex dysfunction and haemodynamic instability during and after CEA. These include chronic hypertension and the effects of antihypertensive medication,¹⁵ recent TIA or stroke,^{23 83} recent alterations in antihypertensive medication after stroke,²⁴ and the effects of age.²⁹ In addition, autonomic dysfunction, for example, in diabetic patients, can impair baroreflex responses. In one study, 93% of patients who became hypertensive after CEA had diabetes.¹⁰²

Effects of carotid cross-clamping and shunting

Cross-clamping of the carotid artery leads to a predictable pattern of reduced cerebral blood flow, which is accompanied by a compensatory increase in arterial pressure mediated by baroreceptor reflexes and an increase in sympathetic nervous activity. This is reversed on restoration of blood flow either by application of a shunt or by unclamping at the end of surgery, and a short period of mild hypotension may follow. The magnitude of these changes depends on a number of factors, including the degree of ipsilateral stenosis, the integrity of the collateral flow, the duration of cerebral ischaemia, and surgical and anaesthetic factors. Changes may be less noticeable in patients undergoing CEA under deep general anaesthesia (GA) as both baroreceptor function and cerebral autoregulation may be attenuated by high concentrations of volatile anaesthetic agents. The duration of cross-clamping may also affect haemodynamic stability and, while hypertension is common, postoperative hypotension has also been reported³³ possibly related to very short carotid cross-clamp times of 10–15 min.

Surgical factors

Several surgical factors may affect haemodynamic stability. Eversion CEA is associated with more postoperative hypertension, greater use of vasodilators, and less use of vasopressors after the operation than the standard longitudinal endarterectomy with or without patch angioplasty.^{8 69} This is most likely related to transection or local anaesthetic block of the carotid sinus nerve during eversion

endarterectomy, which is associated with increased haemodynamic instability.³⁹ Carotid sinus nerve block is no longer recommended as a routine procedure.¹⁰⁸

Symptomatic ICA stenosis may also be treated by carotid angioplasty with stenting (CAS). CAS has a different haemodynamic profile to conventional surgery,¹¹⁸ with peri-procedural hypotension occurring more commonly. In 100 patients randomized to CAS or CEA, patients undergoing carotid stenting had, compared with the surgical group, a predictable and significant decrease in arterial pressure after the procedure, which was sustained even at 6 months.⁶⁸ However, the role of CAS, particularly in symptomatic patients, has not yet been established.^{16 64}

Anaesthetic factors

Although early procedures were generally performed under local anaesthesia, GA became increasingly popular because it was felt to provide better surgical conditions and facilitate cerebral protection. Recent attention has returned to regional anaesthesia (RA), whose advantages include permitting awake neurological monitoring. Recent systematic reviews^{42 79 109} have shown no differences in outcome in patients from randomized controlled trials and only minor differences in morbidity, such as less wound haematoma with RA. The GALA trial compared locoregional and GA for CEA and recruited 3500 patients in more than 90 centres, predominantly in Europe, in 2001–2007. Primary outcomes were death, stroke, and MI at 30 days, and secondary outcomes included stroke at 1 yr. Preliminary results indicate that there is no major difference in 30 day mortality between GA and RA, although further analysis is required.⁴⁰ Meantime, enthusiasts of each technique will continue to debate the merits of their preferred method.

The choice of anaesthesia for CEA does affect the intra- and postoperative haemodynamic profile. Although potentially subject to observer and reporter bias, several non-randomized studies have shown differences in intraoperative arterial pressure profiles between GA and RA techniques.^{25 48 76 94} Patients undergoing CEA under RA tend towards hypertension during the period of cross-clamping, and hypotension after restoration of cerebral blood flow and into the postoperative period. In contrast, the usual pattern under GA is of relative intraoperative hypotension and postoperative hypertension.²⁵

