Outcomes of carotid artery stenting versus historical surgical controls for radiation-induced carotid stenosis

Tiziano Tallarita, MD,[a] Gustavo S. Oderich, MD,[a] Giuseppe Lanzino, MD,[b] Harry Cloft, MD,[c] David Kallmes, MD,[c] Thomas C. Bower, MD,[a] Audra A. Duncan, MD,[a] and **Peter Gloviczki, MD,[a]** *Rochester, Minn*

Purpose: **To evaluate the outcomes of carotid artery stenting (CAS) and open surgical repair (OR) for treatment of radiation-induced carotid stenosis (RICS).**

Methods: **We retrospectively reviewed 60 patients treated for 73 RICSs from a group of 5,824 patients who had carotid interventions between 1992 and 2009. Thirty-three patients (37 arteries) were treated with CAS and 27 patients (36 arteries) with OR. CAS was performed using embolic protection as part of a prospective institutional registry since 2003. End-points included mortality, stroke, myocardial infarction (MI), cranial nerve injury (CNI), wound complication, restenosis, and reintervention.**

Results: **Demographics and cardiovascular risk factors were similar in both groups, with the exception of higher rates ($P <$ .05) of hyperlipidemia (81% vs 56%) and coronary artery disease (63% vs 33%) in OR patients. There were more patients with tracheostomy (31% vs 4%) and time interval from irradiation to intervention was longer in the CAS group. There were no early deaths. At 30 days, OR was associated with one (3%) stroke, two (5.5%) MIs, six (17%) CNIs, and three (8%) wound complications. OR patients with prior radical neck dissections had more wound complications (14% vs 5%) and CNIs (28% vs 9%) compared with those without neck dissections. In the CAS group, there were two (6%) strokes and no MIs, CNIs, or wound complications. Mean length of hospital stay was longer after OR than CAS (4.1 ± 3.7 days vs 2.4 ± 2.1 days; $P = .02$). Median follow-up was 58 months. At 7 years, OR was associated with higher patient survival (75% ± 15% vs 29% ± 13%, $P = .008$) and freedom from neurological events (100% vs 57% ± 9.5%, $P = .058$), but similar freedom from restenosis (80% ± 10% vs 72% ± 9%) and reinterventions (87% ± 10% vs 86% ± 9%) compared with CAS.**

Conclusion: **Carotid artery stenting for radiation-induced stenosis has the advantages of no CNI or wound complications with similar early stroke rate compared with open carotid repair. However, the lower freedom from neurological events may offset the early benefits of carotid stenting in patients who are considered good candidates for open surgery. (J Vasc Surg 2011;53:629-36.)**

Cervical irradiation is often employed for treatment of head and neck cancers. The ionizing effect of radiation causes arteritis, which may lead to stenosis, thrombosis, fibrosis, or acceleration of atherosclerosis.[1-3] Radiation-induced lesions often affect long arterial segments and atypical locations such as the proximal common carotid artery.[4] In addition, the deleterious effects of radiation to the soft tissue and skin result in fibrosis, induration, and ischemia. Open carotid reconstruction for radiation-induced lesions has been associated with higher rates of stroke, cranial nerve injury, and problems related to wound healing such as necrosis, infection, and skin breakdown.[5,6]

Carotid artery angioplasty and stenting (CAS) has clear advantages in this setting. It avoids the need to dissect through scarred tissue and the potential risks of cranial nerve injury or wound healing complications.[4,6-13] However, the enthusiasm with CAS has been tempered by high rates of restenosis and reinterventions in the range of 4% to 51% in contemporary reports dealing with radiation-induced carotid stenosis (RICS).[4,8-10,6,12,13] The aim of this study was to review the outcomes of CAS and of a historical group treated with open carotid repair (OR) for RICS.

From the Divisions of Vascular and Endovascular Surgery,[a] Neurosurgery,[b] and Neuroradiology,[c] Mayo Clinic.

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Reprint requests: Gustavo S. Oderich MD, Gonda Vascular Center, Mayo Clinic, 200 First Street SW, Rochester, MN 55905 (e-mail: oderich.gustavo@mayo.edu).

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METHODS

The study was approved by the Institutional Review Board of the Mayo Clinic.

All patients treated for RICS with OR or CAS from 1992 to 2009 were identified. Patients treated with CAS after 2003 were enrolled in a prospective institutional registry. We excluded patients treated for restenosis, atherosclerosis without a history of prior radiation, or other forms of arteritis.

Demographics, cardiovascular risk factors, clinical presentation, anatomical characteristics, imaging, and operative findings were reviewed. Early and late morbidity, mortality, stroke, or transient ischemic attacks (TIA) were

