Special Article

THE FALL AND RISE OF CAROTID ENDARTERECTOMY IN THE UNITED STATES AND CANADA

JACK V. TU, M.D., PH.D., EDWARD L. HANNAN, PH.D., GEOFFREY M. ANDERSON, M.D., PH.D., KAREY IRON, M.H.SC., KEYI WU, M.SC., KAREN VRANIZAN, M.A., A. JOHN POPP, M.D., AND KEVIN GRUMBACH, M.D.

ABSTRACT

Background Randomized clinical trials have demonstrated the efficacy of carotid endarterectomy in the prevention of stroke when the procedure is performed in regional centers of surgical excellence. However, the relative effects of these studies on the rates of carotid endarterectomy in the United States and Canada have been unclear.

Methods We calculated the annual rate of carotid endarterectomy in the U.S. states of California and New York and in the Canadian province of Ontario from 1983 through 1995. We also studied whether patients in the early 1990s were selectively referred to hospitals with high volumes of procedures and historically low in-hospital mortality rates.

Results Rates of carotid endarterectomy fell in all three regions from 1984 to 1989 (from 126 to 66 per 100,000 adults 40 years of age or older in California, from 65 to 40 per 100,000 in New York, and from 40 to 15 per 100,000 in Ontario), after the publication of studies demonstrating that the rates of complications of carotid endarterectomy were unacceptably high. However, the clinical trials of the 1990s, which showed benefit from carotid endarterectomy, were associated with a dramatic resurgence in the rates of the procedure from 1989 to 1995 (from 66 to 99 per 100,000 in California, from 40 to 96 per 100,000 in New York, and from 15 to 38 per 100,000 in Ontario). These increased rates were not associated with proportionally greater numbers of referrals of patients to hospitals with low mortality rates.

Conclusions There have been a dramatic fall and a rise in the rates of carotid endarterectomy in both the United States and Canada, which correlate with the publication of first unfavorable and then favorable clinical studies. The absence of selective referral of patients to centers with the lowest mortality rates raises questions about whether the benefits of carotid endarterectomy in the general population are similar to those demonstrated in the clinical trials. (N Engl J Med 1998;339:1441-7.)

SINCE its introduction in 1954, carotid endarterectomy for the prevention of stroke has been controversial.[1] Rates of carotid endarterectomy rose until the mid-1980s, when a number of studies were published demonstrating very high rates of perioperative complications (stroke or death) after the procedure, thus raising questions about its benefits for the prevention of stroke.[2-4] Concern about carotid endarterectomy increased further when a study by the Rand Corporation was published in 1988, showing that 32 percent of the endarterectomies performed in the United States in Medicare recipients were performed for inappropriate indications, as judged by an expert panel using a modified Delphi technique.[5]

A series of randomized, controlled trials in the 1990s began to clarify the benefits and risks of carotid endarterectomy. In 1991, the North American Symptomatic Carotid Endarterectomy Trial (NASCET) unequivocally demonstrated that carotid endarterectomy is an effective procedure to prevent stroke in symptomatic patients with carotid stenosis of 70 percent or more if it is performed in high-volume centers by highly skilled surgeons whose patients have low complication rates.[6] Similar results were found in symptomatic patients with high-grade stenosis enrolled in the European Carotid Surgery Trial and the Veterans Affairs Cooperative Symptomatic Carotid Stenosis Trial.[7,8] These studies were followed by release of the Asymptomatic Carotid Atherosclerosis Study (ACAS) results in late 1994, which suggested that the indications for the procedure could be broadened to include asymptomatic patients with carotid stenosis of 60 percent or more.[9,10]

Separate studies in the United States[11] and in Ontario, Canada,[12] have documented declining rates of

From the Institute for Clinical Evaluative Sciences, Toronto (J.V.T., G.M.A., K.I., K.W.); the Department of Medicine, Sunnybrook Health Science Centre (J.V.T.), and the Department of Health Administration (G.M.A.), University of Toronto, Toronto; the State University of New York at Albany, Albany (E.L.H.); the Department of Family and Community Medicine, University of California at San Francisco, San Francisco (K.V., K.G.); and the Department of Surgery, Albany Medical College, Albany, N.Y. (A.J.P.). Address reprint requests to Dr. Tu at the Institute for Clinical Evaluative Sciences, G106-2075 Bayview Ave., Toronto, ON M4N 3M5, Canada.

