The Endovascular Management of Penetrating Carotid Artery Injuries: Long-term Follow-up

D.F. du Toit*, D. Coolen, A. Lambrechts, J. de V. Odendaal, B.L. Warren

Department of Surgery, University of Stellenbosch, Tygerberg Hospital, Tygerberg, P.O. Box 19063, Parow, South Africa

Submitted 18 February 2009; accepted 8 May 2009
Available online 30 June 2009

Abstract

Objectives: To review a single-centre experience with stent-graft treatment of penetrating carotid artery injuries and long-term follow-up.

Methods: All stable patients with carotid artery injuries presenting between August 1998 and February 2009 were considered for endovascular treatment. Patients were selected based on clinical and radiological criteria and data were prospectively collected. Follow-up was conducted clinically, angiographically and by telephonic contact. Endpoints were stroke, death and any other stent-graft-related complications.

Results: A total of 128 patients were treated, of whom only 19 were selected for endovascular management. The recorded technical success rate was 100%, with one early stroke and one non-stent-graft-related procedural death. A further four patients were lost to follow-up. The remaining 14 patients had a mean follow-up of nearly 4 years. No stent-graft-related late deaths, strokes or other complications were reported, although one instance of late stent-graft occlusion was documented.

Conclusion: Endovascular management of penetrating carotid artery injuries is safe and the long-term outcomes justify a more liberal application of this technique in selected patients.

© 2009 European Society for Vascular Surgery. Published by Elsevier Ltd. All rights reserved.

carotid artery injuries account for about 22% of all cervical vascular injuries, to which common carotid artery injuries contribute about 75% and internal carotid artery injuries 20%.1,2 The overall mortality rates can be as high as 66%, with mortality and stroke rates generally being higher for internal carotid than for common carotid artery injuries.1 Internal carotid artery injuries have reported mortality and stroke rates as high as 31% and 23%, respectively.2 Due to their relative inaccessibility, the greatest surgical challenge is posed by injuries to the proximal common carotid and the distal internal carotid arteries. These injuries, with some exceptions, correlate with Zone I and III surface wounds.3 The approach to stable patients with these injuries is controversial, potentially varying from routine exploration, to selective exploration based on clinical findings alone or in combination with radiological findings.4,5,6 Potentially, these types of patients stand to benefit most from endovascular management. The feasibility and safety of stent-graft treatment of selected carotid artery injuries are...
already established. Long-term follow-up is lacking and the perceived risk of thrombo-embolic complications in young trauma patients prevents general acceptance of this technique. This study was undertaken to examine an institutional experience with stent-graft treatment of penetrating carotid artery injuries and to report the results of long-term follow-up.

Methods

During a 10.5-year period from August 1998 to February 2009, all patients presenting with penetrating carotid artery injuries were considered for endovascular management. Given that the safety and long-term outcomes were uncertain, it was decided that only patients who stood to potentially benefit the most would be treated endovascularly. These were patients with proximal common carotid artery injuries. Where a sternotomy for proximal control would be avoided, as well as the distal internal carotid artery, where distal control can be hazardous or severely problematic. Approval for the study was obtained from the Committee for Human Research at the University of Stellenbosch.

In these patients, reduced surgical morbidity and mortality could justify the uncertainty surrounding the safety and long-term outcome concerns. This approach excluded most of the injuries caused by Zone II penetrating wounds. Patient selection was based on clinical presentation and diagnostic angiography. Clinical contraindications to stent-grafting included: active uncontrollable haemorrhage; airway compression; concomitant aero-digestive injuries and infected wounds. Arteriographic contraindications were excessive luminal discrepancy between the proximal and distal involved artery and an inability to traverse the lesion by guide wire and any fresh luminal clot that would prevent safe delivery of a guide wire past the injured area also excluded stent-graft treatment.

Angiography was routinely used throughout the study period in the assessment of stable Zone I and III injuries, and liberally in Zone II injuries based upon clinical and colour duplex Doppler examination. During the early phase of the study, surgeon preference and the availability of stent grafts also influenced decision making.