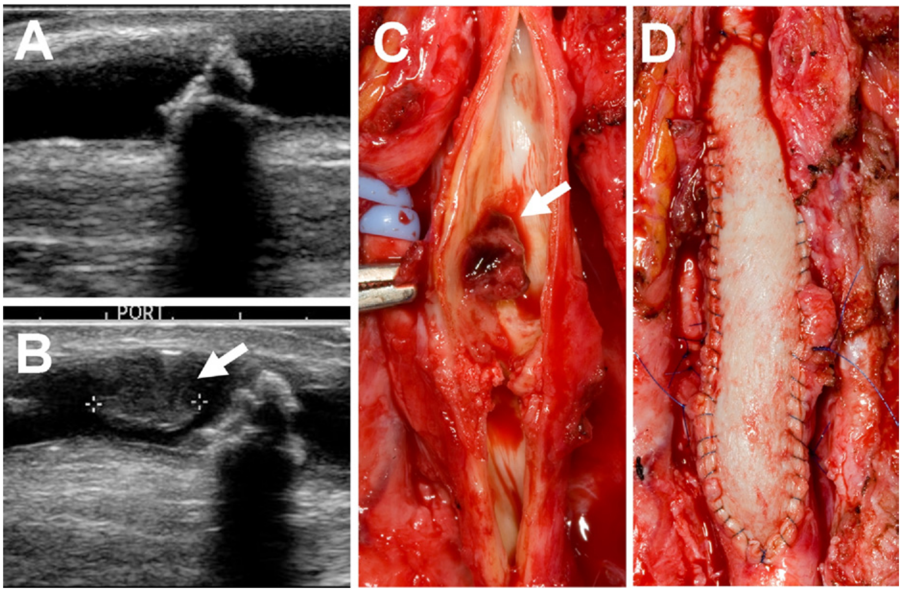

Fig 1. A 78-year-old male patient presented with a high grade carotid artery stenosis **(A)** with development of fresh thrombus (**B**, *straight arrow*) and new onset amaurosis fugax on a 2-week interval. The patient was treated with carotid endarterectomy and patch angioplasty with Bovine pericardial patch **(C** and **D)**. Panel **C** shows high grade stenosis of the common carotid artery with adjacent fresh thrombus distal to the area of stenosis.

noted. Early postprocedure period was defined as occurring within the first 30 days or within the hospital stay. Preoperative imaging studies, including carotid duplex ultrasound, computed tomography angiography (CTA), magnetic resonance angiography (MRA), and conventional angiography, were reviewed to identify lesion characteristics, including length, degree of stenosis, presence and severity of calcification, thrombus, or ulceration. Carotid revascularization was indicated in patients with progressive asymptomatic carotid stenosis > 80% or symptomatic lesions > 50% using the North American Symptomatic Carotid Endarterectomy Trial criteria.[15] Most patients with asymptomatic lesions had an initial period of observation with medical therapy, but revascularization was indicated because of significant progression in the degree of stenosis. Prior to 1999, OR was the only method used for revascularization. Since then, patients were treated preferentially with CAS, except when there was thrombus (Fig 1) or excessive tortuosity of the aortic arch or carotid artery.

Open carotid repair

Open carotid reconstruction was performed under general endotracheal anesthesia using electroencephalographic monitoring and selective in-line shunt. The type of reconstruction was left at the discretion of the operating surgeon. Carotid endarterectomy and patch was used preferentially whenever possible (Fig 1), except for long lesions or when the artery was friable or thin-walled, in which case an interposition graft or bypass was preferred. Myocutaneous flap coverage was indicated if there was concern about the quality of the radiated skin and soft tissue (Fig 2, online only). Medical therapy was aspirin alone in most patients.

CAS

CAS was performed using biplanar image under local anesthesia with monitored care. Antiplatelet therapy (aspirin and clopidogrel) was started 1 week prior to the procedure and continued for at least 6 weeks, after which clopidogrel was discontinued unless there was residual or recurrent stenosis. Percutaneous trans-femoral access was established with a 6 Fr hydrophilic guide catheter (Fig 3, online only). After systemic heparinization, arch and selective carotid and cerebral angiography were performed to confirm the degree of stenosis. The lesion was crossed using an embolic protection device, predilated with a 4- to 5-mm angioplasty balloon, and stented with a nitinol self-expandable stent. Postdilation was performed for residual stenoses >30%. Completion cervical and cerebral angiography was obtained after retrieval of the embolic protection device (Fig 3, online only). Heparinization was not reversed and all patients were monitored for 24 to 48 hours with independent neurological assessment and carotid duplex ultrasound (US) evaluation prior to dismissal.

Follow-up

Follow-up included clinical examination and carotid duplex US every 6 months during the first year and annually thereafter. Stroke and cranial nerve injury (CNI) were confirmed by independent neurological consultation. Carotid duplex US criterion for restenosis >50% was the same for in-stent and for postsurgical restenosis. The criterion included peak systolic velocity of >220 cm/sec, internal carotid artery (ICA) to common carotid artery (CCA) ratio >3.0, or doubling of velocities compared with baseline

Table 1. Clinical characteristics in 60 patients treated for 73 radiation-induced carotid stenosis with carotid artery stenting (*CAS*) or open repair (*OR*)

	CAS *n = 33, %*		*OR* *n = 27, %*		P *value*
Demographics					
Mean age (years) ± SD	66.5 ± 8.5		66.5 ± 11.6		.45
Male	25	76	20	74	.72
Female	8	24	7	26	.72
Cardiovascular risk factors					
Hypertension	21	64	17	63	.97
Hyperlipidemia	18	56	22	81	.039
Cigarette smoking	21	63	15	56	.75
Coronary artery disease	11	33	17	63	.04
Diabetes mellitus	7	22	5	19	.75
Chronic obstructive pulmonary disease	7	22	8	30	.5
Peripheral artery disease	6	18	9	33	.2
Atrial fibrillation	4	13	3	11	.87
Chronic renal insufficiency	2	8	3	11	.5
Dialysis	0	0	0	0	1.0
Anatomical risk factors					
Dissection	24	73	11	31	.2
Tracheostomy	10	31	1	4	.02
Irradiation protocol					
Higher dose protocol (60-75 Gy)	25	76	18	67	.75
Nasopharyngeal/laryngeal cancer	20	61	14	52	.7
Thyroid	1	3	3	11	.3
Lung	4	12	1	4	.4
Lower dose protocol (< 50 Gy)	8	24	9	33	.6
Skin	4	12	0	0	.1
Breast	0	0	1	4	.5
Lymphoma	4	12	8	30	.2
Year irradiation administered					
1970-1989	17	52	16	59	.75
1990-1999	9	27	7	26	1.0
2000-2009	7	21	4	15	.75
Time from irradiation (months)	76 ± 93		21 ± 17		.001
Indications					
Asymptomatic stenosis > 80%	18	49	16	44	.61
Symptomatic stenosis > 50%	19	51	20	56	.61
Transient ischemic attack	16	84	20	100	.71
Stroke	3	16	0	0	.086

carotid US.[14,15] Patients with restenoses were further evaluated by conventional angiography, CTA, or MRA, and reintervention was indicated for symptomatic restenosis >50% or progressive asymptomatic lesions >80%.