carotid endarterectomy in the late 1980s and then rising rates in the early 1990s, but the relation of the changes in the rates of carotid endarterectomy in the two countries has remained unclear. International comparisons of the rates of carotid endarterectomy are of particular interest because they indicate how clinicians practicing in different health care systems respond to the same medical literature. In our study, we analyzed the changes in the rates of carotid endarterectomy from 1983 to 1995 in two large U.S. states (California and New York) and a large Canadian province (Ontario). We were particularly interested in studying whether patients who underwent carotid endarterectomy in the early 1990s were selectively referred to regional centers of excellence (hospitals with high volumes of carotid surgery and low perioperative mortality rates), as recommended by the NASCET collaborators.[6]

METHODS

Sources of Data

We obtained hospital-discharge data on the use of carotid endarterectomy from the Office of Statewide Health Planning and Development data base in California, the Statewide Planning and Regional Cooperative System data base in New York, and the Canadian Institute for Health Information data base in Ontario. Patients who underwent carotid endarterectomy in New York and California were identified by a search of the procedure fields in these data bases for code 38.12 of the *International Classification of Diseases, Ninth Revision* (ICD-9),[13] and patients in Ontario were identified by a search for code 50.12 of the Canadian Classification of Procedures.[14] The age and sex of the patients were determined, along with whether they were considered to have died in the hospital or not. In-hospital death was defined as death that occurred within 30 days after the procedure. In Ontario, 85 percent of all deaths that occur within 30 days after carotid endarterectomy occur during the initial hospital admission. Data on out-of-hospital deaths were not readily available for the two U.S. states. We could not obtain reliable data on the occurrence of postoperative strokes because the two U.S. data bases did not accurately distinguish whether patients coded as having stroke had it as a preexisting condition or as a complication of surgery. Patients who underwent coronary-artery bypass graft surgery (ICD-9 code 36.1) during the same hospital admission (less than 5 percent of each cohort) were excluded from our study in order to maintain the homogeneity of the cohorts.

Rates of Carotid Endarterectomy

The overall age- and sex-adjusted rates of carotid endarterectomy per 100,000 adults 40 years of age or older between 1983 and 1995 were calculated for each region, with the population of California in the 1990 U.S. Census serving as the standard population.[15] Age-specific rates of carotid endarterectomy per 100,000 population (for persons 40 to 64 years, 65 to 74 years, or $\geq$75 years of age) were also calculated in each region for the years 1984, 1989, and 1995. Only the residents of each region were included in the numerators of these rate calculations. The denominators for these rate calculations were obtained from census data of the U.S. and Canadian governments.

Volume of Procedures for Hospitals and Surgeons

The numbers of hospitals performing carotid surgery and their annual numbers of procedures performed (volumes) were drawn from the hospital-discharge data base in each region. Data on the volume of procedures for surgeons in New York were obtained from the Statewide Planning and Regional Cooperative System data base, and data on volume for surgeons in Ontario were obtained from the Ontario Health Insurance Plan's physician-billing data base. We restricted our comparison of surgeons' annual volumes to the years from 1990 through 1995, since Canadian data on surgeons' volumes before 1990 were not available. Data on volume for surgeons were not available for California.

Volume According to Type of Hospital

A minimal case volume of 50 carotid endarterectomies over a period of 2 years, with a rate of perioperative complications (death and stroke) within 30 days after the surgery of 6 percent or less, was required for hospitals to be eligible for participation in the NASCET.[6] To determine whether patients were more likely to be operated on in hospitals with high volumes of cases and low associated mortality rates after the publication of the NASCET study in 1991, we classified each hospital in the three regions according to the following criteria. Hospitals were deemed to have historically low mortality rates if the in-hospital mortality rate associated with carotid endarterectomy was no more than 2 percent in the two years (1989 and 1990) preceding the publication of the NASCET; if the rates were more than 2 percent, the hospitals were considered to have high mortality rates. The 2 percent threshold was based on the guidelines of the Stroke Society of the American Heart Association for an acceptable mortality rate among patients undergoing carotid endarterectomy.[16] Hospitals were classified as having historically low volumes of cases if they performed fewer than 50 carotid endarterectomies in 1989 and 1990. Those that performed 50 or more carotid endarterectomies during this period were classified as having high volumes. The relative proportions of patients undergoing carotid endarterectomy and the in-hospital mortality rates at different types of hospitals before (1989 and 1990) and after (1992 and 1993) the publication of the NASCET were determined in each of the three regions.

