SPECT Quantification of Cerebral Ischemia Before and After Carotid Endarterectomy

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A method to assess changes in cerebral perfusion following carotid endarterectomy was developed using late (2 hr)/early (20 min) single-photon emission computed tomography (SPECT)/[^{123}I]iodoamphetamine count ratios. Using a ratio > 1.0 to indicate redistribution and reversible ischemia, pre- and postoperative studies were compared for 20 patients. Regional polar plots based on 30° angular sectors showed improvement > 2 standard deviations (s.d.s) ipsilateral to surgery in 15/19 (79%) and contralateral to the side of surgery in 8/19 (42%) patients with significant hemodynamic lesions. Using a hemispheric perfusion index (mean of four 30° sectors) ipsilateral perfusion improved in 11/19 (58%) with bilateral improvement in 6/19 (32%). Visual interpretation was similar to the regional analysis with 14/19 (74%) improving on the operative side; however, it was less sensitive for contralateral changes, 4/19 (21%). We conclude that quantitation of redistribution can provide an objective index of improved perfusion and is especially important to detect contralateral changes.

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In spite of controversy surrounding carotid endarterectomy, it is generally agreed that the probability of stroke increases with the severity of carotid stenosis (*1*, *2*). For this reason direct imaging of the carotid arteries by either ultrasound or angiography has become the primary modality for evaluating patients considered for carotid endarterectomy. Several studies have shown that symptoms of cerebral ischemia are correlated with the degree of carotid stenosis (*2*,*3*). Due to a lack of simple and readily available methods for measuring cerebral blood flow, less is known, however, about the significance of chronic ischemia as a stroke risk factor for patients with carotid stenoses (*4*–*6*).

Several new radiopharmaceuticals have been developed for single photon emission computed tomography (SPECT) imaging of the brain whose initial uptake is proportional to cerebral blood flow. Iodine-123-iodoamphetamine (IMP) is currently the only agent which has been shown to demonstrate late redistribution ("filling in") at 2–3 hr postinjection in areas of decreased uptake seen in earlier images, usually acquired beginning 20 min after injection. This redistribution is similar to that observed with the myocardial perfusion agent thallium-201 (^{201}Tl). It has been suggested that IMP redistribution reflects reversibly ischemic areas of the brain (*7*,*8*).

Growing experience with the evaluation of myocardial ischemia with radiotracers such as ^{201}Tl has shown that the use of perfusion studies yields significant additional prognostic information in patients with coronary artery disease which complements assessment of coronary artery anatomy both before and after myocardial infarction as well as after interventions to improve myocardial blood flow (*9*,*10*).

The purpose of this study was to develop a semiquantitative method for measuring cerebral ischemia using IMP-SPECT perfusion imaging. We then applied this method to study patients before and after carotid endarterectomy.

MATERIALS AND METHODS

Under a protocol approved by the Human Research Review Committee of Temple University, 20 consecutive patients scheduled to undergo carotid endarterectomy were studied prospectively with [^{123}I]IMP SPECT imaging both before and within 48–72 hr after surgery. Following explanation of the protocol, informed consent was obtained in all cases.

All patients had experienced a recent transient ischemic attack and cerebral angiography was performed within 6 wk of the IMP-SPECT studies. Significant carotid stenosis was considered to be present if there was at least 60% luminal narrowing present in two imaging planes. Of the 20 patients studied 12 were male and 8 were female with ages ranging from 52 to 80 (mean = 66 yr).

The [^{123}I]IMP (Spectamine®, Medi-Physics Incorporated, Paramus, NJ) was produced by the tellurium-124 (p,2n) ^{123}I reaction. In all cases the ^{124}I contamination was determined prior to injection and ranged from 3.5%–4.6% of the administered dose. For each SPECT study, the patients received 3 mCi (111 MBq) of [^{123}I]IMP intravenously after initial pre-

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treatment with 5 drops of Lugols' solution orally to block the thyroid gland.

Following a 20-min postinjection equilibrium period during which time each patient remained supine and rested in a quiet room with eyes closed, early SPECT imaging was performed using a rotating gamma camera system (Star-Cam, General Electric Corporation, Milwaukee, WI) with a medium-energy 30-degree slanthole collimator to minimize the imaging distance. Data were acquired using 128 projection angles over 360° of rotation for 30 sec each. All data were acquired and processed using a 64 × 64 matrix. Using the Star-Cam commercial software for SPECT reconstruction the raw data were preprocessed with a 9-point smooth and reconstructed using a ramp-Hanning filter with a 0.5 cycle per sec cut-off frequency. Attenuation correction was performed based on the sum of opposing angles (*11*).

A second, late SPECT acquisition was then acquired using the same acquisition and processing protocol but beginning 120 min following injection. Between the two studies there were no restrictions placed on the subject's activities.

For the quantitative analysis, oblique-angle reconstructions were used and standardized to be parallel to the orbital-meatal plane. The 0.6 cm images were summed to create 1.2 cm images. In order to align these images for quantification they were numbered consecutively with the first slice taken as the most inferior section through the brain which did not include any of the cerebellar hemispheres.

A reperfusion index (RPI) was defined as the ratio of late/early counts per pixel obtained from circumferential count profiles from the 1.2 cm-thick brain images. These circumferential count profiles were generated using commercial, circumferential-profile software provided with the nuclear medicine camera-computer system (Mentor®, General Electric Medical Systems, Milwaukee, WI).