End-points and statistical analysis

Clinical data was reported and analyzed using recommended reporting standards.[16] Outcomes were compared in patients who had prior history of radical neck dissection (radical neck dissection present [RND+]) or not (RND−). The primary end point was a composite of any stroke, myocardial infarction, and death; secondary end points included morbidity and mortality, CNIs, wound complications (infection, necrosis, or dehiscence), and freedom from restenosis, reintervention, and neurological events (stroke and TIA). Patients with stroke/TIA had independent neurological consultation, head CT or MR, and carotid duplex US.

Categorical variables were compared using Chi-square or Fisher exact tests and continuous variables using two-tailed, unpaired Student's *t* test. Time-dependent outcomes (survival, neurological events, restenosis, and reinterventions) were reported using Kaplan and Meier survival estimates, and differences were compared using log-rank analysis. Univariate analysis was performed to identify predictors of primary and secondary end point measures, and a logistic regression model was used to identify independent factors when indicated. Results were reported as mean ± standard or median, or hazard ratio with 95% confidence interval (95% CI) when appropriate. A *P* value <0.05 was considered statistically significant.

RESULTS

Patient characteristics

A total of 5,824 patients had carotid interventions for carotid stenosis during the study period. Of these, 60 patients (1%) underwent revascularization of 73 RICS, including 33 patients (37 lesions) treated with CAS and 27 (36 lesions) treated with OR (Table I). Bilateral carotid revascularization was needed in four CAS and in nine OR patients. The average age was 66 years, with similar cardiovascular risk factors, except for higher rates ($P < .05$) of hyperlipidemia (56% vs 81%) and coronary artery disease (33% vs 63%) among OR patients. Indications were asymptomatic stenosis in 18 (49%) CAS and 16 (44%) OR patients, or symptomatic disease in 19 (51%) and 20 (56%), respectively. Patients treated with CAS had more tracheostomies (31% vs 4%) and longer time interval from irradiation to intervention (76 ± 93 months vs 21 ± 17 months; $P = .001$). There were no significant differences in the type of malignancy or year (before or after 1990) of irradiation treatment between groups (Table I). A higher irradiation dose (60 to 75 Gy) protocol for nasopharyngeal, laryngeal, lung, and thyroid cancer was used in 25 (76%) CAS and 18 (67%) OR patients, whereas a lower irradiation dose (< 50 Gy) protocol for breast or skin cancer was indicated in eight (24%) CAS and nine (33%) OR patients. Twenty-four (73%) CAS and 11 (31%) OR patients had prior radical neck dissections ($P = .2$).

Extent of carotid disease

Anatomic characteristics are summarized in Fig 4 and Table II (online only). Isolated ICA lesions occurred in 20 (54%) CAS and 20 (56%) OR patients, and tandem lesions or extensive involvement of both CCA and ICA was noted in nine (25%) CAS and 12 (33%) OR patients. The lesion was ulcerated in 15 (41%) CAS and 22 (61%) OR patients. Fresh thrombus was noted in none of the CAS patients, but occurred in five (14%) OR patients.

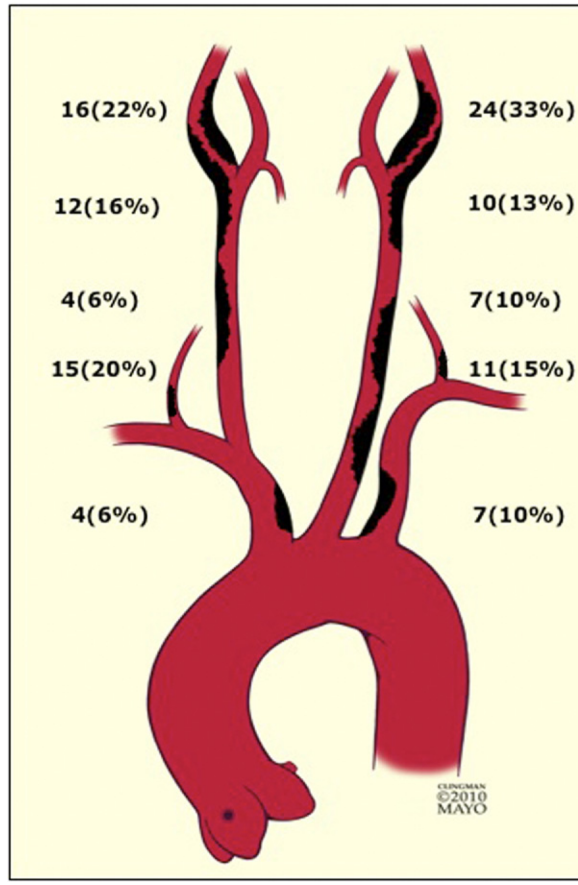

Fig 4. Distribution of carotid, subclavian, and vertebral arteries stenosis in 60 patients who had undergone previous neck irradiation.