Statistical Analysis

All categorical variables were compared with the use of chi-square statistics.[17] All P values were two-sided. Rate ratios comparing rates of carotid endarterectomy between years and across regions were calculated with 95 percent confidence intervals, determined by a Taylor series expansion.[15] Adjusted mortality rates were calculated according to hospital category in each region, after adjustments were made for the age and sex distribution of the patient population of each region.[15] The overall mortality rates for the three regions were adjusted according to the age and sex distribution of California's population of patients undergoing carotid endarterectomy in 1992–1993. The SAS statistical program (Release 6.11, SAS Institute, Cary, N.C.) was used for all statistical analyses.[18]

RESULTS

Trends in Rates of Carotid Endarterectomy

The overall age- and sex-adjusted rates of carotid endarterectomy peaked in all three regions in the mid-1980s and then gradually declined to a low point in the late 1980s, with the rates in California and New York being persistently two to three times as high as that in Ontario throughout this period (Fig. 1). The publication of the NASCET in 1991 was associated with a substantial rise in the rates of carotid endarterectomy in all three regions in the early 1990s. A further increase in the rates occurred after the release of the ACAS results in late 1994, with the most striking increase occurring in New York. By 1995, New York's overall rate of carotid endarterectomy (96 per 100,000 adults 40 years of age or older) was

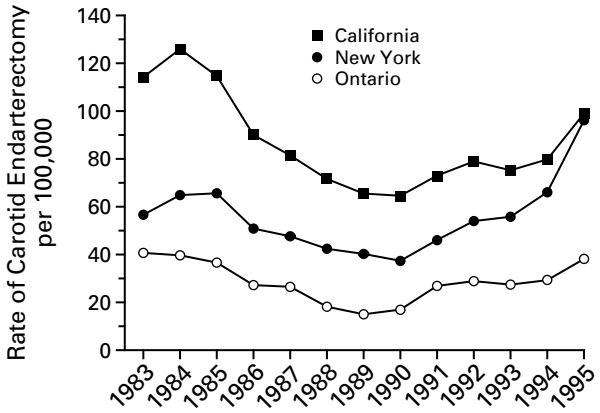

Figure 1. Age- and Sex-Adjusted Rates of Carotid Endarterectomy per 100,000 Adults 40 Years of Age or Older in California, New York, and Ontario from 1983 to 1995.

All rates have been adjusted for age and sex according to the population of California as ascertained by the 1990 U.S. Census.

similar to that of California (99 per 100,000), whereas the rate in Ontario (38 per 100,000) remained less than half that of New York.

Age-Specific Rates and Volumes of Carotid Endarterectomy

Age-specific rates and volumes of carotid endarterectomy in California, New York, and Ontario in 1984, 1989, and 1995 are shown in Table 1. These years were chosen because they corresponded to the initial peak, subsequent trough, and most recent peak in rates of carotid endarterectomy. Ontario had the greatest relative decline in rates of carotid endarterectomy in all age groups between 1984 and 1989, although the absolute decline in the rate was greatest in California. Conversely, the subsequent increase in rates was proportionately greatest in Ontario, with the smallest increase occurring in those under the age of 65 in California. By 1995, the rate of carotid endarterectomy in New York in patients 40 to 64 years of age (33 per 100,000) actually exceeded that in California (27 per 100,000), whereas the rate for those 75 or older (236 per 100,000) remained between that of California (301 per 100,000) and Ontario (73 per 100,000).

Eighty-nine percent of the difference between California and Ontario in the rates of carotid endarterectomy in 1995 could be explained by higher rates for patients 65 or older. The number of women having endarterectomies was also higher in all age groups in the two U.S. states. In 1995, women represented 43 percent of patients undergoing carotid endarterectomy in California and 44 percent in New York, as compared with 33 percent in Ontario ($P<0.001$ for the comparisons with both California and New York).