This semi-automated program requires that the operator place a rectangular boundary to enclose the brain (Fig. 1). Each value of the profile represents the maximum counts per pixel obtained along a radius which originates at the center of the rectangle. This software was originally developed to measure thallium activity in the heart and generates activity curves based on 60 radii spaced at 6-degree intervals plotted clockwise with 0° beginning at 90° from the vertical axis (Fig. 1) (*12*).

Both the early and late curves were normalized to 100% for the maximal count rate. The normalized late curves were then divided by the early curves to obtain a RPI value for each 6° for both the pre- and postoperative studies (Fig. 2). A RPI > 1.0 was considered to show evidence of redistribution (e.g. "filling in") and reversible ischemia.

To perform a statistical comparison of the pre- and postoperative studies the raw data for all RPI values were entered into a personal computer system (Macintosh SE®, Apple Computer Inc., Cupertino, CA). The mean and standard deviations for each set of five preoperative RPIs over a 30° sector were calculated and displayed as a polar plot chosen to correspond to the expected vascular distributions of each of the major cerebral arteries (Figs. 3 and 4) (Cricket Graph, Cricket Software, Philadelphia, PA) (*13*).

The postoperative RPI values were then superimposed on the polar plot of the preoperative mean values minus 2 s.d.s (Fig. 3). A statistically significant improvement in regional perfusion (e.g., less "redistribution") was then considered to have occurred in any sector if the postoperative values improved beyond 2 s.d. (95% confidence interval) below the mean value of the 30° segment of the preoperative tomographic section (Fig. 3). All comparisons were made at the second level above the cerebellar hemispheres (at the midbrain level).

As no normal subjects were studied as a part of this protocol, this method was chosen since by comparing each patient's postoperative study to his own preoperative study each patient could serve as his own control.

In addition to comparing the pre- and postoperative studies on a regional basis using the polar plots, a mean RPI was calculated for each cerebral hemisphere. The mean value for the RPI over the angular sector between 120°–240° was cal-

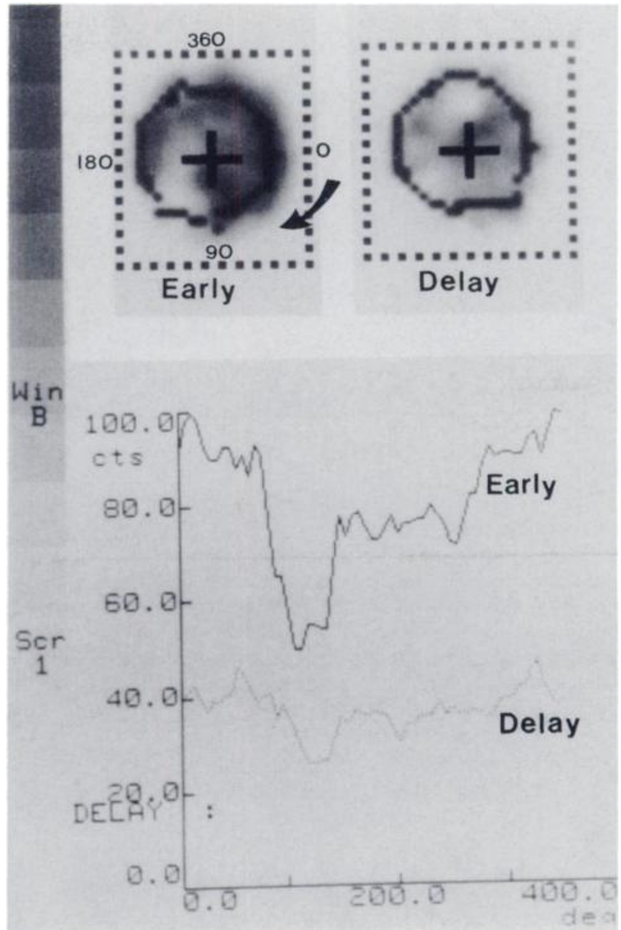

FIGURE 1
Circumferential count profiles. The semi-automated program requires operator placement of a rectangular region of interest (dashed lines) around the SPECT tomographic image. Placement of the ROI is shown for both the early (20 min) (top left) and the delay (2hr) (top right) midbrain tomographic images. The center of the slice is marked with an x. The counts per pixel along 60 radii spaced every 6° are calculated. The pixel with the peak counts in the cortex along that radius is marked and a circumferential count profile of cortical activity is then plotted with 0° beginning at 90° from the vertical axis and rotating clockwise. Early (upper) and delay (lower) profile curves are shown for the patient further illustrated in Figure 6.

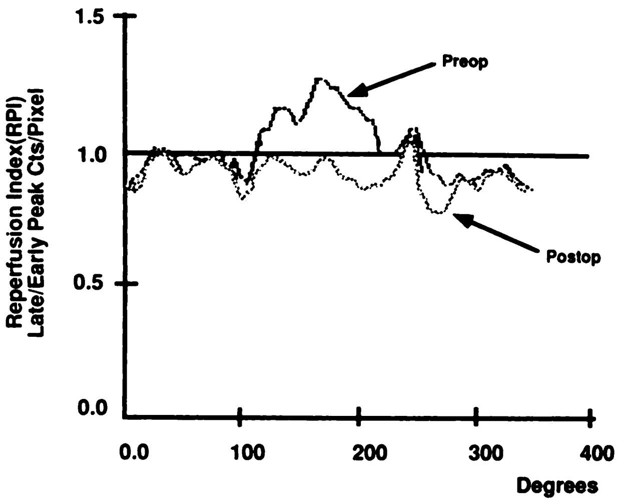

FIGURE 2
Comparison of pre- and postoperative RPI values. To obtain the RPI values for each 6-degree sector of the cortex, the normalized delay (2 hr) circumferential profile curve is divided by the normalized early (20 min) curve (Fig. 1). RPI values >1.0 indicate areas which show redistribution. The data shown are again from the patient illustrated in Figure 6. Areas of improvement can be seen where there is a decrease between the pre- and postoperative curves.