The procedures were performed in an angiography suite fully equipped for immediate conversion to conventional surgery. Transfemoral arterial access was gained under local anaesthesia and a 5Fr Cordis® (Johnson & Johnson, Waterloo, Belgium) introducer sheath was inserted in the right common femoral artery. A 5Fr pigtail (Cook, Inc., Bloomington, IN, USA) diagnostic catheter was advanced over a 0.035-in. diameter guide wire, via the sheath into the proximal aortic arch. Thereafter, an aortic arch and four-vessel outflow arteriogram was performed. The pigtail catheter was then exchanged for a head-hunter diagnostic catheter with which the orifices of the carotid and vertebral arteries were then selectively canalised for angiography. If the arch angiogram clearly demonstrated a single injury, only the injured vessel was selectively canalised; however, if unclear, all four vessels were selectively canalised. Upon completion of the aortic arch and four-vessel outflow arteriogram and appropriate selective views, a final decision regarding suitability for stent-graft treatment was made. If the injury could be treated using a simple anterior neck incision, with easy proximal and distal control, conventional open surgery was preferred. Failing that, and where no other arteriographic contraindications were present, the necessary measurements were made for correct stent-graft selection. These included the proximal and distal vessel diameter and the length that would provide complete cover of the lesion. A second introducer sheath, usually a 9Fr Cordis® (Johnson & Johnson, Waterloo, Belgium), was then inserted into the contralateral femoral artery. At this stage, intravenous heparin (70 U kg⁻¹) and 1 g of cefazolin was administered. The 9Fr sheath was then used to introduce a second head-hunter catheter (Cook, Inc., Bloomington, IN, USA) over a guide wire with which the target vessel was canalised. Through this catheter, a 0.035-in. diameter soft glide wire (Terumo, Tokyo, Japan) was then carefully advanced past the injured area. This was positioned in the external carotid artery if the injury was in the common carotid artery and carefully positioned in the distal internal carotid if the injury was in the internal carotid. The catheter was then advanced past the lesion and the glide wire was exchanged for a 0.035-in. Amplatz Super Stiff guide wire (Boston Scientific, Natick, MA, USA), providing a stable platform for the delivery of the stent-graft. The correct-sized stent-graft was selected aiming to oversize the proximal and distal vessel diameter by 1 mm and to overlap the lesion by at least 1 cm on either side. The stent-grafts used included two Hemobahn® (W.L. Gore), one Wallgraft® (Boston Scientific, Target Therapeutics Fremont CA USA), one Jostent® (Abbott, Illinois, IL, USA) and 10 Fluency® (Bard, Murray Hill, NJ, USA) prosthesis. The stent-graft was introduced over the stiff guide wire and advanced into position using road mapping provided by the second head-hunter catheter in the target vessel. Once in position, it was controlled by local injection of contrast through the same catheter, which can be repeated after partial deployment of the stent-graft. When completely deployed, the delivery catheter was removed leaving the guide wire in place, and a completion arteriogram was performed through the control catheter. If the presence of endoleaks were detected, the stent-graft was carefully seated with an angioplasty balloon of the same size, taking care not to damage the adjacent normal vessel. The completion angiogram was then repeated, and technical success was defined as complete exclusion of the lesion without any visible endoleak. Embolic protection devices were not used in any of these cases. Low-dose subcutaneous heparin and prophylactic antibiotics (1 g cefazolin every 8 h) were prescribed for 24 h. During the initial stages of the study, clopidogrel was not available locally, and although aspirin was prescribed at discharge, patient compliance at follow-up was extremely poor. The completion angiographic example of the above procedure for a left proximal common carotid artery false aneurysm is depicted in Fig. 1.

