Early and late geometric changes after carotid endarterectomy patch reconstruction

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This study examines the degree and location of vessel wall geometric changes after carotid endarterectomy–vein patch reconstruction. The external diameters of the proximal common carotid, common carotid bulb, and internal carotid arteries were measured during operation with a caliper after 349 carotid endarterectomies. There were 309 saphenous vein reconstructions, 31 synthetic patch reconstructions, and 9 primary closures. One or more B-mode ultrasound studies with cross-sectional views for common and internal carotid cursor measurements were performed from 3 months to 5 years after operation. The intraoperative-to-postoperative common carotid diameters were unchanged for the three types of reconstructions. The internal carotid diameters increased 20% to 30% for both the vein and synthetic patched arteries. This dilation was present at 3 and 6 months and progressed slightly over 5 years. Wall thickening ≥ 1 mm was present in 62% of the carotid endarterectomies, with concentric stenosis in 3% and eccentric stenosis in 59%. Eccentric stenosis was present at 3 to 6 months, located on the endarterectomized posterior-medial wall of the common and internal carotid arteries, was always less than 50%, and changed very little over 5 years. No aneurysms or internal carotid occlusions were identified. Carotid endarterectomy–vein patch reconstruction results in early, mild, nonaneurysimal dilation of the internal carotid patched segment, frequent mild eccentric restenosis, and rare hemodynamically significant concentric restenosis. (J VASC SURG 1991;14:258-66.)

A potential advantage of carotid endarterectomy–vein patch reconstruction is the low incidence of early endarterectomy site restenosis.[1,2] Whereas symptomatic restenosis after carotid endarterectomy is reported to be 1% to 4%,[3,4] the incidence of asymptomatic greater than 50% diameter stenosis varies from 9% to 19%.[5-7] A modern series reports the early restenosis rate to be 5% or less after four types of endarterectomy reconstruction.[8] However, a detailed long-term study of carotid geometric and anatomic changes after vein patch reconstruction has not been reported. This is important because of soft evidence and suggestions that vein patching can result in marked enlargement of the carotid bulb, making it prone to thrombus formation on the patch surface, altered hemodynamic conditions, and late aneurysm formation.[9-11]

The acoustic homogenity of myointimal hyperplasia, smooth lumen surfaces, and the absence of calcification makes ultrasonography an excellent technique for serial postcarotid endarterectomy evaluation. High-resolution B-mode ultrasonography and pulsed Doppler velocity spectral criteria are the current standards and have excellent correlation with contrast angiography.[12-14] B-mode ultrasonography can provide detailed geometric measurements after carotid endarterectomy in many patients.[13]

The purpose of this study was to determine the geometry of the common and internal carotid arteries early and late after vein patch reconstruction, with specific attention to be paid to changes from the intraoperative postreconstruction geometry and the location, degree, and configuration of restenosis. A smaller group of patients with synthetic patch reconstruction and primary closure are included for comparative purposes.

PATIENTS AND METHODS

Patients. Of 700 carotid endarterectomies performed between 1982 and 1990, 639 (90%) had postoperative duplex ultrasonography surveillance studies. Of these 639, 349 (55%) had one or more cross-sectional views of the common carotid artery or internal carotid artery or both, that were technically

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adequate for geometric analysis and form the basis of this report. Autogenous greater saphenous vein patch reconstruction was performed in 309 carotid endarterectomies, synthetic patch reconstruction was performed in 31 (22 polytetrafluoroethylene and 9 Dacron), and primary closure was performed in 9. One-hundred-sixty-two men and 148 women had 186 and 163 carotid endarterectomies, respectively. The age at operation was 65 ± 10 (mean, ±1 SD) years. Coronary artery disease was present in 67%, hypertension in 64%, and diabetes in 13% of the patients.