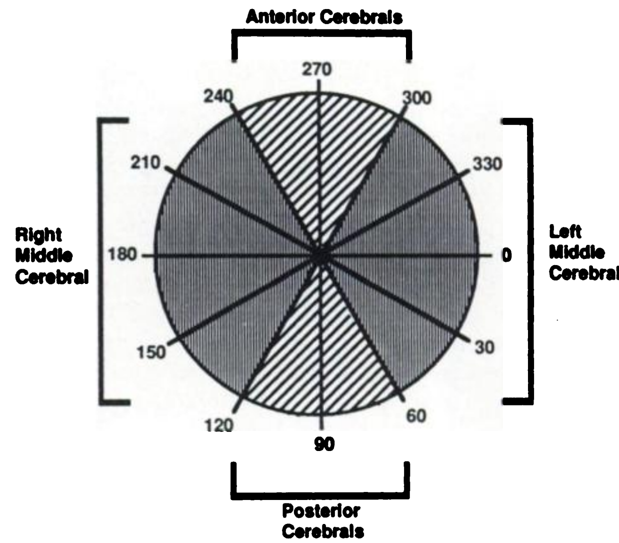

FIGURE 4
Correspondence of cerebral artery vascular distributions with the polar display of the RPI. The 30-degree sectors used to calculate the mean values for the RPIs are shown in relationship to the known vascular distributions for the major cerebral vessels.

culated to correspond to the right middle cerebral artery distribution. Similarly the mean value was calculated for the values between 300° and 60° to correspond to the left middle cerebral artery distribution (Fig. 4). For statistical purposes the mean pre- and postoperative values were compared using the Student's paired t test. The difference was considered to be significant at a p value <0.05.

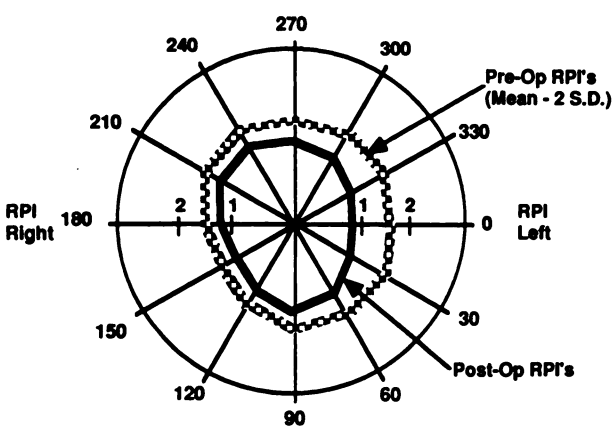

FIGURE 3
Schematic comparison of pre- and postoperative RPIs using the polar plot. This schematic drawing is shown to demonstrate how the polar display permits easy visual assessment of whether a statistically significant improvement has occurred between the pre and postoperative studies. The preoperative mean RPIs minus 2 s.d.s are shown (outer hatched curve). The solid curve (inner) represents the data for the postoperative RPIs. Any portion of the dark curve inside the outer hatched curve indicates where the RPIs improved > 2 s.d.s. In this example, therefore, there is evidence for significant improvement for all segments of both the left and right cerebral hemispheres.

For visual interpretation, SPECT images were reconstructed in three orthogonal planes (transaxial, coronal, and sagittal) and in a fourth plane oriented parallel to the orbital-meatal line using a slice thickness of 0.6 cm. The cortical uptake of IMP was assessed by two experienced nuclear medicine physicians and a consensus interpretation was reached in all cases. Perfusion was considered normal if there was symmetrical uptake throughout the cortical gray matter and this uptake was equal to cerebellar uptake (Fig. 5).

For the subjective interpretation of the images the readers were blinded in all cases as to the results of prior computer tomography (CT) and angiographic studies and to the side of operation. The preoperative studies were analyzed first for the presence of either a normal or abnormal IMP perfusion pattern. The studies were considered to show redistribution and reversible ischemia if decreased radiotracer uptake was visually observed in the early images in comparison to adjacent or contralateral structures which then "filled in" in the later images. If a decreased area of uptake persisted into the late images, the defect was considered nonreversible or "fixed" (Fig. 6). An area of cortical activity in the late images which appeared to show locally increased counts compared to the remainder of cortical gray matter was classified as showing slow "wash-out" (Fig. 7).

Pre- and postoperative studies were then reviewed together to assess the results of surgery. The postoperative studies were classified in comparison to the preoperative study as showing improvement (more symmetric IMP activity initially with less redistribution), worsening (decreased IMP activity in the early images with or without redistribution), or no change.