Carotid revascularization

Open carotid repair included carotid endarterectomy and patch angioplasty for 29 lesions (80%), interposition graft in five, and bypass in two (Table III, online only). Myocutaneous flap coverage was needed in 3 of 14 lesions (22%) in patients with RND+, but in none of the RND− patients ($P = .07$). The surgeon referred in the operative report to excessive scar in ten (28%) patients, including five RND+ (36%) and five RND− (23%), while endarterectomy was difficult in one RND+ (7%) and six RND− (27%) patients. In the CAS group, embolic protection device was used to treat 25 lesions (68%) in 23 patients, but 12 lesions (32%) in 10 patients were treated without embolic protection prior to 2003. All patients had self-expandable stents, including 11 (25%) treated with Wallstents (Boston Scientific, Minneapolis, Minn) and 28 (62%) with 0.014-inch nitinol stents.

Early outcomes

There were no procedure-related deaths (Table IV). The primary end point occurred in three CAS (9%) and three OR (11%) patients ($P = 1.0$). There were two (6%) strokes after CAS and one (4%) after OR, all among RND+ patients ($P = 1.0$). In the symptomatic group, there was one (5%) stroke after CAS and none after OR ($P = 1.0$); for asymptomatic patients, there was one stroke after CAS (6%) and one after OR (5%). Two patients (7.4%) had non-Q-wave sub-endocardial infarctions without major complications after OR. Six (22%) OR patients had CNIs, including 4 of 14 (28%) RND+ and 2 of 22 (9%) RND− lesions ($P < 0.02$). Wound complications after OR occurred in two (14%) RND+ and in one (5%) RND− lesion ($P = .55$). Mean length of hospital stay was longer after OR compared with CAS (2.4 ± 2.1 days versus 4.1 ± 3.7 days; $P = .02$).

Late outcomes

Thirty patients (91%) in the CAS group and 19 (70%; $P = .5$) in the OR group had clinical and imaging follow-up at an average of 58 months (range, 1-132 months). Patient survival at 5 years was 40% ± 9% for CAS and 100% for OR patients (Fig 5, online only; $P = .008$). There were 11 late deaths (33%) after CAS due to malignancy in ten (30%) patients and ipsilateral stroke in one patient (3%) who had carotid stent occlusion 38 months later. In the OR group, there were three late deaths due to malignancy, but none of the patients died from cardiovascular cause.

Late strokes occurred in three (9%) patients (two RND+ and one RND−) after CAS and in none of the OR patients ($P = .25$). All three strokes were ipsilateral (two

Table IV. Early outcomes in 60 patients treated for 73 radiation-induced carotid stenosis with carotid artery stenting (*CAS*) or open repair (*OR*)

	CAS		*OR*		
	RND+ n = 24 patients/28 lesions, %	*RND− n = 9 patients/9 lesions, %*	*RND+ n = 11 patients/14 lesions, %*	*RND− n = 16 patients/22 lesions, %*	P *value*[a]
Stroke	2 (8)	0 (0)	1 (9)	0 (0)	1.0[a]
Myocardial infarction	0 (0)	0 (0)	0 (0)	2 (12)	0.5[a]
Death	0 (0)	0 (0)	0 (0)	0 (0)	1.0[a]
Stroke/death/myocardial infarction	2 (8)	1 (12)	1 (9)	2 (12)	1.0[a]
Cranial nerve injury	0 (0)[b]	0 (0)	4 (28)[b]	2 (9)	.02
Wound complication	0 (0)	0 (0)	2 (14)	1 (4.5)	.2[a]
Acute thrombosis	0 (0)	0 (0)	0 (0)	1 (4.5)	1.0[a]
Dialysis	0 (0)	0 (0)	0 (0)	0 (0)	1.0[a]
Intensive care unit stay (days)	1.3 ± 0.6	1.0 ± 0.4	1.5 ± 2.0	1.3 ± 1.0	.8[a]
Length in-hospital stay (days)	2.7 ± 3.0[b]	2.2 ± 1.3	5.2 ± 4.7[b,c]	3.4 ± 2.0[c]	‡[b,c]

RND, Radical neck dissection present (RND+) or absent (RND−).
[a]*P* value not statistically significant for comparison of totals between CAS and OR patients; comparison of RND+ and RND− patients were not significant.
[b]$P < .02$.
[c]$P = .07$.

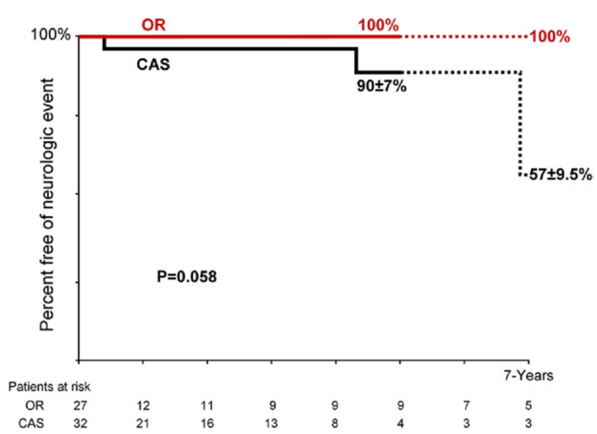

Fig 6. Kaplan-Meier estimates for freedom from neurologic event among 60 patients treated for radiation-induced carotid stenosis with open carotid repair (*OR*, *red*) or carotid artery stenting (*CAS*, *black*). The dotted line denotes a standard deviation >10%.