Numbers of Hospitals and Volumes of Procedures Performed

The numbers of hospitals offering carotid endarterectomy on a per capita basis and the mean annual volumes of carotid surgery at these hospitals in 1984, 1989, and 1995 in the three regions are shown in

TABLE 1. AGE-SPECIFIC RATES OF CAROTID ENDARTERECTOMY AND NUMBERS OF PROCEDURES IN CALIFORNIA, NEW YORK, AND ONTARIO IN 1984, 1989, AND 1995.*

REGION AND AGE GROUP	1984	1989	1995	RATE RATIO (95% CI)	
				1995 VS. 1989	REGION IN 1995 VS. ONTARIO IN 1995
	rate per 100,000 (no.)				
California					
40–64 yr	51 (3124)	24 (1676)	27 (2193)	1.15 (1.08–1.23)	1.61 (1.47–1.77)
65–74 yr	301 (4894)	160 (2918)	244 (4775)	1.52 (1.45–1.59)	2.46 (2.28–2.65)
≥75 yr	294 (3153)	167 (2070)	301 (4503)	1.81 (1.72–1.91)	4.12 (3.72–4.57)
Overall	126 (11171)	66 (6664)	99 (11471)	1.51 (1.47–1.56)	2.59 (2.46–2.72)
New York					
40–64 yr	37 (1721)	19 (928)	33 (1691)	1.70 (1.57–1.84)	1.95 (1.77–2.15)
65–74 yr	152 (1983)	97 (1300)	242 (3263)	2.49 (2.33–2.66)	2.45 (2.27–2.65)
≥75 yr	91 (848)	72 (712)	236 (2544)	3.30 (3.04–3.59)	3.24 (2.91–3.60)
Overall	65 (4552)	40 (2940)	96 (7498)	2.38 (2.28–2.48)	2.52 (2.39–2.66)
Ontario					
40–64 yr	25 (599)	10 (265)	17 (537)	1.72 (1.48–1.99)	1.00
65–74 yr	97 (548)	36 (245)	99 (796)	2.75 (2.38–3.17)	1.00
≥75 yr	37 (137)	15 (66)	73 (394)	4.93 (3.80–6.40)	1.00
Overall	40 (1284)	15 (576)	38 (1727)	2.52 (2.29–2.77)	1.00

*CI denotes confidence interval. Overall rates have been adjusted for age and sex according to the age and sex distributions of the population of California in 1990 and are calculated per 100,000 adults 40 years of age or older.

TABLE 2. NUMBERS OF HOSPITALS OFFERING CAROTID ENDARTERECTOMY AND VOLUMES OF PROCEDURES PERFORMED IN CALIFORNIA, NEW YORK, AND ONTARIO IN 1984, 1989, AND 1995.

VARIABLE	1984	1989	1995
		number	
Hospitals offering carotid surgery			
California	357	329	312
New York	171	144	161
Ontario	35	36	40
Hospitals offering carotid endarterectomy/ million adults ≥20 yr of age			
California	20.1	16.3	14.6
New York	13.4	11.0	12.2
Ontario	5.5	4.9	4.9
Mean annual volume of carotid-endarterectomy cases per hospital			
California	31	20	36
New York	26	20	52
Ontario	38	16	44

Table 2. The two U.S. states had two to four times as many hospitals offering carotid surgery on a per capita basis as Ontario throughout the study period. Sharp decreases followed by increases in the annual volume of carotid surgery per hospital rather than large changes in the numbers of hospitals performing the procedure per capita were factors associated with the observed changes in surgical rates in all three regions.

Numbers of Surgeons and Volumes of Procedures Performed

Changes in the numbers of surgeons performing carotid endarterectomy and the volumes of procedures performed by these surgeons in New York and Ontario between 1990 and 1995 are shown in Table 3. The number of surgeons on a per capita basis was approximately three to four times as high in New York as in Ontario throughout this period. However, the proportion of high-volume surgeons (those performing more than 15 carotid endarterectomies per year) was greater in Ontario than in New York. The increase in the rates of carotid endarterectomy in Ontario in the 1990s was driven primarily by the increasing volume of procedures performed per surgeon, whereas the increase in New York was a function of both increasing volume per surgeon and an increasing number of surgeons performing the procedure. Despite this difference, there was still a large number of surgeons with very low annual volumes (one to five cases per year) in both New York and Ontario in the mid-1990s, as shown in Table 3.