Vessel patency was confirmed postoperatively for all pa-

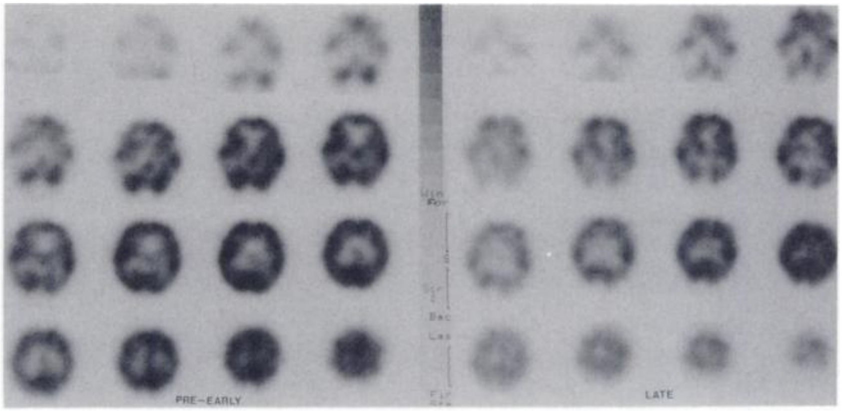

FIGURE 5
Normal study. This preoperative study is from the one patient included in this series who was found to have an ulcerated plaque but no hemodynamically significant lesion at angiography. The initial images (left) show uniform cortical uptake equal in intensity to the cerebellar hemispheres. The late images (right) also demonstrate uniform distribution of the radiotracer with no localized areas of increased activity to indicate a region of slow "washout." Washout from the visual cortex normally appears increased compared to cortical activity.

tients with postoperative carotid ultrasound examinations within 4 wk of surgery.

RESULTS

By angiographic criteria 12 patients had unilateral carotid disease, 7 bilateral, and 1 patient was found to have an ulcerated plaque but no hemodynamically significant lesion (Table 1).

In this series no patient experienced a new neurologic deficit following surgery and all operated vessels appeared patent on the follow-up ultrasound examinations. Four patients who had preoperative neurologic deficits had CT evidence for cerebral infarctions. No patient was interpreted as showing a new fixed or reversible perfusion defect following surgery.

Visual interpretation of the preoperative SPECT

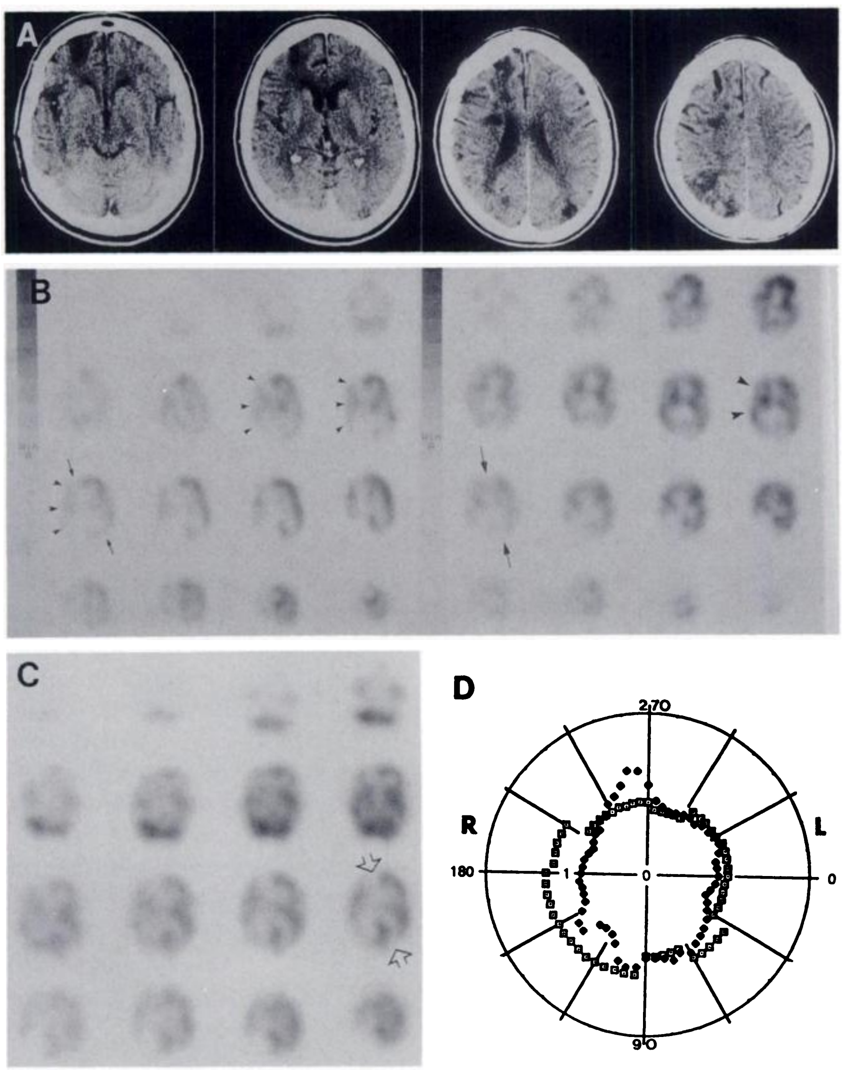

FIGURE 6
Reversible and nonreversible perfusion defects. (A) The CT of this 80-yr-old female with a history of prior infarcts and a recent TIA shows evidence of right frontal as well as right and left posterior areas of infarction. The cerebral angiogram showed a total right internal carotid occlusion and a plaque but no significant stenosis on the left. (B) The early (20 min) preoperative SPECT images (left) show generalized decreased perfusion to the right hemisphere (small arrowheads) compared to the left hemisphere. A large portion of the right hemisphere appears to fill-in (large arrowheads) in the late (2 hr) images (right). In contrast to the reversible changes, initial perfusion defects (small arrows) which correspond to the CT areas of infarction appear unchanged ("fixed") in the late images (large arrows). (C) The early postoperative study following a right carotid endarterectomy shows improvement in perfusion to the right hemisphere but with persistent focal defects corresponding to the areas of infarction (open arrows). (D). The polar plots of the preoperative RPIs-2 s.d. (open squares) and the postoperative values (dark squares) show significant improvement in both the right and left hemispheres (right > left) but not in those sectors with "fixed" perfusion abnormalities corresponding to the infarcts (60°–90° and 240°–270°).