major and one minor), and two occurred in patients treated for symptomatic lesions. Freedom from any neurological event at 5 years was 90% ± 7% for CAS and 100% for OR, reaching statistical significance at 7 years (Fig 6). Restenosis > 50% occurred in eight patients (24%) treated with CAS (six RND+ and two RND−), including two patients who developed stent occlusion, one fatal. All restenosis and occlusions affected the stented segment; six were asymptomatic and two presented with symptoms. Five patients required reinterventions, which included redo CAS in three or percutaneous angioplasty in two. In the OR group, four patients (15%) had asymptomatic restenosis, including one RND+ and three RND−. Of these, two patients with progressive asymptomatic lesions were treated with CAS. Freedom from restenosis and reintervention at 5 years was 72% ± 9% and 86% ± 9% for CAS and 80% ± 10% and 87% ± 10% for OR ($P = .15$ and $P = .30$, respectively; Fig 7A, 7B). Freedom from reintervention at 5 years was 80% ± 9% and 100% for RND+ ($P = .08$), and 100% and 80% ± 13% for RND− patients ($P = .2$) treated by CAS and OR, respectively.

DISCUSSION

Open carotid revascularization in patients with previous neck irradiation has always been performed with trepidation. There is a legitimate concern that radiation predisposes patients to higher rates of stroke, cranial nerve injury, and wound complications including infection, necrosis, or skin breakdown.[5,6] Carotid angioplasty and stenting has emerged as a promising alternative to open surgery, avoiding some of the challenges described above. This study provides the largest single-center analysis and the first outcome comparison between endovascular and open surgical techniques for RICS.

Radiation has been accepted as a high-risk criterion for carotid endarterectomy because of the complications described above. Mozes and associates[17] reported our experience with 776 consecutive carotid endarterectomies, including 323 patients (42%) who were considered high-risk based on clinical or anatomical factors. In that study, radiation was the most important predictor of perioperative stroke, and local factors such as radiation, high carotid bifurcation, and reoperation were associated with cranial nerve injury in 8% of patients. In this study, the rate of cranial nerve injury was higher (17%), but compared favorably with other reports dealing with carotid reoperations (7%-17%) or radiated wounds (up to 27%).[5,18-30] We have found higher rates of cranial nerve injury (28% vs 9%) and wound complications (14% vs 5%) among patients with prior radical neck dissections compared with those without

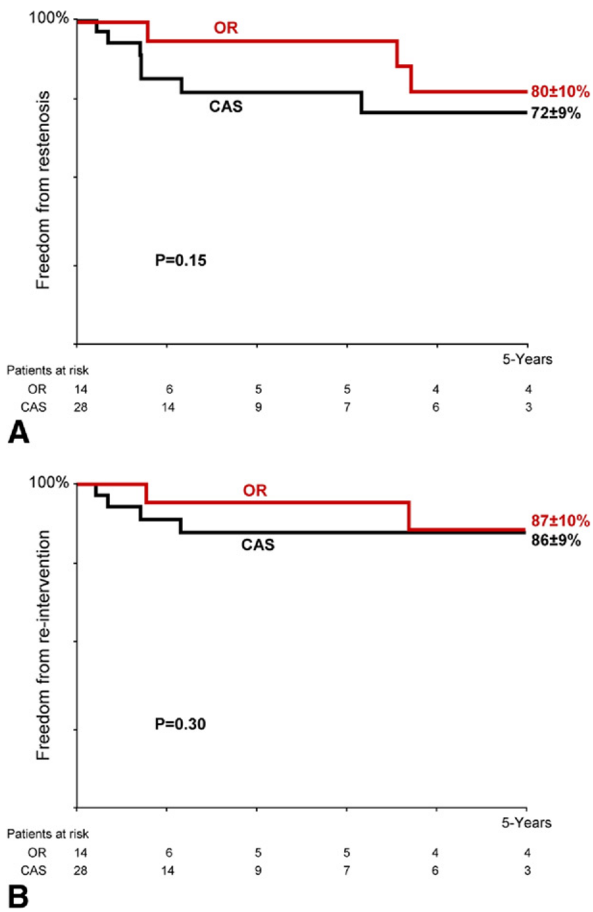

Fig 7. Kaplan-Meier estimates for freedom from restenosis **(A)** or reintervention **(B)** among 60 patients treated for radiation-induced carotid stenosis with open carotid repair (*OR*, *red*) or carotid artery stenting (*CAS*, *black*).

such a history, although some of the differences did not reach statistical significance. A similarity to other reports is the use of myocutaneous flaps in 27% of our patients with prior neck dissections; along with others, we believe that this helps prevent wound breakdown, which can expose the arterial repair and lead to blowout of the anastomosis (Fig 2, online only).[21]

Recent studies have shown that open surgery can be performed safely in selected patients with cervical irradiation. Friedell et al reported 13 patients treated with carotid endarterectomy for radiation-induced lesions, with no perioperative death, cranial nerve injury, or stroke after an average follow-up of 37 months.[24] Leseche and associates reported the largest series to date, which included 27 patients with previous radiation treated with open surgery. In that study, there was one perioperative death from hemorrhage, one early TIA, no late neurological event, and only two reinterventions.[27] Similar to other reports, we have found that open carotid repair can be performed safely with no early death, and low stroke (4%) and restenosis rates (11%).[4,6-13,31-33]

Conversely, carotid stents may not be as durable as open carotid repair in the radiated neck. Protack et al[12] reported restenosis in 43% of 23 patients treated for radiation-induced lesions with carotid stenting, including two (8.5%) who had stent occlusion. Favre and associates reported a retrospective review of 135 patients treated in multiple centers with carotid stents for cervical irradiation. Although there were no deaths and only two early strokes, six patients developed late strokes, nine had stent occlusions, and 18 developed restenoses.[6] Other reports have shown high restenosis rates for carotid stents in the range of 12% to 42%.[3,6,10] In our study, we found a trend towards higher rates of restenosis (22% vs 11%) and reintervention (13.5% vs 5.5%) among patients treated with CAS compared with open surgery, although these differences were not significant. However, similar to others, we also found late stent occlusions in two of our patients, one of which was fatal.[3,6,10]