Operating room measurements. After completion of carotid endarterectomy reconstruction and before closure, a caliper (Weck No. 7700) was used to measure the external diameter of the common carotid artery proximal to the arteriotomy, the bulb segment of the common carotid artery included in the arteriotomy, the bulb or patched segment of the internal carotid artery, and the distal internal carotid above the arteriotomy. Caliper diameter measurements were made visually with ×2.5 power optical manification to ensure that the two ends of the caliper just touched the surface of the artery. The arteriotomy length and patch length proximal and distal to the origin of the internal carotid artery were measured and available to the vascular technologist for subsequent ultrasound studies.

Greater saphenous veins 5 mm or less in distended diameter were used in total, whereas larger diameter veins were trimmed to produce a patch comparable to that of a 5 mm diameter vein. In the undistended open state this is a 7 to 9 mm wide vein patch before use and results in a patch with a 6 to 8 mm cord. Synthetic patches 10 mm in width were used. This generally produced a common carotid wall circumference composed of 15% to 30% patch material and an internal carotid segment of 40% to 60% patch.

Postoperative ultrasound measurements. All studies were performed by an experienced registered nurse–registered vascular technologist using a 7.5 MHz B-mode imager and 5 MHz pulsed Doppler with real-time spectral analysis (Ultramark 8; Advanced Technology Laboratories, Bothell, Wash.). Multiplanar common and internal carotid artery longitudinal and cross-sectional images were used to identify the regions of maximal wall thickness of the endarterectomized segments. Cursors were used to measure the outside diameters and the wall thickness when the outer wall to inner wall thickness was ≥1 mm. Center-stream peak systolic Doppler frequency shift (velocity) was measured in the common

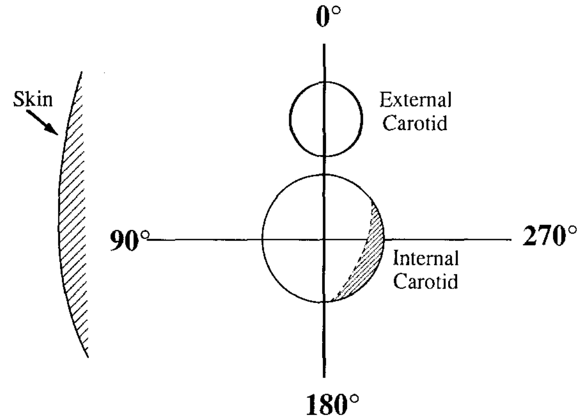

Fig. 1. Schematic of 0 to 360 localization of region of maximum wall thickening of common and internal carotid arteries.

and internal carotid arteries at the regions of minimal residual lumen diameter. The location of maximum eccentric wall thickening was measured in degrees relative to the location of the external carotid artery as illustrated in Fig. 1. Studies were performed at 3 months (113), 6 months (108), 1 year (90), 2 years (38), 3 years (47), 4 years (55), and 5 or more years (80) after carotid endarterectomy. A total of 531 studies were technically acceptable, of which 507 were of the common carotid (469 vein patches, 29 synthetic patches, and 9 primary closures) and 422 of the internal carotid (391 vein patches, 27 synthetic patches, and 7 primary closures). Thus 24 of the 531 carotid artery studies were only of the internal carotid artery, and 109 were only of the common carotid segments. Since the common and internal carotid segments were evaluated separately, the 109 studies with only common carotid and the 24 with only the internal carotid data are included in the data analysis. Thus each carotid endarterectomy had an average of 1½ technically acceptable B-mode studies. These studies were spread over the 5+ year postoperative period in a nonuniform way because it was several years after reconstruction for some patients when the B-mode studies were begun, some returned as scheduled but had technically unacceptable studies at some time periods, and others failed to return for late studies. Therefore sequential postoperative changes within patients are more difficult to determine than are changes between operative and postoperative dimensions for different sets of patients at each time interval. In addition, distal internal carotid diameter measurements were obtained in most studies and were used to compute percent stenosis by the usual angiographic method described below.