Postoperative evaluation was initially planned to comprise 3, and then 6-monthly clinical and sonographic follow-ups. Arteriography was reserved for equivocal findings, or if intervention was a possibility. All data were collected prospectively from the time of admission. These included patient demographics, mechanism of injury,
The Endovascular Management of Penetrating Carotid Artery Injuries

Results

During the study period, a total of 128 patients (11 gunshot injuries and 117 stab injuries) with penetrating carotid artery injuries were treated, whilst 109 patients underwent conventional surgery, primarily for easily accessible Zone II injuries. The remaining open repairs performed were for active bleeding, airway obstruction, other concomitant injuries and radiological contraindications for endovascular repair. Nineteen male patients with a mean age of 30 years (range: 18–58 years) were considered suitable for stent-graft placement. All injuries were the result of stab wounds. The average delay between the acute injury and the start of treatment was 26 h. The vessels involved were 14 proximal common carotid arteries (eight left and six right) and five left-sided distal internal carotid arteries (Table 1). The pathology included 10 false aneurysms and nine arteriovenous fistulae. Three patients presented with neurological dysfunction. Two patients with left common carotid artery injuries had established right-sided hemiparesis, and a third patient presented with coma as a result of a right common carotid artery injury. All three had signs of ischaemic cerebral infarction on preoperative CT scan.

Stent-graft treatment was successful in all 19 patients. Success being defined as complete exclusion of the lesion, with no endoleaks, as confirmed by completion angiography. No procedure-related complications were encountered, and no conversion to open surgery was required. Postoperative neurological evaluation did not reveal any new neurological dysfunctions, and two of the three patients with an existing stroke condition had an unchanged neurological status. The patient that presented in a comatose state also had a stent-graft successfully inserted, however, despite patency of the repair being confirmed at completion angiography and subsequent duplex Doppler studies, the patient died on day 3 as a result of cerebral herniation and brainstem compression. A postoperative CT scan reconfirmed a large ischaemic infarction and massive brain swelling.

The follow-up data of all 19 patients with stent-grafts are depicted in Table 1. Four patients were lost to follow-up after discharge from the hospital. One patient died within the first week as described. The 14 remaining patients had a mean follow-up of 44 months (range: 1–125 months). Seven of these patients were contactable at the end of the study period (mean follow-up of 68 months). One of them had an arteriographically confirmed occluded stent-graft at 25 months, with no neurological or other complications. The patient was followed-up for a further 92 months without complications until the end of the study period. Two other patients had stent-graft patency confirmed on arteriogram at 27 and 56 months, respectively. Both of the aforementioned patients could be contacted by telephone at 93 and 125 months, respectively, with no reported symptoms. The two remaining patients had patency of stent-grafts confirmed on duplex Doppler at 11 and 75 months, respectively, and were contacted telephonically at 21 and 83 months also reporting no further problems.

One patient presented with an early right common carotid artery stent-graft thrombosis resulting in a left hemiparesis with an ischaemic cerebral infarction, which was reflected on a CT scan. This patient was the only one in whom a Jostent® (Abbott, Illinois, USA) stent-graft was used. The stent-graft thrombosis occurred exactly 30 days after insertion. Unfortunately, the patient presented only 1 week later to the hospital and thrombolytic therapy was not considered to be of any benefit. This patient was contacted 12 months later at the end of the study period and demonstrated good recovery of neurological function. In total, two (14%) of the patients that were available for follow-up had occluded stent-grafts, of which one (7%) resulted in a stroke. Two patient deaths
occurred, one as a result of preoperative ischaemic brain damage and one as result of suicide 13 months after successful treatment.

The 30-day stroke and mortality rate for the whole group were both 5%, and no graft sepsis or other stent-graft-related complications were recorded.

Discussion

Carotid artery injuries occur infrequently; morbidity and mortality rates however remain high.\(^1,2\) The use of stent-grafting is reported with increasing frequency in the treatment of blunt and penetrating carotid artery injuries.\(^9,10\) Although most reports claim high technical success rates and very low neurological complications, the uncertainty regarding long-term outcomes in predominately young patients has prevented widespread acceptance of these techniques.

The present study included a carefully selected group of patients treated by stent-grafting. No blunt injuries were included. The diagnostic protocol that was followed determined routine angiography for Zone I and III neck injuries. Arteriography was also liberally used for Zone II injuries based on clinical and duplex Doppler assessment. It was decided that stent-grafts would be used only in the management of injuries, whereby avoiding the morbidity of difficult surgical access justified the uncertainty of a long-term outcome. These included proximal common carotid artery injuries requiring sternotomy for proximal control, and distal internal carotid artery injuries with uncertain distal control near the skull base.