IV and inhalation anaesthetic drugs both affect cardiovascular function in a dose dependent manner by reducing central sympathetic tone, attenuating baroreflex activity, and by direct effects on the heart and peripheral vasculature.^{92 95 98} Other drugs such as opioids affect cardiovascular function by attenuation of sympathetic afferent and efferent activity,⁹⁶ direct central or peripheral vagal stimulation, and direct and indirect effects on the myocardium and vascular smooth muscle.³⁰ These may be compounded by the effects of positive pressure ventilation causing

hypotension during CEA under GA. Nitrous oxide is associated with increased plasma homocysteine concentrations and postoperative myocardial ischaemia in patients undergoing CEA and should arguably be avoided.⁷ One small study has suggested that specific anaesthetic drugs may affect cardiovascular stability,³⁴ but overall there is no good evidence that the use of specific anaesthetic agents affects cardiovascular stability or outcome after CEA.¹⁰⁵ Other possible reasons for observed differences in arterial pressure between RA and GA include the effects of analgesics and differences in fluid management. Possible surgical confounding factors include the duration of carotid cross-clamping and the increased use of arterial shunts under GA.

Other drugs administered by the anaesthetist can clearly affect haemodynamic status and outcome. Augmentation of arterial pressure intraoperatively may be used to reverse developing neurological deficit while the carotid is cross-clamped.¹⁰⁶ However, augmentation of arterial pressure, which is practised routinely in some centres,¹¹⁴ is itself not without risk and could precipitate myocardial ischaemia in susceptible patients.^{81 104}

Indications and timing of surgery

Recent data have also shown that the risk of stroke early after TIA is higher than previously appreciated,^{85 89} and guidelines in the UK now suggest that intervention should be performed within 48 h of a TIA.²¹ Although this target is not yet routine practice in many centres, the heightened awareness and urgency for surgery will significantly impact upon preoperative assessment and perioperative management, particularly in patients with active cardiac disease or uncontrolled hypertension.⁵² Baroreceptor dysfunction is common after acute ischaemic stroke⁸³ and is associated with adverse long-term outcome.⁸² Hypertension is common after ischaemic stroke, but there is no consensus on arterial pressure targets after stroke.⁸⁴ Patients with recent TIA may have also increased perioperative arterial pressure lability. Recent stroke is an established risk factor for adverse neurological outcome after CEA, so higher risk patients will be presenting for urgent surgery, with less time available for control of risk factors including hypertension. Data on optimum perioperative arterial pressure management are therefore required urgently.

Practical aspects of arterial pressure management

Slightly different considerations apply during the pre-, intra- and postoperative periods. Before operation, it is important to control and maintain arterial pressure but avoid excessive decreases in cerebral perfusion distal to a carotid stenosis. Intraoperative goals are to maintain cerebral perfusion pressure and collateral flow during a period when cerebral pressure autoregulation may be

impaired by the effects of anaesthesia, baroreflexes are impacted by the direct effects of surgery, but cerebral blood flow may be impaired by carotid clamping or by surgery itself. Postoperatively, cerebral circulation distal to the surgical site is increased compared with preoperative values in the presence of impaired autoregulation and baroreflexes. The new endarterectomy site is also a potential site for the formation of haematoma or thrombus.

Preoperative control of arterial pressure

Targets for arterial pressure control in the general population have been revised recently.¹⁴ However, in patients presenting for CEA, arterial pressure control is difficult for several reasons and the benefits gained from delaying surgery until acceptable arterial pressure is achieved may be outweighed by the risks of delaying surgery. In addition, cerebral blood flow in the presence of carotid stenosis may depend critically on collateral circulation, and autoregulation of cerebral blood flow may be impaired, particularly in chronically hypertensive patients or after TIA or minor stroke. The optimum arterial pressure targets in those with asymptomatic carotid stenosis or after TIA or minor stroke are not established.⁸⁴ The best therapy in these circumstances may differ from that in other hypertensive patients because responses to treatment may differ.²³ Vigorous antihypertensive treatment before surgery or hypotension during anaesthesia in these circumstances can cause ischaemic stroke due to cerebral hypoperfusion³² and is to be avoided.