In addition to this compelling data indicating that carotid stents for radiation-induced lesions are not as durable as open surgery, recent prospective randomized studies have shown higher stroke and death rates for carotid stents compared to endarterectomy. In the Carotid Revascularization Endarterectomy versus Stenting Trial study, the incidence of stroke/death for carotid stenting versus endarterectomy was 6% and 3.2% for symptomatic, and 3.2% and 1.4% for asymptomatic lesions, respectively. Other prospective randomized studies (Stent-protected Angioplasty versus Carotid Endarterectomy in Symptomatic Patients, Endarterectomy Versus Angioplasty in Patients with Symptomatic Severe Carotid Stenosis, and International Carotid Stenting Study trial) have also shown higher stroke/death rates for CAS compared with endarterectomy in the symptomatic group, questioning its indication for those patients who are good candidates for a carotid endarterectomy.[34-36]

The indication of any type of revascularization for asymptomatic carotid lesions remains controversial, particularly in the higher risk group. The benefit of carotid endarterectomy in the Asymptomatic Carotid Atherosclerosis Study was modest, with only 1% annual stroke risk reduction over 5 years.[37] In addition, medical therapy in the randomized trials did not include some of the current treatment strategies that constitute best medical therapy today, such as strict control of hypertension, intensive lipid lowering therapy, and combined anti-platelet regimens. A recent population-based study on patients with asymptomatic carotid stenoses showed only a 0.34% annual risk of ipsilateral stroke with intensive contemporary medical therapy over a mean follow-up of 3 years.[38] It is possible that intensive medical therapy could have lowered the risk of stroke in the Asymptomatic Carotid Atherosclerosis Study trial, potentially negating any benefit from carotid endarterectomy. Nonetheless, we still recommend revascularization in a patient who has objective evidence of significant progression of a high-grade RICS.

The extent of radiation damage to the skin, soft tissue, and artery likely affect outcomes of revascularization. Unfortunately, previous reports dealing with radiation-induced lesions have not analyzed any of the surrogates for radiation damage, such as type of radiation protocol, dose administered, or prior radical neck dissection. Radiation protocols have improved over time, mainly since the use of two-dimensional (after 1990) and three-dimensional imaging (after 2000) to target the lesion and spare the skin and adjacent structures.[39] In our study, we found that lesions treated by CAS occurred on average 6 years after cervical irradiation, compared with 2 years for open surgical lesions, indicating perhaps that CAS patients received a less aggressive form of irradiation. However, we found no differences in the type of malignancy, radiation dose, or year in which radiation was administered. Nonetheless, we found that patients with prior radical neck dissections had higher rates of stroke, cranial nerve injuries, wound complications, restenosis, and reinterventions, although some of these differences did not reach statistical significance.

Carotid artery stenting has clear advantages in the hostile neck, but its use as the sole method of revascularization for radiation-induced stenosis should be questioned. A history of previous radical neck dissection, tracheostomy, and neck examination indicating significant soft tissue and skin induration or scar should discourage one from open surgery. However, open carotid reconstruction may be the best option in the patient who does not have significant radiation damage to the skin or soft tissue, particularly if other anatomical factors are not favorable for stent placement (difficult arch, tortuosity, or thrombus). If an open reconstruction is selected, we prefer to use a carotid endarterectomy and patch angioplasty whenever possible. However, this contrasts with other surgical series where bypass with saphenous vein was the most common type of reconstruction.[21,22] We usually use an interposition graft or bypass for longer lesions or in patients with friable or thin-walled arteries after endarterectomy. The type of patch or graft material may affect restenosis rate, based on prior reports.[21,22] All four patients with restenosis after open repair in our study had polyester patches or grafts, while there were no restenosis among those treated with vein grafts or bovine pericardial patches. Other authors have also reported a preference for autologous veins to reconstruct radiation-induced lesions.[21,22] A compelling reason for selecting vein, in addition to less restenosis, is their resistance to infection.[5,21]

The main cause of late death in our study was malignancy, regardless of the type of treatment. Patient survival, however, was significantly less after CAS compared with open surgery. This is likely due to patient selection, which has changed over the last decade; carotid stents allowed treatment of patients who were previously denied open surgery because of a hostile neck. This is evident by the higher rates of tracheostomy and a trend towards more radical neck dissections in the CAS group. It is likely that selection bias has accounted for some the differences in outcomes which favored open repair, including patient survival and restenosis rates.

This study has other shortcomings that need to be discussed. Because of the retrospective design and long study period, the exact circumstances involved in decision-making of type of treatment (stent vs open surgery) or method of surgical reconstruction (endarterectomy vs bypass) cannot be determined. Because of the small number of patients, differences in subgroup analysis may have not reached statistical significancy because of type II error. It is possible that other factors such as radiation dose, number of treatment sessions, and type of anti-platelet therapy could have accounted for some of the differences in restenosis rates and neurological events. Restenosis after open surgical repair may have been underestimated because of less rigid follow-up compared with CAS patients, who participated in a prospective institutional registry. Conversely, the strength of the study relies on a relative large number of patients given the rarity of RICS, and the quality of data in our CAS group, which had independent neurological examination and close monitoring with duplex US imaging.