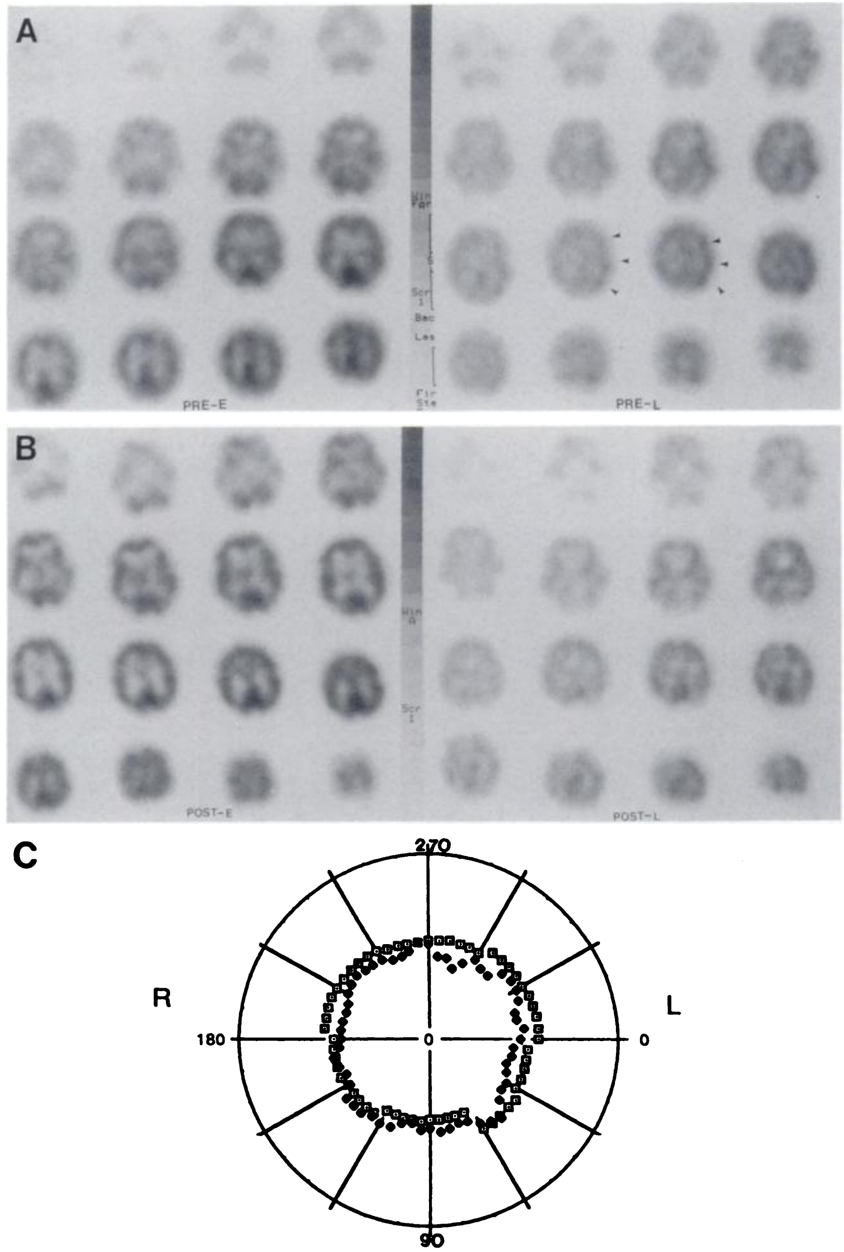

FIGURE 7
Slow IMP "wash-out." (A) This 70-yr-old male with bilateral internal carotid stenoses (left, 95%; right, 80%) and a normal CT shows only a very mild decrease in IMP uptake in the left hemisphere compared to the right in the early (E) preoperative images probably due to balanced bilateral disease. In the late (L) images there is a localized increase of IMP activity in the left hemisphere (small arrowheads) which appears as a "slow washout" of IMP from the area associated with the most severe stenosis. (B) The postoperative early (E) and late (L) images show normalization of IMP uptake in the early images and the washout abnormality is no longer present. (C) The quantitative polar plots of the RPIs demonstrate bilateral improvement (L > R) for the postoperative study (dark squares) compared to the preoperative values - 2 s.d. (open squares).

studies for the 19 patients with significant carotid stenoses yielded evidence for redistribution in the vascular distribution of the affected carotid artery in 9/12 (75%) of the patients with unilateral stenoses. Only 2/7 (29%) of the patients with bilateral disease visually demonstrated bilateral perfusion defects in the early images while 5/7 (71%) showed predominately unilateral perfusion defects. Three of the patients with unilateral disease also had evidence for redistribution in both cerebral hemispheres. Visual improvement postoperatively was present in 14/19 (74%) of the patients on the operative side with contralateral hemisphere improvement evident visually in only 4/19 (21%).

