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The Application of Operative Ultrasound Immediately Following Carotid Endarterectomy

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One hundred and seventy-five carotid bifurcations have been scanned using intraoperative ultrasonic imaging. The technique is simple, reproducible, rapid, and reliable. Intimal flaps, clamp stenoses, residual plaques, and platelet accumulations were detected by this method. Most technical defects occurred in the external carotid artery (12%), and it is recommended that significant lesions remaining in this vessel should be removed. Defects in the internal carotid artery and common carotid artery were much less common (7%) and most of these were quite small, not requiring reopening. In fact, only 2% required reopening. In 1% of patients there were defects detected that led to stroke, which would have been removed on present criteria. Although there were other causes of stroke, technical error remains an immediately reversible source of postoperative stroke that can be avoided by the use of operative ultrasonic imaging. Long-term minor defects, as followed by noninvasive tests, rarely became significant and bore no relationship to the development of restenosis.

In terms of technical excellence, there is no operation in vascular surgery that is more important than carotid endarterectomy. A simple operative oversight may result in irreversible neurological damage and death. To detect such technical defects, operative angiography has been the standard mechanism for evaluation of the procedure [1, 2], but it is logistically unattractive, invasive, requires injection of contrast, and exposes the surgeon and the patient to repeated irradiation. Small parts B-mode and duplex scanning have been well accepted among vascular surgeons in detecting lesions transcutaneously, particularly in the carotid bifurcation, and, therefore, the logical progression is to use operative high-resolution small parts scanning to detect technical errors in place of operative angiography at the time of carotid endarterectomy.

The aim of this study was to assess the use of operative ultrasound in the detection of technical error and to assess the change in operative stroke rate, if any, in a parallel series of unscanned patients in addition to determining the long-term outcome of minor technical oversights in relationship to carotid restenosis.

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Material and Methods

One hundred seventy-five patients were scanned intraoperatively after closure of the arteriotomy of carotid endarterectomy and after all clamps and Vessiloops® had been removed and the blood flow restored. A total of 380 carotid endarterectomies were performed during the time; the 205 instances in which a scan was not performed were essentially related to logistical problems with the use of the equipment and to the initial high mechanical failure of the prototypes. The cases were, therefore, randomized according to the logistical availability of the scanner. All of the carotid endarterectomies were performed using a standard Javid shunt.

Three prototypes were used. Initially, the Xenotec® small parts scanner was used, then the Cooper Intrascan®, and then the Diasonics Surgiview® was used as better systems became available. The latter system is a dedicated intraoperative scanner and is now routinely used during carotid endarterectomy. The systems were initially soaked in gluteraldehyde for sterilization purposes, then sterilized with ethylene oxide, but in recent times, a large plastic sheath containing a small amount of acoustic coupler has been used routinely and is by far the most logistically attractive of all methods tested. All of the operative ultrasound systems have a digital scan converter, a large 17-inch monitor (to allow the imaging devices to be well away from the sterile field), and an acoustic standoff on the probe itself (to facilitate a large segment of artery to be imaged). In addition, the total system is electrically isolated. The Surgiview® system has a preset gain control which has been optimized for intraoperative imaging. This facilitates the operating learner requirements, and, indeed, it is rare that any change in the receiver gain or any manipulation of the dials is required.

Table 1. Results of ultrasound scanning of 175 carotid bifurcations.

Vessel (n = 175)	Abnormal	Major defect	Minor defect	Reopened	Reversible ischemic neurologic defect	Bruit	Restenosis
External carotid artery (ECA)	21	13	8	10	1	6	1
Internal carotid artery (ICA)	12	2	10	1	0	0	0
Common carotid artery (CCA)	10	2	8	1	0	4	1

Scanning Technique

After all instruments had been removed from the vessels and flow restored, both ends of the wound were held upward with a retractor to obviate leakage of saline out of the wound. To facilitate further the coupling of the vessel with saline, the patient was commonly rotated 15° to the opposite side. Scanning was performed longitudinally initially using both hands with the thumb and the index finger of the left hand projecting beyond the tip of the probe, touching both sides of the vessel, thereby allowing the probe to move easily parallel to the vessel being scanned. The transverse scan requires no such guidance. Scans were recorded on Polaroid® film or videotape, and the freeze frame was used, if required, to assess a lesion more closely. The criteria for a major or minor defect was based on a 30% stenosis. If the patient was reopened, a repeat scan was performed to reassess the operative result.