Open carotid repair for RICS was associated with higher rates of cranial nerve injury and a trend towards more wound complications compared with carotid stenting. These complications occurred more frequently among patients with previous neck dissections. However, the higher rates of late neurologic events, restenosis, and reinterventions after carotid stenting may offset its benefits in patients who do not have excessive radiation damage to the skin and soft tissue, and who are potentially good candidates for open carotid reconstruction.

AUTHOR CONTRIBUTIONS

Conception and design: GO
Analysis and interpretation: TT, GO, GL, HC, DK, TB, AD, PG
Data collection: TT
Writing the article: TT, GO, GL, HC, DK, TB, AD, PG
Critical revision of the article: TT, GO, GL, HC, DK, TB, AD, PG
Final approval of the article: TT, GO, GL, HC, DK, TB, AD, PG
Statistical analysis: TT, GO
Obtained funding: GO
Overall responsibility: GO
TT and GO contributed equally to this work and share first authorship.

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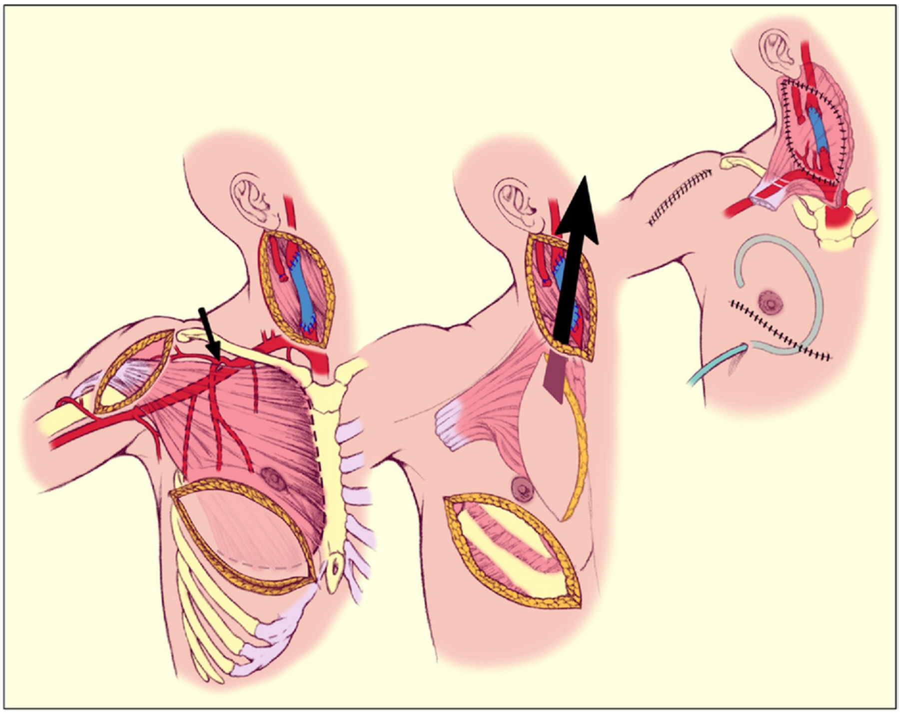

Fig 2, online only. Technique of pectoralis major myocutaneous flap coverage based on the thoracoacromial pedicle (*arrow*). An island of skin and soft tissue is selected in the inframammary region. The flap is elevated by dividing the pectoralis muscle attachments from the anterior chest wall (inferiorly), sternum (medially), clavicle (superiorly), and the humerus (laterally). The flap is rotated 180 degrees and advanced through the subcutaneous tunnel up to the neck. Closed-drainage system is used in the anterior chest and neck wound.

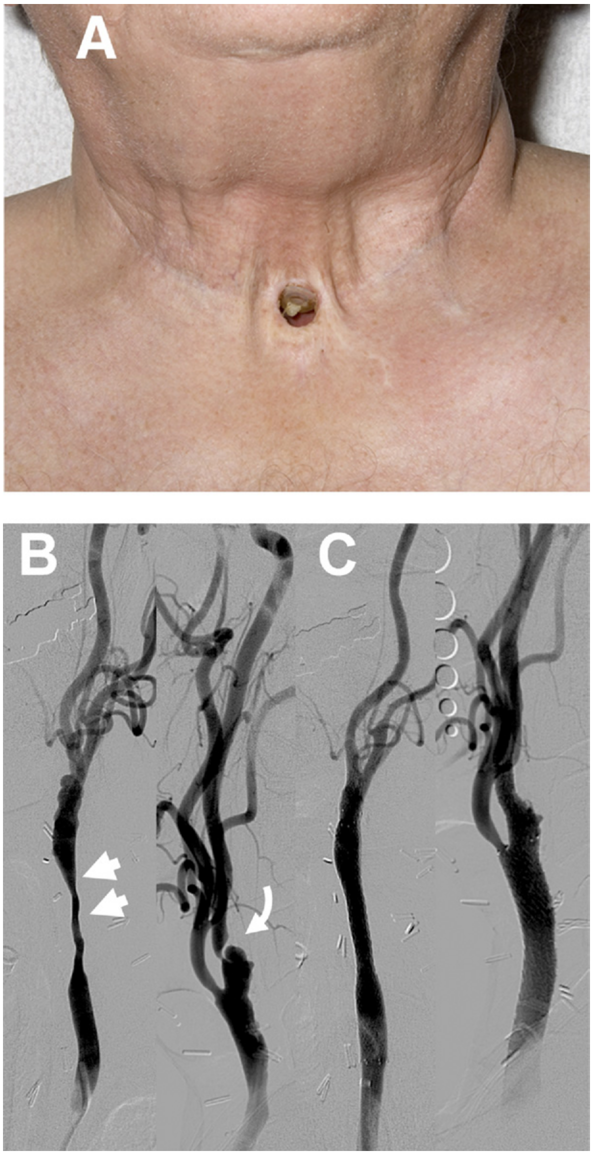

Fig 3, online only. Technique of carotid artery stenting (CAS) in a 77-year-old male with prior cervical irradiation, radical neck dissection, and tracheostomy who presented with progressive high-grade left common and internal carotid artery stenosis **(A)**. Cervical angiography confirmed tandem lesions involving the left common carotid artery **(B**, *two arrows*) and the proximal internal carotid artery **(B**, *curved arrow*). Completion angiography **(C)** after CAS with good anatomical result.