The question of optimum arterial pressure targets in CEA patients who have isolated systolic hypertension is therefore unclear, with few data to guide the clinician. Notwithstanding this lack of data to guide practice, it seems reasonable to aim for SAP <180 or DAP <100 mm Hg in patients presenting acutely for CEA. Alpha- and beta-blockers have theoretical advantages and have been shown to reduce the incidence of myocardial ischaemia in patients at high risk of cardiac morbidity.^{22 63} Conversely, drugs which block the renin-angiotensin system may be associated with perioperative hypotension.¹⁵ The period of preoperative starvation and postoperative disturbance to gastric emptying may be relevant in deciding whether to use oral or parenteral routes of drug administration.

As a general rule, many anaesthetists and surgeons aim for a systolic pressure of 160 mm Hg or less before elective CEA, continuing therapy up to the morning of surgery, with the possible exceptions of angiotensin-converting enzyme inhibitors and angiotensin II receptor antagonists, and restarting normal therapy as soon as possible after surgery. However, it is important to emphasize that therapy should be tailored to the individual patient and rapid reductions in arterial pressure should be avoided, particularly in patients with recent acute neurological symptoms presenting for urgent surgery. Not only is optimum arterial pressure difficult to achieve in a short

time frame, but it may be counterproductive in these circumstances.

Intraoperative control of arterial pressure

Traditional anaesthetic teaching for vascular surgery suggests maintaining systolic arterial pressure at $\pm 20\%$ from the preoperative baseline value. However, fears about 'watershed' stroke during the period of carotid cross-clamping,⁵⁹ together with some clinical evidence from patients undergoing awake CEA whose developing neurological deficits were reversed by elevation of arterial pressure to 'normal' values,¹⁰⁶ has revised these limits in patients undergoing CEA to between normal and 20% above baseline. These values should be viewed as guidelines and adjusted in the light of information from cerebral monitoring, including in the awake patient. For example, if reliable monitoring shows that cerebral blood flow is adequate despite relative hypotension, then our own practice for patients undergoing GA (J.P.T.) or RA (M.D.S.) is not to augment further the arterial pressure to any predefined target. Perioperative augmentation of arterial pressure is not without risk and has been associated with an increased incidence of MI in one observational study.⁸¹ Intraoperative hypertension can itself also make surgical shunt placement more difficult, predispose to myocardial ischaemia, and has been associated with intracerebral haemorrhage.⁹⁰

On balance, it is probably beneficial to avoid hypotension if possible, particularly during the period of carotid cross-clamping, whereas after restoration of flow, it is preferable to avoid hypertension. The importance of this also relates to the duration of cross-clamping, and therefore to surgical technique, including the use of shunts. There is no evidence that any particular drug is superior and our own practice is to administer i.v. fluids, together with i.v. aliquots of ephedrine, metaraminol, or phenylephrine depending on comorbidity, medication history, and heart rate, administered promptly and titrated to effect. The precise effects of particular vasoactive drugs on cerebral blood flow are difficult to predict and will depend on the absolute systemic arterial pressure, the effects of the drug on cerebral vasculature, the extent of carotid disease, collateral flow and the effect of a shunt, baroreflex function, and the effects of other agents as discussed above.

Postoperative control of arterial pressure

Postoperative hypertension is common after CEA. It is usually transient and peaks in the first few hours after surgery, and is related to impaired baroreceptor function. It predisposes to wound haematoma, myocardial ischaemia and in some cases may be a harbinger of cerebral hyperperfusion. The incidence of severe postoperative hypertension is up to 66%,^{18 27 75 93 101 102 112} with 40% or more patients requiring specific therapeutic intervention.¹¹⁷ Intraoperative hypotension and postoperative hypertension

put the patient at risk of developing wound haematoma.⁹ Routine CEA causes airway narrowing due to oedema in all cases,¹³ and a wound haematoma can cause severe airway obstruction by a combination of direct compression and oedema. In some cases, emergency wound exploration is needed,⁷⁰ which carries significant risks.⁹⁷ In the NASCET trial, this patho-physiological mechanism was responsible for all non-stroke related fatal surgical complications.²⁸ The incidence of postoperative wound haematoma is 3–8%. This may be minimized by surgical manoeuvres such as closing the artery at normal arterial pressure, wound drainage, and an aggressive approach to control arterial pressure during and after surgery.^{9 46}