Table I. Intraoperative postreconstruction diameters; mean ± 1 SD, mm

	No. of operations	*Proximal common carotid artery*	*Common carotid artery*	*Internal carotid artery*	*Distal internal carotid artery*
Vein patch	309	8.5 ± 1.3	12.8 ± 1.6	8.4 ± 1.2	4.8 ± 0.8
Synthetic patch	31	8.4 ± 0.9	12.5 ± 1.5	8.5 ± 1.4	4.5 ± 0.7
Primary closure	9	8.5 ± 0.8	11.8 ± 1.9*	7.9 ± 1.5*	4.9 ± 0.8
Combined	349	8.5 ± 1.3	12.7 ± 1.6	8.4 ± 1.2	4.8 ± 0.8

*$p < 0.01$ when compared to each patch reconstruction by ANOVA.

Table II. Postoperative B-mode ultrasound diameters for vein patch reconstructions, mean ± 1 SD, mm

	No.	*Proximal common carotid artery*	*No.*	*Common carotid artery*	*No.*	*Internal carotid artery*
3 mo	105	7.9 ± 1.3	99	12.1 ± 2.0	82	10.5 ± 1.9
6 mo	100	8.2 ± 1.3	98	12.4 ± 2.0	78	10.2 ± 1.9
1 yr	84	8.4 ± 1.6	80	12.0 ± 1.9	61	9.9 ± 1.9
2 yr	35	7.8 ± 1.1	35	11.5 ± 1.4	28	10.0 ± 1.8
3 yr	43	8.0 ± 1.1	42	11.5 ± 2.2	35	9.7 ± 2.1
4 yr	48	8.0 ± 1.3	47	11.5 ± 2.3	38	9.8 ± 2.1
5 yr	71	8.0 ± 1.2	68	11.7 ± 2.0	69	10.0 ± 1.9

Calculations and statistical methods. The data were tabulated and stored in a computerized registry for later analysis. Paired and unpaired *t* tests between intraoperative and postoperative measurements and analysis of variance (ANOVA) between sequential postoperative measurements were performed by use of commercial software programs (BMDP, Statistical Software Inc., Los Angeles, Calif.). Values in the tables and text are mean ± 1 SD and values in figures are mean ± 2 SD. Percent stenosis was calculated when wall thickness was ≥1 mm. If the wall thickening was concentric or "donut" shaped in cross-section, standard formulas used are the following: percent diameter stenosis = (1 − inside diameter/outside diameter) × 100, and percent area stenosis = 1 − [inside diameter/outside diameter]^2) × 100. When the wall thickening was eccentric or "quarter moon" shaped in cross-section the formulas used are the following: percent diameter stenosis = (maximum wall thickness/outside diameter) × 100, and percent area stenosis approximately = 4/3 ([maximum wall thickness/outside diameter] − [maximum wall thickness/outside diameter]^2) × 100. The latter formula is one-third the area of a concentric stenosis of the same wall thickness and is an approximation. Other methods of estimating the eccentric area stenosis could be used. In addition, percent stenosis according to the usual angiographic method of comparing the residual lumen diameter or area to that of the normal proximal common carotid for the common carotid segment, and the normal distal internal carotid for the internal carotid segment, were calculated by use of the above equations to compute the residual lumen diameter and area of the stenosed segments.

RESULTS

The postendarterectomy intraoperative diameters for the 349 carotid endarterectomies are given in Table I. Women had 7% to 10% smaller diameters than men at each location. Although the common and internal carotid artery diameters of the primary closure group were significantly smaller than the diameters of the two patched groups, this may not be a representative example of primarily closed carotid diameters because this is a highly selective group with large carotid bulbs in which the arteriotomy did not extend distal to the bulb and therefore was not patched. No difference was found in the diameter measurements of the two types of synthetic patches. The sequential 3-month to 5-year diameters for the vein patch reconstruction group are given in Table II. The intraoperative to postoperative percent difference in the 349 proximal common carotid diameters was −6.3% ± 12.4% (mean ± 1 SD) and the absolute difference was 0.51 ± 1.03 mm. These are the control data between the two methods of measurement because the proximal common carotid diameter should not change. The negative value means that the B-mode ultrasound measurements were smaller than the caliper intraoperative measurements. Sequential postoperative-to-postoperative