Table II, online only. Extent of carotid disease in 60 patients treated for 73 radiation-induced carotid stenosis with carotid artery stenting (*CAS*) or open carotid repair (*OR*)

	CAS		*OR*		
	RND+ n = 24 patients/28 lesions, %	*RND− n = 9 patients/9 lesions, %*	*RND+ n = 11 patients/14 lesions, %*	*RND− n = 16 patients/22 lesions, %*	P *value*[a]
Right side	13 (44)	2 (25)	8 (57)	9 (41)	.6
Left side	16 (55)	6 (75)	6 (43)	13 (59)	.6
Stenosis 50-79	5 (17)	1 (13)	0 (0)	0 (0)	.03
Stenosis >80	24 (83)	7 (88)	14 (100)	22 (100)	.6
Ulceration	13 (45)	2 (5)	6 (43)	16 (73)	.3
Fresh thrombus	0 (0)	0 (0)	2 (14)	3 (13.5)	.02
Common carotid artery	5 (17)	3 (37)	0 (0)	4 (18)	.4
Internal carotid artery-short lesion (<2 cm)	4 (14)	2 (25)	3 (21)	3 (14)	1.0
Internal carotid artery-long lesion (>2 cm)	12 (41)	2 (25)	6 (43)	8 (36)	1.0
Common and internal carotid arteries	8 (28)	1 (13)	5 (36)	7 (32)	.6

RND, Radical neck dissection present (RND+) or absent (RND−).

[a]*P* value for comparison of totals between carotid artery stenting and open carotid repair patients; comparisons of RND+ and RND− patients were not significant.

Table III, online only. Procedural characteristics in 60 patients treated for 73 radiation-induced carotid stenosis with carotid artery stenting (*CAS*) or open repair (*OR*)

	OR				
	RND+ n = 11 patients/14 lesions		*RND− n = 16 patients/22 lesions*		
	n = 14	*%*	*n = 22*	*%*	P *value*
Difficult dissection	5	36	5	23	.72
Difficult plaque cleavage plane	1	7	6	27	.39
Difficult dissection + difficult plaque cleavage plane	0	0	1	4.5	1.0
Myocutaneous flap coverage	3	22	0	0	.07
Reconstruction technique					
Carotid endarterectomy ± patch angioplasty	12	86	17	77	.88
Interposition segment	2	14	3	14	1.0
Ascending aorta-carotid bypass	0	0	2	9	.52
Total conduit	2	—	5	—	.6
Saphenous vein graft	2	100	1	20	.5
Polytetrafluoroethylene	0	0	2	40	1.0
Polyester	0	0	2	40	1.0
Total patch	11	—	17	—	1.0
Polyester patch	4	36	13	76	.3
Bovine patch	6	54	1	8	.02
Saphenous vein patch	1	10	3	16	.6

	CAS				
	RND+ n = 24 patients/28 lesions	*%*	*RND− n = 9 patients/9 lesions*	*%*	
Predilatation alone	23	84	5	64	.71
Pre- and postdilatation	3	7	2	24	.54
Postdilatation alone	2	6	0	0	1.0
Embolic protection device	19	65	6	75	.8
Type of stent					
precise Rx	20	56	8	72	.52
Wallstent	9	26	2	18	.8
Acculink	3	9	1	9	1.0
SMART	1	3	0	0	1.0
Balloon expandable stent	1	3	0	0	1.0
Mean of stent for procedure	1.2 ± 0.4		1.3 ± 0.5		.3
Mean length (mm ± SD)	30 ± 7.6		27.0 ± 4.7		.29
Mean diameter (mm ± SD)	7.6 ± 1.2		9.8 ± 4.3		.65
Residual stenosis < 20%	24	86	6	75	.87
Residual stenosis 20-40%	4	14	2	25	.61

RND, Radical neck dissection present (RND+) or absent (RND−).

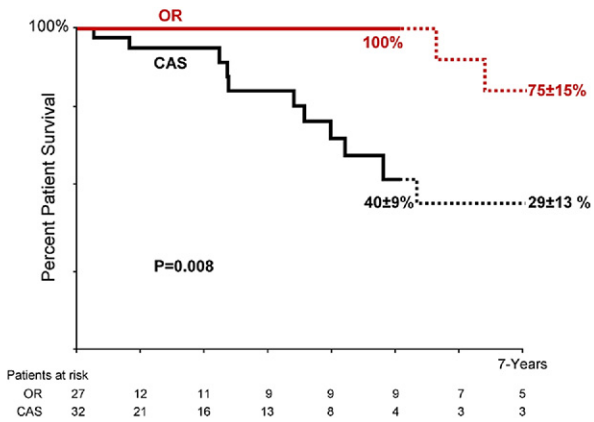

Fig 5, online only. Kaplan-Meier estimates for patient survival among 60 patients treated for radiation-induced carotid stenosis with open carotid repair (*OR*, *red*) or carotid artery stenting (*CAS*, *black*). The *dotted line* denotes a standard deviation >10%.