Technical success was 100% with the 30-day stroke rate and mortality both 5%. This result compares well to our reported open surgery results of a mortality of 18% and a stroke rate of 5% after arterial repair.\(^2\) Similar results were reported by others and the feasibility and safety of this procedure is well established.\(^11,12,13\) Maras et al.\(^14\) reviewed all reported cases of internal carotid artery false aneurysms treated with covered stents since 1990. In this 16-year period, 20 cases were treated with no peri-operative neurological or other serious complications. The three stent-graft occlusions that were reported on follow-up were asymptomatic. In contrast to carotid stenting for occlusive lesions, luminal stenosis is not a significant concern in traumatic lesions. Traversing the injured area poses different challenges in traumatic lesions. Unstable fresh clot may partially obstruct the vessel lumen at, or adjacent to, the damaged area. In large false aneurysms with discontinuity of the lumen, and compression causing malalignment of the

<table>
<thead>
<tr>
<th>Patient</th>
<th>Artery Injured</th>
<th>Arterial Pathology</th>
<th>Telephonical follow-up at end of study (months)</th>
<th>Prior Follow-up (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(R) CCA</td>
<td>AVF</td>
<td>Asymptomatic (125 months)</td>
<td>Arteriogram: patent (56 months)</td>
</tr>
<tr>
<td>2</td>
<td>(L) ICA</td>
<td>AVF</td>
<td>Lost to follow-up</td>
<td>Asymptomatic (90 months)</td>
</tr>
<tr>
<td>3</td>
<td>(L) CCA</td>
<td>AVF</td>
<td>Initial hemiparesis improved (93 months)</td>
<td>Arteriogram: patent (27 months)</td>
</tr>
<tr>
<td>4</td>
<td>(L) CCA</td>
<td>AVF</td>
<td>Initial hemiparesis improved (92 months)</td>
<td>Arteriogram: occluded (25 months)</td>
</tr>
<tr>
<td>5</td>
<td>(L) CCA</td>
<td>FA</td>
<td>Asymptomatic (83 months)</td>
<td>Duplex Doppler : Patent stent (75 months)</td>
</tr>
<tr>
<td>6</td>
<td>(R) CCA</td>
<td>FA</td>
<td>Lost to follow-up</td>
<td>Asymptomatic clinically (5 months)</td>
</tr>
<tr>
<td>7</td>
<td>(L) CCA</td>
<td>AVF</td>
<td>Lost to follow-up</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>(L) CCA</td>
<td>FA</td>
<td>Lost to follow-up</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>(L) ICA</td>
<td>FA</td>
<td>Asymptomatic (45 months)</td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>(R) CCA</td>
<td>FA</td>
<td>Lost to follow-up</td>
<td>Duplex Doppler: Patent stent (2 months)</td>
</tr>
<tr>
<td>11</td>
<td>(L) ICA</td>
<td>AVF</td>
<td>Dead</td>
<td>Pt committed suicide Asymptomatic clinically (13 months)</td>
</tr>
<tr>
<td>12</td>
<td>(L) CCA</td>
<td>FA</td>
<td>Lost to follow-up</td>
<td>Asymptomatic clinically (12 months)</td>
</tr>
<tr>
<td>13</td>
<td>(L) ICA</td>
<td>AVF</td>
<td>Asymptomatic (21 months)</td>
<td>Duplex Doppler Patent (11 months)</td>
</tr>
<tr>
<td>14</td>
<td>(L) CCA</td>
<td>FA</td>
<td>Lost to follow-up</td>
<td>—</td>
</tr>
<tr>
<td>15</td>
<td>(L) ICA</td>
<td>AVF</td>
<td>Asymptomatic (19 months)</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>(R) CCA</td>
<td>FA</td>
<td>Dead</td>
<td>Death day 3 due to cerebral swelling and herniation</td>
</tr>
<tr>
<td>17</td>
<td>(R) CCA</td>
<td>AVF</td>
<td>Lost to follow-up</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>(R) CCA</td>
<td>FA</td>
<td>Initial hemiparesis improved (12 months)</td>
<td>Early stroke, Arteriogram: Occluded stent (1 month)</td>
</tr>
<tr>
<td>19</td>
<td>(L) CCA</td>
<td>FA</td>
<td>Clinically asymptomatic</td>
<td>Clinically asymptomatic (1 month)</td>
</tr>
</tbody>
</table>