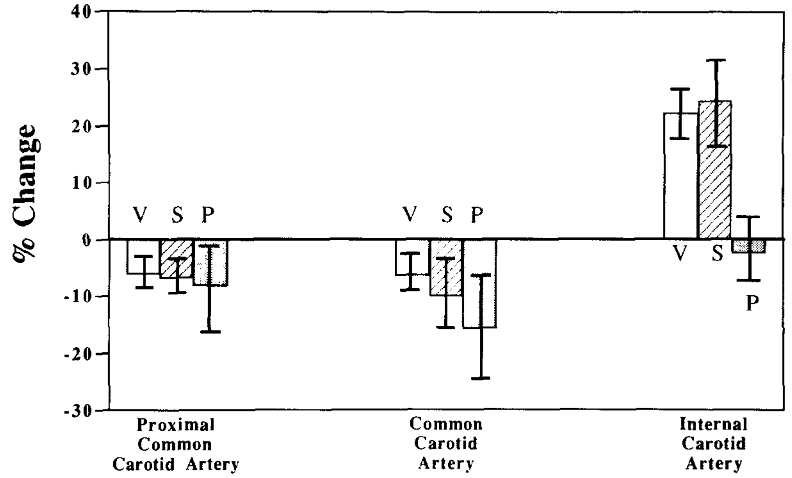

Fig. 2. The percent change from intraoperative to 3- to 6-month postoperative diameter measurements for 193 vein patch *(V)*, 22 synthetic patch *(S)*, and 6 primary closure *(P)* reconstructions. The bars are mean ± 2 SD. The internal carotid vein and synthetic patch reconstruction diameters were significantly increased ($p < 0.001$ by ANOVA) when compared to the proximal common carotid controls, the common carotid diameter changes, and the internal carotid primary closure group.

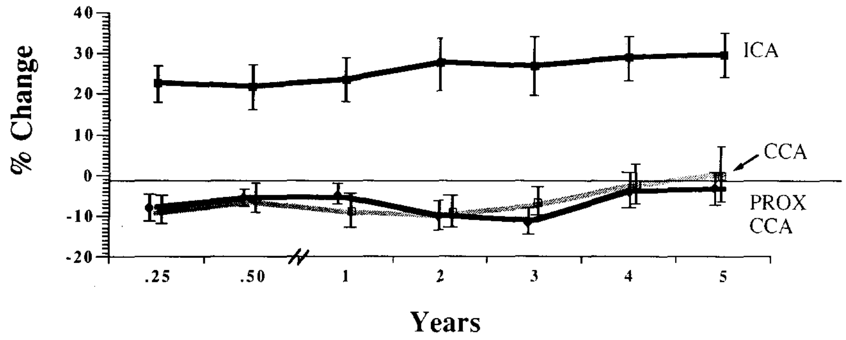

Fig. 3. The percent diameter change from intraoperative measurements for vein patch reconstructions. The data points and bars are mean ± 2 SD. The number of arteries measured at each period and location is given in Table II.

B-mode diameter measurements of 182 proximal common carotid artery diameter measurements varied by 0.11% ± 9.7% with an absolute difference of 0.1 ± 0.9 mm. These are B-mode methodology control measurements since the proximal common carotid artery diameter should not change.