It remains uncertain whether postoperative hypertension is a causative factor in the development of cerebral hyperperfusion after CEA or a response to increased intracranial pressure.⁹⁰ However, there is indirect evidence that prompt control of arterial pressure in patients who are hypertensive after CEA does improve the outcome by reducing neurological complications, wound complications, or both,^{9 72} and most practitioners would consider rapid treatment of postoperative hypertension to be important.¹⁰¹ In the absence of definitive data, target pressures of <160 mm Hg systolic or within 20% of preoperative values are widely used, but a lower threshold may be appropriate in those at high risk for cerebral hyperperfusion or wound haematoma.

There are also few comparative data on the efficacy of different drugs to prevent or treat hypertension in patients undergoing CEA. In the UK, practice among vascular anaesthetists varies widely in terms of thresholds for therapy and preferred hypotensive drugs.¹ Important considerations include the availability of a parenteral formulation, duration of onset and mechanism of action, and coexisting therapy or disease. Most patients should be able to take oral medication within 2 h of uncomplicated CEA whether performed under GA or RA, but i.v. medication is usually required in the early postoperative period.

Although they have been used widely, direct acting vasodilators (e.g. sodium nitroprusside, glyceryl trinitrate, nicardipine, and hydralazine) have theoretical disadvantages after CEA as they cause cerebral vasodilatation. This may be deleterious in patients with newly increased cerebral blood flow and impaired autoregulation after CEA, though this may be outweighed by the effects of therapy on systemic arterial pressure, and it is difficult to predict the precise effects of different drugs on cerebral haemodynamics in individual patients.

Nifedipine capsules also cause cerebral vasodilatation and when administered sublingually can cause precipitous decreases in arterial pressure, which have been associated with serious adverse events. Sublingual nifedipine is therefore not indicated for the treatment of acute hypertension.⁴¹ Alpha or beta adrenergic antagonists are often effective for the prevention or treatment of postoperative hypertension. Available i.v. preparations include labetalol,

Table 3 Suggested arterial pressure management strategy**Intraoperative aims/goals**

Estimate the patient's 'baseline' arterial pressure—from the chart, the preoperative visit, the patient's records, and the arterial pressure in the anaesthetic room before sedation/anaesthesia is administered
Measure the arterial pressure in both arms as there can be significant difference between them³¹

Note the patient's presenting neurological symptoms. The unpublished observations of one of the authors (M.D.S.) suggest that a patient undergoing awake CEA is likely to present with the same symptoms during cross-clamping if hypoperfusion develops

Aim to maintain arterial pressure at, or up to 20% above, the documented baseline arterial pressure during carotid cross-clamping using fluids, vasopressors, and hypotensive drugs as required

Interpret these arterial pressure targets according to information available from cerebral monitoring or neurological symptoms

Postoperative management

If a patient is hypertensive after operation, sit him/her up in bed which can itself reduce arterial pressure and may make the patient more comfortable
All patients: monitor for 2–4 h using invasive arterial pressure. In one of the authors' centres (J.P.T.), trans-cranial Doppler is monitored in the recovery room for 30 min in all patients to detect cerebral micro-emboli and for longer if >10 micro-emboli are detected during this time. If the embolus rate is >25 within 10 min, dextran 40 (20 ml bolus and infusion at 20 ml h⁻¹) is administered i.v.

Aim target systolic pressure <170 mm Hg or within 20% of preoperative values

Continue invasive monitoring >2 h if vasoactive drugs have been required after surgery

Table 4 University Hospitals of Leicester NHS Trust practice for the management of post-CEA hypertension**(1) Postoperative care unit: systolic pressure >170 mm Hg****General points**

Does the patient have urinary retention or is he/she in pain?

Has the patient received his/her normal antihypertensive medication today?