Long-Term Follow-Up

One hundred three patients have been followed for more than 6 months with noninvasive tests, i.e., 1 or more of duplex scanning, oculoplethysmography, color-coded Doppler imaging, and B-mode scanning.

Results

Of the 175 carotid bifurcations scanned, 136 were normal and 39 showed some abnormality in any vessel. There were 4 that had defects in 2 of the carotid vessels in the same patient.

The external carotid artery was the site of 21 abnormal postendarterectomy scans, of which 13 were major and 8 were minor. Ten of the major defects were opened, and in every case, abnormality was confirmed. Rescanning at the time of the operation indicated in all but 1 case that there had been adequate removal. In 1 case, a further reopening was undertaken, and, indeed, this remained unsatisfactory and, therefore, the vessel was tied off flush with the internal carotid artery. There were 3 other lesions which were greater than 30% in the early part of the series that were not reopened. All 3 of these patients developed a postoperative bruit. One patient developed occlusion of the external carotid artery and, at reoperation, had a fresh thrombus in the external carotid artery extending into the bifurcation. It was probably the source of embolus for 1 patient developing a transient ischemic attack postoperatively.

There were only 2 major defects in the internal carotid artery. One had a 40% stenosis and was out of reach of the endarterectomy, and the other had a suture line stenosis which was revised with a vein patch. There were 2 major defects in the common carotid artery. One was associated with a clamp stenosis which was 40%, but this was not reopened. The patient developed a bruit postoperatively. The second was associated with a very prominent and irregular proximal junction of the normal common carotid artery and the beginning of the endarterectomy. This was not reopened, and there was no bruit postoperatively. These results are summarized in Table 1.

Table 2. Incidence of stroke and death in scanned and unscanned patients.

	No.	Stroke	Death
Abnormal scans	39	0	0
Normal scans	136	3	1
Not scanned	205	5	1
Total	380	8	2

In the group of 136 patients with normal scans, 1 patient died in cardiac failure with a subsequent stroke. One other stroke was due to thrombosis of the common carotid artery as found on reexploration. Two others who were operated on in the evolution stage of the stroke had some progression of that stroke. There were 2 others with transient ischemic deficits referrable to the side of the lesion with normal intraoperative scans. There were 205 patients in the nonscan group with 5 strokes and 1 reversible ischemic neurological deficit. Four of the strokes were associated with permanent sequelae, and there was a further death. This death was related to a technical error caused by the shunt. The intraoperative scanner was being used elsewhere at the time, and it was only because the patient developed postoperative symptoms that the intraoperative scanner was used before reopening. The arteriotomy showed dissection, probably related to the shunt, and despite restoration of normality, the patient developed a profound stroke and died.

Summary

Of the 380 carotid endarterectomies performed, there were 2 postoperative deaths due to stroke (0.5%) and there were 8 further strokes (2%) with 2 recovering fully, leaving a residual of 1.5% with a permanent deficit. There was no difference statistically in the incidence of stroke in the scanned and the nonscanned groups (Table 2).

Noninvasive tests revealed that of the 16 defects detected in the internal carotid artery and common carotid artery and followed with noninvasive testing at a mean of 22 months, only 1 has developed a hemodynamically significant lesion, and this has been documented with an angiographically proven restenosis. In the normal group, 87 patients have been followed

Table 3. Logistical comparison of operative angiography and operative ultrasound.