Referrals after the Publication of the NASCET

We assessed the extent to which the increase in the rates of carotid endarterectomy after the NASCET was published occurred among high-volume hospitals with historically low mortality rates. In 1989–1990, 55.1 percent of the patients in California, 52.3 percent of those in New York, and 20.6 percent of those in Ontario underwent carotid endarterectomy at hospitals with low mortality rates and

TABLE 3. NUMBERS OF SURGEONS PERFORMING CAROTID ENDARTERECTOMY AND VOLUMES OF PROCEDURES PERFORMED IN NEW YORK AND ONTARIO FROM 1990 THROUGH 1995.*

VARIABLE	1990	1991	1992	1993	1994	1995
Surgeons performing carotid endarterectomy — no.						
New York	406	429	444	462	492	518
Ontario	78	98	102	95	97	98
Surgeons performing carotid endarterectomy/million adults ≥20 yr of age — no.						
New York	30.8	32.5	33.6	34.9	37.3	39.4
Ontario	10.4	12.8	13.1	12.0	12.1	11.9
Surgeons performing carotid endarterectomy according to region and volume — no. (%)						
New York						
1–5 cases/yr	278 (68)	260 (61)	255 (57)	253 (55)	261 (53)	250 (48)
6–15 cases/yr	77 (19)	97 (23)	103 (23)	129 (28)	131 (27)	129 (25)
>15 cases/yr	51 (13)	72 (17)	86 (19)	80 (17)	100 (20)	139 (27)
Ontario						
1–5 cases/yr	39 (50)	44 (45)	44 (43)	32 (34)	35 (36)	28 (29)
6–15 cases/yr	24 (31)	31 (32)	28 (27)	36 (38)	30 (31)	31 (32)
>15 cases/yr	15 (19)	23 (23)	30 (29)	27 (28)	32 (33)	39 (40)

*Data on volume of procedures performed were not available for surgeons in California. Percentages do not all total 100 because of rounding.

TABLE 4. CHANGES IN NUMBERS OF PATIENTS UNDERGOING CAROTID ENDARTERECTOMY AND IN MORTALITY RATES ACCORDING TO HOSPITAL TYPE.*

REGION AND HOSPITAL CATEGORY†	BEFORE NASCET (1989 AND 1990)			AFTER NASCET (1992 AND 1993)‡		
	NO. OF PATIENTS (%)	IN-HOSPITAL MORTALITY RATE		NO. OF PATIENTS (%)	IN-HOSPITAL MORTALITY RATE	
		crude	*adjusted§*		*crude*	*adjusted§*
		%			%	
California						
Low mortality, high volume	7,203 (55.1)	0.58	0.58	9,399 (56.7)	0.81	0.80
Low mortality, low volume	3,345 (25.6)	0.00	0.00¶	4,399 (26.5)	0.91	0.92
High mortality, high volume	1,606 (12.3)	2.93	2.96¶	1,680 (10.1)	1.13	1.13¶
High mortality, low volume	917 (7.0)	4.69	4.80¶	1,111 (6.7)	1.89	1.92¶
Overall	13,071	1.00	1.02	16,589	0.94	0.94
New York						
Low mortality, high volume	2,971 (52.3)	0.64	0.64	4,138 (48.4)	0.84	0.84
Low mortality, low volume	1,280 (22.5)	0.23	0.24¶	2,259 (26.4)	1.11	1.11
High mortality, high volume	737 (13.0)	3.25	3.29¶	1,045 (12.2)	0.77	0.78
High mortality, low volume	697 (12.3)	4.30	4.24¶	1,106 (12.9)	0.99	0.99
Overall	5,685	1.34	1.43‖	8,548	0.92	0.95
Ontario						
Low mortality, high volume	258 (20.6)	0.78	0.78	434 (18.1)	0.92	0.97
Low mortality, low volume	270 (21.6)	0.00	0.00¶	634 (26.4)	1.74	1.73¶
High mortality, high volume	645 (51.6)	2.94	2.99¶	1,095 (45.7)	1.46	1.49
High mortality, low volume	77 (6.2)	3.90	5.38¶	235 (9.8)	2.55	2.39¶
Overall	1,250	1.92	2.42‖	2,398	1.54	1.72‖

*Percentages do not all total 100 because of rounding. NASCET denotes North American Symptomatic Carotid Endarterectomy Trial.

†Hospital categories were defined as follows: low mortality, in-hospital mortality rate of ≤2 percent in 1989 and 1990; high mortality, in-hospital mortality rate >2 percent in 1989 and 1990; low volume, ≤50 carotid endarterectomies performed in 1989 and 1990; and high volume, >50 carotid endarterectomies performed in 1989 and 1990.