The percent change between intraoperative and 3- to 6-month postoperative diameter measurements for vein and synthetic patch reconstructions and primary closures are given in Fig. 2. There was a 20% to 30% dilation of the internal carotid diameters for both vein and synthetic patched arteries. No difference was found between polytetrafluoroethylene and Dacron patch diameter changes. The early and long-term diameter changes for the vein patch reconstruction group are given in Fig. 3. Although a trend exists to increasing dilation of the internal carotid vein patch segments after 6 months, the changes up to 5 years were not statistically significant by ANOVA. No difference was observed in the diameter changes for male and female patients.

Wall thickening ≥1 mm was present in the common or internal carotid arteries or both in 218 or of 349 (62.5%) carotid endarterectomies. The proportion of carotid arteries with wall thickening for the three types of endarterectomy reconstructions is given in Table III. The 3-month to 5-year eccentric wall thickness for vein patch reconstructions is given in Fig. 4 for the common and internal carotid arteries. The average maximum eccentric wall thickness for all

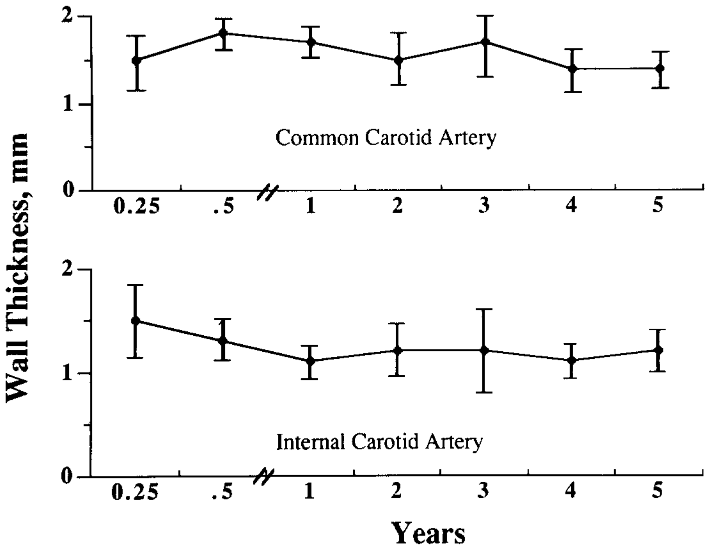

Fig. 4. Maximum eccentric wall thickness measurements for the common and internal carotid artery vein patch segments. The data points and bars are mean ± 2 SD. The number of arteries with measurable wall thickness ≥ 1 mm at 3 months, 6 months, 1 year, 2 years, 3 years, 4 years, and 5 + years was 42, 51, 38, 28, 33, 39, and 38 for the common carotid and 25, 41, 29, 22, 24, 25, and 22 for the internal carotid.

Table III. Proportion of carotid arteries with and without wall thickening of the common carotid artery, internal carotid artery, or both

	No.	*Normal (< 1 mm)*	*Eccentric thickening (≥ 1 mm)*	*Concentric thickening (≥ 1 mm)*
Vein patch	309	116 (37.6%)	184 (59.5%)	9 (2.9%)
Synthetic patch	31	11 (35.5%)	20 (64.5%)	0
Primary closure	9	4 (44.8%)	4 (44.4%)	1 (11.1%)
Total	349	131 (37.6%)	208 (59.6%)	10 (2.9%)

three types of closures for the common carotid artery was 1.58 ± 0.80 mm and for the internal carotid artery was 1.23 ± 0.86 mm. The percent of arteries having measurable eccentric thickening at each time interval remained unchanged from 49% to 71%. A slightly higher proportion of women, 65% (96/148), than men, 59% (95/162), had wall thickening, but the differences were not statistically significant by chi-square analysis. The locations of the maximum eccentric wall thickness as defined in Fig. 1 are given in Fig. 5. The within-patient percent change for sequential B-mode examinations on 177 vein patch reconstructions are given in Table IV for the common and internal carotid artery diameters and eccenteric wall thickness. Two common carotid arteries and two internal carotid arteries had wall thickness ≥ 1 mm at the first postoperative study but less than 1 mm at a subsequent study, whereas three common carotid arteries and one internal carotid artery had less than 1 mm thickening initially but ≥ 1 mm thickening subsequently. The fractional percent of carotid arteries with measurable eccentric wall thickening at each postoperative time period remained unchanged between 46% and 73%.