Aspect	Operative angiography	Operative ultrasound
Invasiveness	Requires arterial puncture	Noninvasive
Contrast	Essential	Not required
User	Surgeon	Surgeon and radiographer
Time	10–15 minutes	Less than 5 minutes
Repeatability	Requires repeat injections	Instantaneous
Dimension	Compressed biplanar	Multidimensional
Accuracy	Lesions may be missed by overlying contrast	Collections of ultrasonically "soft" thrombus may be missed
Radiation	Repeated to surgeon and patient	Nil
Protection from radiation	Surgeon needs to wear apron	Nil
Cerebral toxicity	Contrast suspect	Nil
Intracerebral views	Poor	Nil
Imaging of the ECA	May be difficult as contrast selectively images ICA (low resistance)	Excellent
Resolution	1 mm	1 mm at 10 MHz

ECA = external carotid artery; ICA = internal carotid artery.

for a mean of 16 months, 12 have developed a bruit, and 8 have developed a restenosis on noninvasive testing, which is hemodynamically significant (9%). All of those patients, however, have remained asymptomatic. Statistically, there is no difference between those with and without a major or minor defect in the common carotid artery and the development of a restenosis in any vessel.

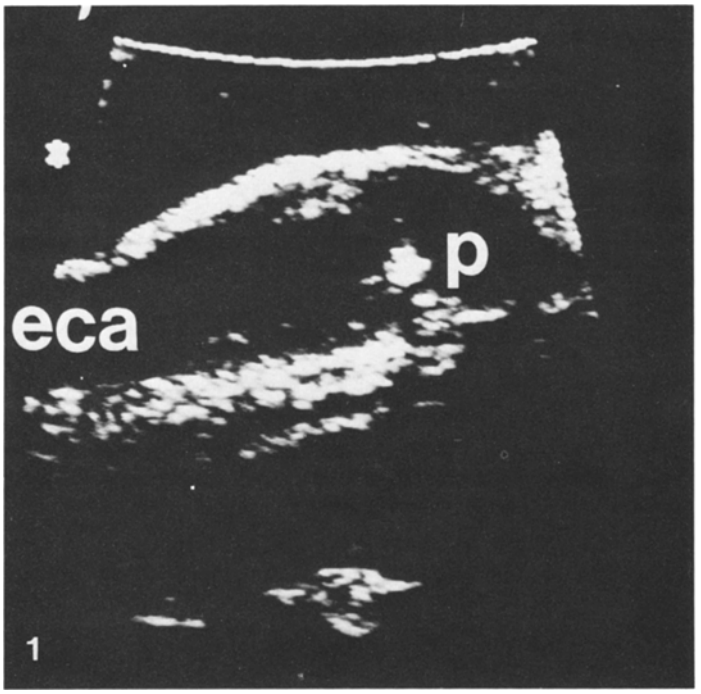
Discussion

Ultrasound used intraoperatively has particularly high resolution and compares favorably with transcutaneous ultrasonic imaging. This relates to the removal of skin, subcutaneous tissue, and muscles which attenuate and scatter incident sound waves. In addition, the interface between artery and blood is a specular reflector, having a very easily detectable change in velocity and attenuation at the solid fluid interface. This excellent 2-point discrimination has been well documented in the experimental model as well as in human studies [3–9]. Another way of detecting operative error with ultrasound is the use of a high-frequency Doppler probe which can be used to indicate lesions associated with high-velocity changes, but this only indicates the need for operative angiography or some other type of imaging system rather than being able to determine where and when to reoperate [10]. There has been only 1 series [11] in which operative ultrasound and operative angiography have been directly compared in the same patients. In a study of 155 patients, Bernstein [11] indicated that both operative ultrasound and operative angiography, for the most part, detect the same lesions, but there are some hemodynamically significant lesions that are missed by both techniques. His conclusion was that the techniques are complementary and he could not decide which technique to exclude. There are numerous advantages to the use of operative ultrasound over operative angiography, and these are summarized in Table 3.

The accuracy of operative ultrasound and angiography has been very well elucidated experimentally by Sigel et al. [3, 4, 8], but the overwhelming attributes relate to its ease of use, simplicity, and reproducibility. The images are anatomically clear in the vast majority of cases, and vascular surgeons are familiar with B-mode ultrasound images because of the widespread use of ultrasonic noninvasive testing. In direct contrast, general surgeons are unfamiliar with the "fuzzy" images and have a much longer learning curve in detecting stones in the common bile duct or hepatic neoplastic disease which are other applications of the same technique.