‡Rates do not include patients at hospitals that offered carotid endarterectomy in 1992 and 1993 but not in 1989 and 1990.

§Adjusted rates are adjusted to the age and sex distribution of patients in that region in those years. Overall rates are adjusted to the age and sex distribution of the patient population that underwent carotid endarterectomy in California in 1992 and 1993.

¶$P<0.05$ for the comparison with low-mortality, high-volume hospitals in that region.

‖$P<0.05$ for the comparison with the mortality rate in California in 1992 and 1993.

high volumes of procedures (Table 4). However, the publication of the NASCET in 1991 did not result in a substantial increase in the relative proportion of patients referred to these institutions in any of the three regions. Increases in the volume of carotid-endarterectomy cases at hospitals with historically low mortality rates were similar to those at other types of institutions (Table 4). Although the overall mortality rates declined between 1989 and 1990 and 1992 and 1993, particularly in hospitals with historically high rates, the adjusted mortality rates in 1992 and 1993 for patients undergoing carotid surgery at hospitals with historically high mortality rates and low volumes of procedures continued to be significantly higher than those at hospitals with historically low mortality rates and high volumes of procedures; this was true in California (mortality, 1.92 percent vs. 0.80 percent; $P<0.05$) and Ontario (2.39 percent vs. 0.97 percent, $P<0.05$), but not in New York (0.99 percent vs. 0.84 percent, $P=0.30$). The higher overall in-hospital mortality rate in Ontario (1.72 percent) in 1992–1993, as compared with New York (0.95 percent) and California (0.94 percent), should be interpreted cautiously, because it could reflect unmeasured differences in the case mix or differences in the proportion of deaths that occurred outside the hospital.

DISCUSSION

Between 1983 and 1995, several landmark studies on carotid endarterectomy were published. We observed considerable regional variation in the rates of carotid endarterectomy during this period, with rates in California and New York consistently higher than those in Ontario. Rates of carotid endarterectomy declined in all three regions during the late 1980s after the publication of several studies showing unacceptably high complication rates for this procedure.[2-5] However, there was a dramatic resurgence in performance of the surgery during the 1990s after the publication of the NASCET and ACAS, with a particularly striking increase in New York. By 1995, the rate of carotid endarterectomy in New York had exceeded the rate in California among nonelderly persons,

whereas among older patients it remained between the rates in California and Ontario.

The results of our study provide new insights into the previously observed phenomenon of wide geographic variations in rates of carotid endarterectomy.[19] We found that each region we studied had a unique "surgical signature" that reflected the practice patterns of local physicians in that region with respect to the performance of carotid endarterectomy.[20] We have shown that the publication of new scientific data did not lead to a convergence toward a uniform rate in these geographic areas. Rather, the new information appeared to be interpreted by physicians in the context of their own community's pattern of practice, with physicians rapidly decreasing or increasing their enthusiasm for the procedure according to the baseline rates in their communities. The rapid change in surgical rates after the publication of the major studies of carotid endarterectomy probably reflects the heavy publicity surrounding the release of these studies and the definitive and consistent nature of their results.

The rate of carotid surgery remained much lower in Ontario than in the two U.S. states during the period of our study. Our data suggest a strong relation between the number of hospitals and surgeons performing the procedure and the overall surgical rates observed. For example, the fact that four times as many hospitals in California offered carotid surgery as in Ontario, after adjustment for the size of the population, almost certainly contributed to the markedly higher rates of surgery observed in California in the mid-1980s. Although there are no formal restrictions on the availability of carotid endarterectomy in Ontario, the relatively low number of surgeons per capita who perform carotid endarterectomy and their relatively high surgical volumes may limit the number of procedures that are performed. Interestingly, the smallest proportional increase in rates of carotid surgery in the 1990s was among persons under the age of 65 in California, which may be a reflection of the high penetration of managed care in this age group in the state.