The calculated concentric and eccentric percent stenosis for the three types of carotid endarterectomy reconstructions are given in Table V. Table VI gives the peak systolic velocities for all carotid endarterectomies. By frequency (velocity) criteria one vein patch had 76% to 99% common carotid stenosis,[14] and one vein patch and one primary closure had 50% to 75% internal carotid artery stenosis. No internal carotid artery occlusions were observed. The 3- to 6-month velocities were not significantly different from the long-term values. Of the 10 concentric stenoses, two were greater than 50% diameter (75% area) for both the common and internal carotid arteries, one a vein patch and one a primary closure.

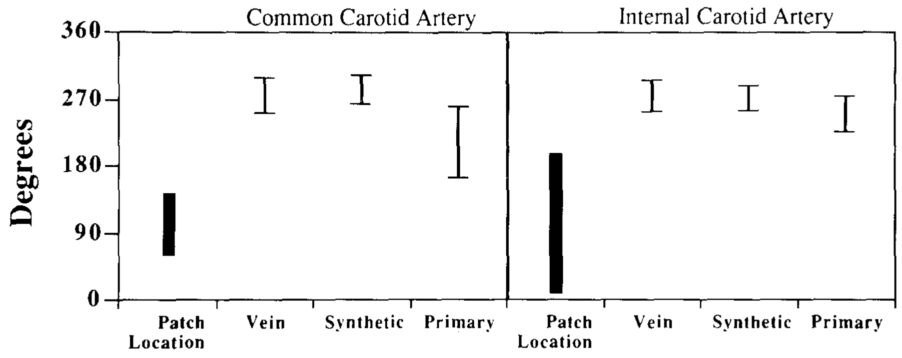

Fig. 5. The range of locations of maximum eccentric wall thickness for the three types of reconstructions and the location of the patch. The 0 to 360 format is given in Fig. 1. The number of arteries for each type closure is given in Table III.

Table IV. Sequential post–vein patch reconstruction B-mode within-patient percent change in diameter and eccentric wall thickness, mean ± 1 SD

	No.	*Common carotid artery*	*No.*	*Internal carotid artery*
Diameter				
0-1 yr	86	−1.1 ± 11.4	78	0.7 ± 11.7
1-3 yr	57	−1.2 ± 12.7	51	1.9 ± 13.1
3-5 yr	25	2.6 ± 13.2	20	1.3 ± 14.0
Eccentric wall thickness				
0-1 yr	52	3.1 ± 13.5	49	−2.8 ± 12.8
1-3 yr	35	0.9 ± 11.8	32	−0.6 ± 12.1
3-5 yr	16	1.4 ± 15.0	13	1.1 ± 14.6

No p values <0.10 by paired t testing.

The maximum concentric diameter stenosis was 72%. The maximum eccentric stenosis in the common carotid artery, was 41% diameter (32% area) and in the internal carotid artery was 48% diameter (34% area).

When the residual lumen diameter of the common carotid endarterectomized segment was compared to the control proximal common carotid artery, the concentric diameter stenosis was 17.6% ± 27.0% (25.7% ± 42.4% area), and the maximum concentric diameter stenosis was 52% (77% area). Similarly, when the residual lumen diameter of the internal carotid artery was compared to the distal internal carotid artery diameter the maximum concentric diameter stenosis was 32%. For eccentric wall thickening the common carotid diameter stenosis was −29.2% ± 64.2%, with a maximum of 34.0%. Negative values mean the endarterectomized common carotid segment residual diameter was greater than the proximal common carotid diameter. Similarly, the internal carotid artery had an eccentric diameter stenosis of −54.8% ± 38.0%, with a maximum of 45.6%.