Quantitative evaluation of improved perfusion was performed using both regional and global measures of the RPI. Using the global hemispheric RPI (Table 1, mean values ± 1 s.d.) improved perfusion postoperatively was present in 11/19 (58%) of the patients. The improvement was bilateral in 6/19 (32%).

The quantitative regional analysis using polar plots was more similar to the visual assessment of the images with improved perfusion in at least one 30-degree angular sector ipsilateral to the side of surgery found in 15/19 (79%) of cases while 8/19 (42%) also showed improved perfusion to the contralateral hemisphere.

The one patient included in this study who had an ulcerated plaque but no significant hemodynamic lesions had normal IMP-SPECT images prior to and after surgery. The quantitative studies in this patient also demonstrated no preoperative ischemia or significant change postoperatively.

Slow washout of IMP from cortical areas fed by a

TABLE I
Comparison of Pre- and Postoperative RPIs

Patient No.	Left Pre-Op	Left Post-Op	p Value	Right Pre-Op	Right Post-Op	p Value	Operative side	Stenosis (left)	Stenosis (right)
1	1.11 ± 0.09	0.90 ± 0.10	<0.001	1.27 ± 0.14	0.85 ± 0.13	<0.001	Right	0%	100% RIC
2	1.16 ± 0.13	1.03 ± 0.17	<0.05	1.14 ± 0.12	1.02 ± 0.14	<0.01	Right	0%	60% RIC
3	1.32 ± 0.19	1.10 ± 0.09	<0.001	1.15 ± 0.19	0.99 ± 0.01	<0.01	Right	50% LCC	90% RIC
4	1.09 ± 0.20	1.08 ± 0.17	NS	1.17 ± 0.08	1.00 ± 0.18	<0.001	Right	30% LIC	60% RIC
5	1.04 ± 0.09	1.00 ± 0.09	NS	1.07 ± 0.07	1.00 ± 0.07	<0.01	Right	40% LIC	70% RIC
6	1.07 ± 0.13	1.04 ± 0.09	NS	1.18 ± 0.09	1.01 ± 0.07	<0.001	Left	70% LIC	50% RIC
7	1.11 ± 0.15	1.07 ± 0.10	NS	1.12 ± 0.21	1.00 ± 0.13	<0.05	Right	0%	70% RIC
8	0.96 ± 0.08	0.96 ± 0.09	NS	1.01 ± 0.07	0.97 ± 0.07	NS	Right	50% LIC	90% RIC
9	1.06 ± 0.13	1.08 ± 0.12	NS	1.06 ± 0.07	1.06 ± 0.11	NS	Left	80% LIC	30% RIC
10	0.96 ± 0.14	1.21 ± 0.07	NS	0.98 ± 0.17	1.04 ± 0.06	NS	Left	90% LIC	0%
11	1.08 ± 0.13	1.05 ± 0.12	NS	1.14 ± 0.17	1.12 ± 0.18	NS	Right	0%	60% RIC
12	0.92 ± 0.09	0.95 ± 0.07	NS	0.95 ± 0.08	1.05 ± 0.12	<0.01	Left	95% LIC	40% RCC
13	1.22 ± 0.11	1.04 ± 0.14	<0.001	1.23 ± 0.17	1.00 ± 0.08	<0.001	Right	100% LIC	80% RIC
14	1.25 ± 0.12	0.99 ± 0.12	<0.001	1.18 ± 0.13	0.99 ± 0.07	<0.001	Left	100% LCC	90% RIC
15	1.09 ± 0.11	1.12 ± 0.15	NS	1.09 ± 0.10	1.04 ± 0.15	NS	Right	60% LIC	100% RIC
16	1.23 ± 0.09	1.10 ± 0.16	<0.01	1.10 ± 0.07	1.10 ± 0.11	NS	Left	80% LIC	80% RIC
17	1.06 ± 0.09	0.94 ± 0.08	<0.001	1.18 ± 0.06	1.05 ± 0.07	<0.001	Left	80% LIC	70% RIC
18	0.92 ± 0.08	1.10 ± 0.09	<0.001	1.00 ± 0.09	1.22 ± 0.09	<0.001	Left	70% LIC	75% RIC
19	1.03 ± 0.07	0.99 ± 0.05	NS	0.99 ± 0.11	1.06 ± 0.16	NS	Left	95% LIC	80% RIC

vessel with a significant stenosis has not been previously reported. We observed four cases that demonstrated washout abnormalities that corresponded to the expected vascular distribution of a stenosed vessel. In all of these cases bilateral disease was present but the washout abnormality was unilateral (Fig. 3).

DISCUSSION

Two primary mechanisms have been theorized to explain the pathophysiology underlying transient ischemic attacks: either embolization of thrombus or atheroma from an ulcerated plaque or ischemia from a high grade stenosis of a carotid artery.

While CT and magnetic resonance imaging (MRI) both play an important role in the diagnosis of cerebrovascular disease, there is increasing recognition of the need to include functional imaging studies to better understand the pathophysiologic basis of stroke (*14*). Studies have shown that CT and MRI images reveal different physical and biochemical changes in the brain (*15*). Although it is one of the most frequently used tests, CT demonstrates the fewest lesions associated with chronic cerebrovascular disease because of its inability to image perfusion (*15*).

Functional imaging of cerebral metabolism and perfusion is available using either positron emission tomography (PET) or SPECT. Because of its higher sensitivity and spatial resolution together with the availability of a wider range of physiologic radiopharmaceuticals which can better quantify blood flow and metabolism, PET has become the "gold standard" to which all other functional imaging techniques are compared. The high costs associated with installation and operation of PET imaging centers, however, will limit its availability.