A further criticism of intraoperative carotid ultrasound relates to the inability of the operator to image the distal internal carotid artery. This problem may arise in very high bifurcations, but, in general, difficulty is extremely rare. Operative angiography has no such access problem. Further evidence relating to the ability of ultrasound to detect technical errors relates to the similar incidence (26%) detected by Blaisdell et al. using operative angiography [1] and the incidence (24%) in this series using operative ultrasound.

Most of the defects (12%) were found in the external carotid artery. Many surgeons would not reopen this vessel since it primarily supplies the extracranial tissues. There is no doubt, however, that it is an important cerebral collateral, and it is known that contralateral lesions are very common and progress rapidly following carotid endarterectomy [12]. There is also 1 case in this series in which it is surmised that thrombosis in the external carotid caused retrograde thrombosis up to the junction with the common carotid giving rise to an embolus into the cerebral circulation. It was considered advisable to amputate the external carotid artery at the bifurcation in another patient in order to avoid retrograde thrombosis and embolization because adequate clearance of the external carotid artery could not be obtained after 3 attempts. After detection of an external carotid artery plaque (Fig. 1), it is relatively easy to remove this directly because a shunt is not required, and a separate incision can be made at the site of the residual plaque. With regard to defects of the common carotid artery, the most important is a dissection related to a shunt insertion, and this was unfortunately demonstrated in 1 case—as a prerearteriotomy scan after the patient had developed a stroke in the immediate postoperative period. The other uncommon defect to be looked for is clamp stenosis in which a large amount of atheroma can be partially detached from the wall and possibly lead to dissection as well as thromboembolic phenomenon. The other more common finding is a simple step where the endarterectomy begins. This apparently has no significance either in the short- or



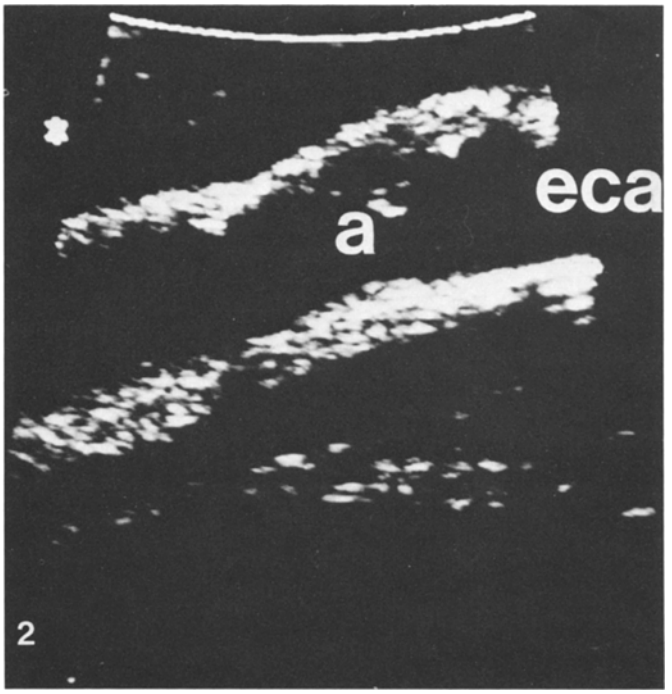


Fig. 1. An external carotid artery (eca) and a residual plaque (p) with a small ultrasonic shadow posteriorly.
Fig. 2. An accumulation of platelets and thrombus (a) in the external carotid artery (eca).

long-term. Another finding that is relatively uncommon but can occur in any of the vessels is platelet accumulation, which is usually relatively soft on ultrasound because it contains a mixture of red cells, fibrin, and platelets that can be relatively hyperechoic and therefore difficult to detect. Figure 2 shows the accumulation of platelets in the external carotid artery with some thrombus. Although detectable, it is relatively sonolucent. Suture stenoses are also uncommon and occurred only once in the internal carotid artery which, in fact, required a vein patch. This luminal reduction is optimally characterized by the use of the operative ultrasound in the transverse mode.