The possible role of postreconstruction carotid artery geometry on the development of concentric and eccentric wall thickening was evaluated by calculating four dimensionless diameter ratios. These results, given in Table VII, do not indicate that diameter shape factors play a role in carotid restenosis. The only statistically significant result suggests that concentric stenosis may occur more frequently in arteries with a smaller not a larger common carotid bulb to proximal common carotid diameter ratio.

Finally, none of the 531 postoperative duplex scans of the 349 carotid endarterectomies in this report showed evidence of thrombus on the patch surface or of gross aneurysmal dilation of the patched segments. Nor have either of these findings been present in another 290 carotid endarterectomies that had postoperative duplex scans not technically adequate to be included in this report.

DISCUSSION

The current controversy over the advisability of carotid endarterectomy patch reconstruction has not been resolved. Although the patch or not to patch

Table V. Percent diameter and area stenosis for carotid arteries with measurable stenosis, mean ± 1 SD

	No. arteries measured	*Percent diameter stenosis (maximum)*	*Percent area stenosis (maximum)*
Eccentric common carotid artery			
Vein patch,	179	13.2 ± 6.3 (41)	14.7 ± 5.6 (32)
Synthetic patch,	18	12.8 ± 4.3 (23)	14.6 ± 4.1 (24)
Primary closure,	4	14.8 ± 5.2 (24)	16.5 ± 4.6 (24)
Eccentric internal carotid artery			
Vein patch,	158	11.8 ± 7.4 (45)	13.1 ± 5.3 (33)
Synthetic patch,	15	12.5 ± 5.2 (20)	14.3 ± 4.8 (22)
Primary closure,	4	12.2 ± 1.3 (14)	14.3 ± 1.3 (16)
Concentric common carotid artery*	5	38.4 ± 16.9 (72)	59.5 ± 19.8 (92)
Concentric internal carotid artery*	8	34.5 ± 17.8 (58)	54.4 ± 23.4 (82)

*Concentric stenosis present in nine vein patches (four common and seven internal carotid arteries), no synthetic patches, and one primary closure (common and internal carotid arteries).

Table VI. Peak systolic velocity, mean ± 1 SD, cm/sec

	No.	*Common carotid artery (maximum)*	*Internal carotid artery (maximum)*
Vein patch	309	82 ± 38 (700)	100 ± 36 (600)
Synthetic patch	31	75 ± 21 (120)	113 ± 45 (250)
Primary closure	9	81 ± 27 (180)	106 ± 32 (180)
Combined	349	81 ± 37 (700)	101 ± 37 (600)

issue is overshadowed by the larger question of the value of carotid endarterectomy in stroke prevention, it remains important to continue to study and refine carotid endarterectomy with the goal of optimizing short- and long-term results. The gold standard of 3% or less 30-day morbidity and mortality is obtained by attention to multiple details of management, each of which may be worth only 1% or 2% on the projected outcome. Patching may be one of these details.

Of the two ways of analyzing these geometric data, intraoperative-to-postoperative at various time intervals in varying groups of patients, and sequential postoperative-to-postoperative in the same patients, only the former demonstrate significant changes, of which there were two. First, a 20% to 30% dilation of vein and synthetic patched internal carotid arteries was present at 3 to 6 months and did not change over the next 5 years. Second, endarterectomized segment wall thickening occurred in 62% of carotid endarterectomies, was primarily eccentric in shape, was mild, was present early on the nonpatched posterior lateral wall, and did not significantly change over 5 years.