Several SPECT radiopharmaceuticals which accurately reflect cerebral blood flow have become available for routine clinical use. Early IMP uptake has been closely correlated with cerebral blood flow and oxygen consumption rate ($CMRO_2$) (*16*). In addition, IMP is the only SPECT agent which has been shown to demonstrate the property of late redistribution in patients with transient ischemic attacks and in the peri-infarct area surrounding completed cerebral infarctions (*7,8,17*).

The mechanism by which IMP redistributes into areas of ischemia has not been determined. Theories concerning the area surrounding the central zone of an infarct have been proposed suggesting that chronic ischemia results either in decreased neuronal function or actual neuronal loss with preservation of tissue structure (*16*). Neither of these theories would appear to be applicable to the redistribution seen in patients with TIAs prior to stroke. It has been suggested that IMP accumulation is dependent on several factors including: metabolic activity, neuronal density, glial condition, blood-brain barrier integrity, and local pH (*16*).

Moretti has suggested that redistribution reflects a balance between initial cellular uptake which is dependent on blood flow and subsequent washout following metabolism (*8*). A slowed metabolic rate secondary to impaired blood flow would explain the washout abnormalities observed in our study. Regardless of the mechanisms controlling late redistribution, the correlation observed in this study between improved perfusion in early images following revascularization suggests that redistribution correlates with reversible ischemia.

Several previous studies have shown that SPECT cerebral perfusion imaging can be used to document successful reperfusion following either extracranial-intracranial arterial bypass grafting (*17*) or carotid endarterectomy (*18*). Neither of these studies used quantitative methods to document their results.

The earliest approaches to quantitative assessment of cerebral perfusion with SPECT agents have used ratios to assess asymmetries in left to right count ratios (*19*). Recently Podreka et. al. have reported on a relatively invasive method which requires arterialized, venous-blood sampling to obtain an absolute measure of cerebral blood flow from IMP-SPECT images (*20*). This work is based on earlier studies by Kuhl et. al. (*21*).

Using existing software originally developed to display a polar plot of myocardial perfusion with thallium (*22*), Lord et. al. found it helpful to display a "bull's eye" polar map of cerebral perfusion (*23*). These authors found that manual regions of interest subdividing transverse sections of the brain on SPECT images proved insensitive because of inclusion of low count areas (scalp, and white matter).

From the beginning of our investigations into quantification of IMP-SPECT imaging we were concerned with the problem of trying to obtain normal control data for elderly, age-matched individuals. Because of the risks inherent in cerebral arteriography our institutional research review committee did not permit study of normal volunteers. One patient in this series did turn out to have no significant hemodynamic lesion and only an ulcerated plaque. It is difficult, however, to consider a symptomatic elderly patient as a "normal" control even if arteriography is negative for extracranial stenoses. For this reason we did not include quantitative analysis of IMP washout rates as a part of this study since no "normal" values were available for comparison.

Since we were primarily concerned with developing a method to evaluate the results of an intervention such as carotid endarterectomy, we chose a method where each patient could serve as his own control. We have begun to apply the method in other areas such as the interventional challenge to cerebrovascular reserve using the potent vasodilator acetazolamide (*24*). While we recognize that the method requires a comparison of two studies we believe it has further potential clinical applications such as the evaluation of thrombolytic therapy which recently has begun to be investigated in acute stroke.

We have found in earlier studies that IMP-SPECT imaging has good sensitivity for detecting cerebral ischemia in patients with known extracranial disease (*25*). While 16/19 (84%) of the patients studied in this series had visually detectable ischemia the purpose of this study was not to determine sensitivity and specificity values for IMP. First, no normal subjects were included to attempt to obtain specificity data. In addition, we recognize the obvious bias introduced in that those interpreting the images were aware that these were symptomatic patients with a high pre-test probability of disease.

For those with unilateral disease there was a good correlation (9/12, 75%) with the interpretation of the side of ischemia and the vessel stenosed. The low incidence of detecting bilateral ischemia preoperatively in the patients with bilateral disease (2/7, 28%) probably reflects the inherent limitation of visual inspection which is dependent on comparing relative uptakes.

Since there may be a symmetrical decrease in flow to both cerebral hemispheres, we found it important to visually review the images in multiple planes and compare the cortical uptake to the cerebellar hemispheres in the sagittal view. In this series 5/7 (71%) of the patients with bilateral disease appeared to have predominately unilateral ischemia. Bilateral ischemic changes can be identified and the presence of redistribution is especially helpful to confirm initial perfusion abnormalities which may be of questionable significance (Fig. 8). Only a small number of patients with bilateral disease were included in this study and a larger number of patients will need to be studied to determine the effect of "balanced" disease on the IMP-SPECT detection of ischemia.

It is interesting to note that in those cases with washout abnormalities, decreased IMP uptake in the early images was subtle or not present visually. Identification of IMP washout abnormalities appears to increase sensitivity for detecting regional ischemia just as it has for thallium myocardial imaging (*26*).

Ultimately, the importance of functional imaging of cerebral blood flow either with PET or SPECT depends upon whether it improves patient diagnosis and/or treatment. Experience with myocardial perfusion imaging has shown that the ability to assess regional ischemia in the heart has yielded prognostic information beyond that obtained with anatomic assessment of coronary lesions determined angiographically (*27*).