First-line LABETALOL

100 mg labetalol in 20 ml of 0.9% saline (i.e. 5 mg ml⁻¹)

Give 10 mg (2 ml) boluses *slowly* every 2 min up to 100 mg (i.e. 20 ml given over 20 min)

If BP remains elevated after 20 min, move to second-line agent

If BP decreases and does not rebound, continue regular BP observations

If BP decreases initially but increases again, start infusion at 50–100 mg h⁻¹, titrating dose to BP

Patient remains in PACU/HDU while labetalol infusion is running. After cessation of the infusion, the patient should remain in PACU/HDU for a further 2 h to minimize rebound hypertension

Second-line HYDRALAZINE

10 mg hydralazine in 10 ml of 0.9% sodium chloride (i.e. 1 mg ml⁻¹)

Give 2 mg (2 ml) boluses *slowly* every 5 min up to 10 mg (i.e. 10 ml given over 25 min)

If BP remains elevated after 25 min, move to third-line agent

If BP decreases and does not rebound, continue regular BP observations

If BP decreases initially but increases again, move to third-line agent

Patient remains in PACU/HDU while hydralazine therapy is underway. After cessation of hydralazine therapy, the patient should remain in PACU/HDU for a further 2 h to minimize rebound hypertension

Third-line Glyceryl trinitrate (GTN)

50 mg GTN in 50 ml 0.9% sodium chloride (i.e. 1 mg ml⁻¹) start infusion at 5 ml h⁻¹ (5 mg h⁻¹), increasing rate to 12 ml h⁻¹ (12 mg h⁻¹), titrated to BP

Patient remains in PACU/HDU while GTN infusion is underway. After cessation of GTN infusion, the patient should remain in PACU/HDU for a further 2 h to minimize rebound hypertension

(2) Patient is on the surgical ward**systolic BP >170 mm Hg, but NO headache/neurology**

There are three scenarios

(1) *Patient is not normally on antihypertensive therapy*

(2) *Patient is normally on antihypertensive therapy*

Table 4 Continued

(3) *Patient cannot swallow tablets*

(2.1) Patient is NOT normally on antihypertensive therapy

First line: Nifedipine Retard (10 mg), repeated after 1 h if no change in BP
DO NOT use crushed Nifedipine capsules

If no reduction in BP, move to second-line agent

Second line: Bisoprolol 5 mg

If either contra-indicated or no effect, move to third-line agent

Third line: Ramipril 5 mg, repeated at 3 h if necessary

Contact hypertension specialists for clinical review

(2.2) Patient IS normally on antihypertensive therapy**First line**

Check whether the patient has received normal antihypertensive medication. If not, administer this

Second line

A, ACE inhibitor; B, β -blocker; C, calcium channel blocker; D, diuretic

If patient is on A, add in C (nifedipine LA 10 mg)

If patient is on C, add in A (ramipril 5 mg)

If patient is on D, add in A (ramipril 5 mg)

If patient is on A+C, add in D (bendroflumazide 2.5 mg)

If patient is on A+D, add in C (nifedipine LA 10 mg)

If patient is on A+C+D, add in B (bisoprolol 5 mg)

Contact Hypertension Specialists for clinical review

2.3 Patient cannot swallow tablets

Pass nasogastric tube and administer appropriate medicines in liquid form as prescribed above

(3) Patient is on the surgical ward**Systolic BP >160 mm Hg+headache/seizure or deficit**

Treatment should start *immediately* on the ward using non-invasive monitoring.

Antihypertensive protocol is the same as used in Recovery (see below)

On call surgical SpR/SHO must:

Contact on call consultant vascular surgeon to inform him of increase in BP associated with seizure/headache or onset of neurological deficit

Contact on call ICU SpR to arrange urgent transfer to SACU, HDU, or PACU for invasive arterial BP monitoring

Administer 8 mg dexamethasone i.v.