Fragments of residual wall tissue projecting into the lumen are quite common (myointimal flaps) and although, after distal clamping, these can occasionally be sutured back (under ultrasonic control), without reopening the vessel, it is possible to detach the fragment from the wall leading to cerebral embolization without the operator being aware. It is, therefore, recommended that these flaps be removed directly under vision.

The 9% restenosis rate in the relatively short postoperative follow-up is considerably less than the 18% internal carotid artery occlusion rate reported by Aukland using the duplex scanner [13]. Hertzer et al. [14], using digital subtraction angiography, showed a 2% immediate internal carotid artery occlusion rate with a hemodynamically significant defect in the internal or common carotid artery in 3.6% of patients in addition to a 4.7% external carotid artery occlusion rate. Only rarely were these technical errors assumed to be directly related to neurological sequelae.

Clearly, there are multiple causes of postendarterectomy strokes as indicated by Jernigan and Hamman [15], but at least 2 patients (one with an instrument-related dissection and another with a retrograde external carotid thrombosis with embolization) had neurological deficits detectable by operative ultrasound and ostensibly preventable by simple rearteriotomy. Based on these small numbers alone, the cost of the machine is justifiable considering the cost of rehabilitation of stroke patients.

The minor irregularities detected in this series tended to reendothelialize and essentially become normal. In fact, the development of restenosis was not directly attributable to minor technical errors left at the time of surgery. It would seem that myointimal hyperplasia is not related to focal technical errors at the time of operation. Specifically in this series, the 3 internal carotid artery occlusions and 5 of the 6 restenoses were associated with the normal operative ultrasound.

Conclusion

In conclusion, it is clear that a large number of patients would have to be scanned before a definite statistical advantage in using operative ultrasound in the prevention of neurological deficit could be obtained. The operative scan has, however, demonstrated its ability to detect all types of lesions with great accuracy and reliability. The simple logistics compared with operative angiography make ultrasound a very attractive alternative. It is comforting to the surgeon to know that he/she has performed a quality control maneuver, and if defects are found, it has a salutary effect on the surgical technique. Minor lesions are apparently not associated with perioperative neurological defects nor does their presence at operation predict the development of carotid restenosis. Similarly, a normal scan does not indicate a reduced risk of restenosis. Nevertheless, the use of intraoperative B-mode scanning is considered mandatory after every carotid endarterectomy in our institution.

Résumé

Cent soixante-quinze fourches carotidiennes ont été soumises à une échographie per-opératoire. La méthode d'exploration est simple, aisée à répéter et fiable. Les lambeaux d'intima, les sténoses secondaires au clampage, les plaques laissées en place, les accumulations de plaquettes peuvent être détectées par cette exploration. La majorité des impairs opératoires s'observent au niveau de la carotide externe (12% des cas) et imposent la correction des lésions patentes. Les malfaçons au niveau de la carotide interne et de la carotide primitive sont moins fréquentes (7% des cas). Les lésions sont souvent peu importantes, leur correction ne s'imposant que dans 2% des cas. Dans 1% des cas, ces lésions artérielles opératoires aboutissent à une lésion cérébrale qui aurait pu être évitée. En effet, bien que d'autres causes de lésion cérébrale existent, les altérations imputables à l'acte chirurgical sont réversibles dès lors qu'elles sont mises en évidence par l'échographie opératoire. Les lésions mineures persistantes qui sont décelées par les tests non-invasifs ne sont que rarement à l'origine d'une sténose artérielle post-opératoire.