Early postcarotid endarterectomy vein and synthetic patch segment dilatation and contour irregularities were reported by Lord et al.[11] who used intravenous digital subtraction angiography, but the degree of dilation was not quantitated. They reported dilation of the common or internal carotid artery to more than twice the intraoperative measured diameter in 7 of 41 (17%) vein patches and 4 of 43 (9%) polytetrafluoroethylene patches. Our findings were of a more uniform and predictable 20% to 30% dilation of the internal carotid patched segment. The reasons for these discrepancies are unclear and may be related to the methods used to determine the diameters. Their study does not include proximal common carotid diameter controls between the intraoperative and postoperative measurement methods.[11] Although the definition of aneurysmal dilation of the carotid bulb is unclear, none of our carotid segment diameters doubled in the 5-year postoperative period.

Since the observed dilation was only in the internal carotid segment of patched arteries it is probable that the patch and possibly the suture lines play the major role in dilation. Expansion of the two suture lines a few tenths of a millimeter could explain some of the observed differences but not all. The patch occupies 40% to 60% of the internal carotid wall but only 15% to 30% of the common carotid. This may explain why the measurable effect of patch material dilation is in the internal carotid segment. If the endarterectomized arterial wall dilated, one would expect to measure significant dilation of the common carotid segments as well.

The frequent presence of measurable wall thickening is interesting as is its location. Hemodynamically significant stenosis was present in less than 2% of the carotid endarterectomies. This is consistent with other reports of a low rate of restenosis or residual stenosis after patch reconstruction.[1,2,15] The

Table VII. Intraoperative common and internal carotid diameter ratios and the presence of postoperative stenosis in 116 normal, and 193 stenotic vein patch reconstructions, mean ± 1 SD

	Common carotid / Proximal common carotid	*Internal carotid / Proximal common carotid*	*Internal carotid / Distal internal carotid*	*Proximal common carotid / Distal internal carotid*
Common carotid artery				
Normal	1.41 ± 0.14	0.90 ± 0.16	1.70 ± 0.29	1.91 ± 0.30
Eccentric stenosis	1.42 ± 0.14	0.88 ± 0.14	1.64 ± 0.26	1.88 ± 0.28
Concentric stenosis	1.28 ± 0.09*	0.91 ± 0.22	1.62 ± 0.42	1.78 ± 0.20
Internal carotid artery				
Normal	1.41 ± 0.14	0.88 ± 0.15	1.67 ± 0.27	1.90 ± 0.29
Eccentric stenosis	1.42 ± 0.14	0.90 ± 0.16	1.66 ± 0.28	1.88 ± 0.28
Concentric stenosis	1.34 ± 0.15	0.85 ± 0.14	1.60 ± 0.24	1.89 ± 0.26

*$p = 0.016$ when compared to normal and concentric stenosis.

milder eccentric restenosis is probably a benign finding. It does not appear to be a precursor of more significant concentric stenosis. Its early presence suggests a myointimal process. The location on the endarterectomized wall of both synthetic and vein patched common and internal carotid segments supports the concept that endothelium-lined patches do not spread endothelial cells to the arterial wall.[16] Endothelium may, however, protect against thrombosis on the vein patch segment, but this has not been proved.

Carotid artery anatomy and geometry is thought to play a major role in the development of localized atherosclerotic plaque. Similarly, one could propose that reconstruction geometry may play a role in the degree and location of myointimal hyperplasia after carotid endarterectomy. The location of eccentric wall thickening is similar to that of early atherosclerotic plaque formation in the carotid bulb. However, analysis of the various diameter shape factors and the presence of wall thickening gave only one statistically significant correlation between geometry and wall thickening. The ratio of the common carotid diameter to the proximal common carotid diameter of arteries with concentric stenosis was smaller, not larger, than the diameter ratios of the normal and eccentric stenosis groups. This does not support the concept that making the carotid bulb larger, as with a patch, is a precursor for myointimal hyperplasis.

This study supports the use of saphenous vein patch carotid endarterectomy reconstruction and to a lesser degree, because of smaller numbers, synthetic patch reconstruction. Mild postoperative dilation of the internal carotid patched segments and mild posterior lateral endarterectomized segment wall thickening occurs. Neither of these findings lead to aneurysmal dilation or hemodynamically significant stenosis.

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