First-line LABETALOL

100 mg labetalol in 20 ml of 0.9% saline (i.e. 5 mg ml⁻¹)

Give 10 mg (2 ml) boluses *slowly* every 2 min up to 100 mg (i.e. 20 ml given over 20 min)

If BP remains elevated after 20 min, move to second-line agent

If BP decreases and does not rebound, continue regular BP observations

If BP decreases initially but increases again, start infusion at 50–100 mg h⁻¹, titrating dose to BP

Second-line HYDRALAZINE

10 mg hydralazine in 10 ml of 0.9% sodium chloride (i.e. 1 mg ml⁻¹)

Give 2 mg (2 ml) boluses *slowly* every 5 min up to 10 mg (i.e. 10 ml given over 25 min)

If BP remains elevated after 25 min, move to third-line agent

If BP decreases and does not rebound, continue regular BP observations

If BP decreases initially but increases again, move to third-line agent

Third-line Glyceryl trinitrate (GTN)

50 mg GTN in 50 ml 0.9% sodium chloride (i.e. 1 mg ml⁻¹) start infusion at 5 ml h⁻¹ (5 mg h⁻¹), increasing rate to 12 ml h⁻¹ (12 mg h⁻¹), titrated to BP

Patient remains in PACU, SACU, or HDU while antihypertensive treatment is ongoing. After cessation of treatment, the patient should remain in SACU, PACU, or HDU for a minimum of a further 6 h to minimize rebound hypertension

esmolol, metoprolol, atenolol or clonidine. Labetalol and esmolol have been found effective in neurosurgical patients and both can be titrated to effect,³⁵ but other drugs may be used.⁴³ Beta adrenoceptor antagonists are useful to counteract the reflex tachycardia seen with other agents. Alpha₂ adrenoceptor agonists, such as clonidine administered before or during surgery, decrease

Continued

myocardial ischaemia, arterial pressure, and plasma catecholamine concentrations,¹¹⁵ although there are no data for the use of clonidine in patients undergoing CEA. No matter which drug is used, it should be given in a controlled manner and titrated against effect as precipitous decreases in arterial pressure can be associated with watershed cerebral ischaemia.⁵⁸ Beat-to-beat arterial pressure monitoring is advised if parenteral drugs are required, and response to therapy should be closely monitored in a HDU or ICU environment if necessary for a period of at least 2–4 h until arterial pressure is stable. Suggestions for management are given in Tables 3 and 4.

Late postoperative management of arterial pressure differs in that oral medication is likely to be tolerated. However, it is particularly important to assess neurological symptoms and signs, as severe hypertension and CHS can present several days after CEA.

Postoperative hypotension is less common in patients undergoing CEA under GA compared with awake CEA,^{25 94} which may be related to better cerebral autoregulation or baroreceptor function. Hypotension may be caused by residual effects of anaesthetic drugs or over-zealous pharmacological treatment of hypertension. If the patient is asymptomatic, and provided the pressure is not altered too expeditiously, it is usually well tolerated. However other possible causes, for example, low cardiac output states (vaso-vagal episodes, cardiac failure, and MI), or hypovolaemia (bleeding into the surgical drain), should be identified and addressed.

It is important to decide whether postoperative hypotension requires treatment. It is the authors' practice to decide on acceptable low and high limits for postoperative arterial pressure. These are determined on an individual patient basis as written instructions to the postoperative staff. Treatment of postoperative hypotension may involve adequate i.v. fluid replacement with a suitable crystalloid or colloid, followed by infusion of a vasopressor (e.g. phenylephrine) if the response to fluid is inadequate. If cardiac causes are implicated, further investigation and monitoring are warranted.

Summary

Perioperative arterial pressure management in patients scheduled for carotid surgery presents some specific difficulties. Overzealous treatment may be harmful and therapeutic targets should be revised within this specific context. Postoperative haemodynamic instability is very common, and although it is usually self limiting, may require acute intervention and invasive monitoring. Although most would agree that good perioperative control of arterial pressure contributes to neurological and cardiovascular outcome, there are few data on which to base firm guidelines or protocols. Close monitoring and titration of therapy are probably the most important considerations rather than specific choice of agents.

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