FA = false aneurysm; AVF = arteriovenous fistula; CCA = common carotid artery; ICA = internal carotid artery; (L) = left (R) = right.
vessel ends, crossing to the distal intact vessel may pose a major challenge. In difficult cases, guide-wire manipulation can cause thrombo-embolism and stroke. These situations should be approached with great care. Undue and forced manipulation should be restricted to a minimum. In this study, lesions were crossed with the 0.035-in. glide wire (Terumo, Tokyo, Japan), but visible intraluminal clot was regarded as a relative contraindication to endovascular repair. The use of embolic protection devices in the management of traumatic lesions is not often reported, but should be considered in this situation.\textsuperscript{15} This allows careful crossing of the damaged area with a 0.014-in. wire and deployment of the protection device in the distal internal carotid prior to stent-graft placement. This wire will not provide enough support to deliver the stent-graft as these devices are rigid and of size 8–9 Fr. Stability can be increased by inserting a stiff buddy 0.018-in. wire such as a V-18 Control wire (Boston Scientific/Medi-tech, Natick, MA, USA) and delivering the stent-graft over both wires. Support can be further increased by using a long 9–10 Fr sheath (Arrow International, Reading, PA, USA) delivered to the proximal common carotid artery, as is used in stenting of occlusive lesions. We successfully used this combination in the treatment of an internal carotid false aneurysm near the end of the study period. Unfortunately, most of the injuries treated in this study were located in the proximal common carotid artery, and this did not allow for sufficient space to position a long sheath in a stable position, proximal to the lesion. The double-puncture technique without the use of a long introducer sheath and embolic protection device was, therefore, routinely used in most cases. Proximal protection devices with reversed flow can be used to the same effect.\textsuperscript{16} The use of these devices might increase the safety of endovascular management in selected cases of carotid artery trauma.

In terms of long-term follow-up, it is acknowledged that the numbers were small and that no objective evidence of graft patency is available for most patients. Review of the literature fails to identify any long-term follow-up results for open surgical repair of carotid artery injuries. Open surgery for trauma therefore does not represent a gold standard as in the case of carotid endarterectomy for the management for occlusive carotid lesions. Considering the fact that up to 30–50% of patients with carotid artery injuries are repaired with prosthetic grafts, the scepticism about stent-graft use becomes even more questionable.\textsuperscript{2,17} The acceptable short- and long-term results for stent-grafts in Zone I and III carotid injuries raise the question of their use in Zone II injuries. These injuries are generally regarded as easy to manage with open surgery, but if this is not considered to be safer, with a better long-term outcome than endovascular management, exposure of patients to the morbidity of a more invasive repair could be questioned.

In this study, no routine long-term anti-platelet therapy or anti-coagulation was used. Early in the study, all patients were discharged on aspirin as clopidogrel was not freely available. Patient compliance was extremely poor, and few patients were still on treatment at follow-up. The stroke that occurred due to early stent-graft thrombosis and the availability of clopidogrel as a standard of care after carotid stents for occlusive disease dictate that post-operative treatment with this drug now forms part of the routine protocol in this unit. This occluded stent-graft was the only Jostent\textsuperscript{0} (Abbott, Illinois, USA) that was used, and, as this is a balloon-mounted stent-graft, it was thought that arterial damage caused by minor over-dilatation at the uncovered tips of the balloon may have contributed to the early thrombosis.

In summary, endovascular treatment of penetrating carotid artery injuries in selected patients is a safe and effective method of treatment. Although small in numbers, long-term outcomes were satisfactory in patients for whom follow-up was possible. There exists no gold standard in terms of reported superior long-term results for open surgery. In this category of patient, reliable follow-up will always be problematic; therefore, prospective randomised trials may not be feasible. In this unit, endovascular management is now the treatment of choice for Zone I and III carotid artery injuries in stable patients and is being seriously considered for use in all Zones. It can be expected that stent-grafting will in future be more liberally considered in the treatment of penetrating carotid artery injuries.

**Conflict of Interest/Funding**

None.

**References**