Resumen

Ciento setenta y cinco bifurcaciones carotídeas han sido estudiadas intraoperatoriamente al cierre de la arteriotomía para endarterectomía y una vez que los "clamps" y asas habían sido retirados y el flujo restaurado, mediante la imagenología de ultrasonido. La técnica es simple, reproducible, rápida, y confiable. Pliegues ("flaps") de la íntima, estenosis por "clamps," placas residuales, y acumulaciones plaquetarias fueron detectadas por este método. La mayoría de los defectos de técnica operatoria se presentaron en la carótida externa (12%) y por ello se recomienda que lesiones de significación que queden presentes en este vaso deben ser removidas. Los defectos en la arteria carótida interna y en la carótida primitiva fueron mucho menos frecuentes (7%) y su mayoría fueron mínimos y no requirieron reapertura del vaso. En 1% de los pacientes se presentaron defectos que dieron lugar a accidente cerebral los cuales, bajo criterios actuales, habrían sido removidos. Aunque hubo otras causas de accidente cerebral, los errores técnicos siguen siendo una fuente reversible inmediata de accidente cerebral postoperatorio que puede ser evitado con el uso de imagenología de ultrasonido intraoperatoria. Los defectos menores estudiados a largo plazo por medios no invasivos muy rara vez probaron ser de significación y no aparecieron relacionados con el desarrollo de reestenosis.

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References

1. Blaisdell, F.W., Lim, R., Hall, A.D.: Technical result of carotid endarterectomy: Arteriographic assessment. Am. J. Surg. *114*:239, 1967
2. Rosental, J.J., Gaspar, M.R., Movius, H.J.: Intraoperative arteriography in carotid endarterectomy. Arch. Surg. *106*:805, 1973
3. Sigel, B., Coelho, J.C., Flanigan, P., Schuler, J.J., Spigos, D.G., Machi, J.: Comparison of B-mode real time ultrasound scanning with arteriography in detecting vascular defects during surgery. Radiology *145*:777, 1982
4. Sigel, B., Coelho, J.C., Flanigan, P., Schuler, J.J., Spigos, D.G.: Ultrasonic imaging during vascular surgery. Arch. Surg. *117*:764, 1982
5. Sigel, B., Coelho, J.C., Machi, J., Flanigan, D.P., Donahue, P.E., Schuler, J.J., Beitler, J.C.: The application of real time ultrasound imaging during surgical procedures. Surg. Gynecol. Obstet. *157*:33, 1983
6. Lane, R.J.: Intraoperative B-mode scanning. J. Clin. Ultrasound *8*:427, 1982
7. Lane, R.J., Appleberg, M.: Real time intraoperative angiosonography after carotid endarterectomy. Surgery *92*:5, 1982
8. Coelho, J.C., Sigel, B., Flanigan, D.P., Schuler, J.J., Spigos, D.G., Nyhus, L.M.: Detection of arterial defects by real time ultrasound scanning during vascular surgery: An experimental study. J. Surg. Res. *30*:535, 1981
9. Coelho, J.C., Sigel, B., Flanigan, D.P., Schuler, J.J., Spigos, D.G., Tan, W.S., Justin, J.: An experimental study of arteriography and imaging ultrasonography in detecting arterial defects at operation. J. Surg. Res. *32*:130, 1982
10. Zierler, R.E., Bandyk, D.F., Berni, G.A., Thiele, B.L.: Intraoperative pulsed Doppler assessment of carotid endarterectomy. Ultrasound Med. Biol. *9*:65, 1983
11. Bernstein E.: On whom should we operate? Presented at the Annual meeting of the Royal Australian College of Surgeons, Adelaide, South Australia, May, 1986
12. Ackroyd, N., Lane, R., Appleberg, M.: Carotid endarterectomy: Long-term follow up with specific reference to recurrent stenosis, contralateral progression, mortality and recurrent neurological episodes. J. Cardiovasc. Surg. *27*:418, 1986
13. Aukland, A., Hurlow, R.A., Hamer, J.D.: Carotid artery occlusion following endarterectomy: Evaluation by special analysis of Doppler ultrasound signals. Br. J. Surg. *69*:45, 1982
14. Hertzer, N.R., Beven, E.G., Modic, M.T., O'Hara, P.J., Vogt, D.P., Weinstein, M.A.: Early patency of the carotid artery after endarterectomy: Digital subtraction angiography after two hundred and sixty-two operations. Surgery *92*:1049, 1982
15. Jernigan, W.R., Hamman, J.L.: The causes and prevention of stroke associated with carotid artery surgery. Am. Surg. *48*:79, 1982