In a recent review, it was stated that "essential to the ideal management of acute stroke, is the knowledge of whether the jeopardized brain tissue is reversibly or irreversibly damaged" (*14*). Metabolic measures available from PET studies can yield such information but at a high cost and with limited availability. A quantitative measure of IMP-SPECT redistribution as proposed in this study may provide a practical approach to this problem.

The role of carotid endarterectomy remains controversial. While in this study we have demonstrated evidence for improved cerebral perfusion following carotid endarterectomy we recognize that other factors (e.g., the presence of ulcerated plaques and emboli) affect long-term prognosis. What role treatment of chronic ischemia may play in the long-term prognosis of patients with extracranial disease still needs to be determined. We believe that quantitation of IMP redistribution can play an important role in evaluating this, particularly in patients with high degrees of stenosis.

We have used a modified approach to the "bull's

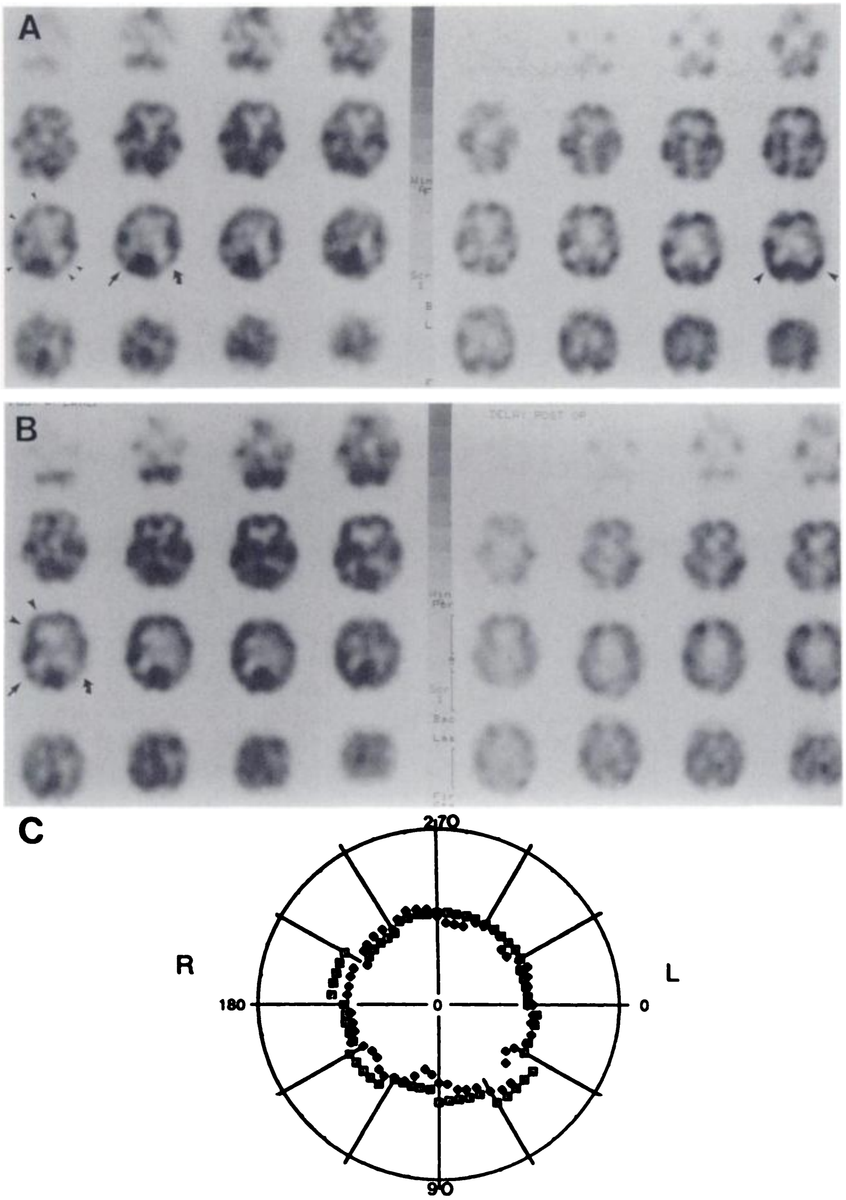

FIGURE 8
Detection of bilateral ischemia. This 80-yr-old male with an 80% right internal carotid stenosis and 95% stenosis on the left had a normal CT. (A) The initial (early) images on the left show patchy areas of decreased perfusion throughout the right cerebral hemisphere and the left posterior watershed area (small arrowheads). There is confirmation of reversible ischemia in these areas by observing filling-in (redistribution) (large arrowheads) especially in the posterior watershed areas bilaterally in the late (delay) images. (B) The postoperative study following a right carotid endarterectomy shows improved perfusion to the right hemisphere with a persistent initial perfusion defect in the left posterior watershed area (curved arrow). This again fills in in the late (delay) image. (C) The polar plot confirms improvement bilaterally (R > L).

eye" analysis which is in common use today to map out myocardial perfusion with ^{201}Tl. An advantage of this form of polar representation of the brain is that it permits in one two-dimensional image a depiction of perfusion over the entire three-dimensional surface of the brain. Because of limitations on the software currently available to us we were required to take the raw data from our circumferential profiles and enter them into a personal minicomputer to generate the polar plots. It is possible to automate this process and generate count profiles for all transaxial SPECT sections of the brain. These could then be superimposed to create a surface map of the brain indicating all areas of ischemia. Such software is currently under development.

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