The NASCET and ACAS have proved that a low rate of perioperative complications (e.g., a 30-day mortality rate of 0.6 percent in the NASCET and 0.1 percent in the ACAS) is important if patients are to derive a long-term benefit from carotid surgery.[6,10] However, we found the mortality rates at many hospitals in both countries to be substantially higher than the rates reported in these trials. We also found no evidence that patients were selectively referred to high-volume centers with historically low mortality rates, even though the mortality rates of the low-volume hospitals with historically high mortality rates in 1992 and 1993 were two to three times as high in both California and Ontario. The absence of selective referral may reflect a lack of awareness of local rates of mortality and stroke in patients undergoing carotid endarterectomy in the two countries, with patient referrals depending more on local availability and convenience than on better outcomes. A recent nationwide survey of U.S. physicians found that only 19 percent were aware of the mortality rate associated with carotid endarterectomy at their local hospital.[21]

Our study had certain limitations. First, details were not available on the clinical characteristics (e.g., the degree of stenosis) and postoperative outcomes (e.g., stroke) that would have allowed us to compare more definitively the appropriateness and outcomes of carotid surgery in the two countries. More detailed clinical data would have allowed us to determine whether unmeasured differences in the case mix (e.g., the proportion of asymptomatic patients) or in other factors accounted for the higher in-hospital mortality after carotid endarterectomy in Ontario. Second, we relied on historical data on in-hospital mortality and the volume of procedures to classify hospitals that performed carotid endarterectomy in each region. Data on the occurrence of death and stroke within 30 days after carotid endarterectomy would have allowed us to identify high-quality centers more accurately. Centers with lower mortality rates may not necessarily have had lower rates of stroke, since perioperative deaths are mostly due to myocardial infarction. Third, our findings may not be generalizable to other states in the United States or to other provinces in Canada.

In conclusion, we found substantial variation in the rates of carotid endarterectomy among California, New York, and Ontario throughout the 1980s and the first half of the 1990s. These rates fell dramatically in all three regions in the late 1980s and then rose again in the 1990s, as scientific studies questioned the value of carotid endarterectomy and then defined the appropriate indications for the procedure. Striking variations in the use of carotid surgery in older patients account for much of the difference in the rates of carotid endarterectomy between the two countries; large differences in the numbers of surgeons who performed the procedure and in the numbers of hospitals offering the procedure probably contributed to the variations observed. The absence of selective referral of patients to high-volume centers with historically low mortality rates suggests that caution should be exercised in drawing conclusions about the effectiveness of carotid endarterectomy in the general population on the basis of trials of clinical efficacy conducted at highly selected facilities. The benefits of carotid endarterectomy demonstrated in the NASCET and ACAS were highly sensitive to the ability of the participating centers to maintain low rates of perioperative complications, and the lack of more selective referral may blunt the effectiveness of carotid endarterectomy in the community setting.

Supported in part by a grant (NA-3751) from the Heart and Stroke Foundation of Ontario. Dr. Tu is the recipient of a Medical Research Council of Canada Scholar award. The results and conclusions are those of the authors and should not be attributed to any of the sponsoring agencies.

We are indebted to Kathy Knowles-Chapeskie, Moira Kapral, James Perry, and Carl Van Walraven for helpful comments on earlier versions of the manuscript, and to Francine Duquette for assistance in preparing the tables and figure.

REFERENCES

1. Eastcott HH, Pickering GW, Rob CG. Reconstruction of internal carotid artery in a patient with intermittent attacks of hemiplegia. Lancet 1954;267:994-6.
2. Brott T, Thalinger K. The practice of carotid endarterectomy in a large metropolitan area. Stroke 1984;15:950-5.
3. Muuronen A. Outcome of surgical treatment of 110 patients with transient ischemic attack. Stroke 1984;15:959-64.
4. Warlow C. Carotid endarterectomy: does it work? Stroke 1984;15: 1068-76.
5. Winslow CM, Solomon DH, Chassin MR, Kosecoff J, Merrick NJ, Brook RH. The appropriateness of carotid endarterectomy. N Engl J Med 1988;318:721-7. [Erratum, N Engl J Med 1988;319:124.]
6. The North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Engl J Med 1991;325:445-53.
7. The European Carotid Surgery Trialists' Collaborative Group. MRC European Carotid Surgery Trial: interim results for symptomatic patients with severe (70–99%) or with mild (0–29%) carotid stenosis. Lancet 1991;337: 1235-43.
8. Mayberg MR, Wilson SE, Yatsu F, et al. Carotid endarterectomy and prevention of cerebral ischemia in symptomatic carotid stenosis. JAMA 1991;266:3289-94.
9. Clinical advisory: carotid endarterectomy for patients with asymptomatic internal carotid artery stenosis. Stroke 1994;25:2523-4.
10. Endarterectomy for asymptomatic carotid artery stenosis: Executive Committee for the Asymptomatic Carotid Atherosclerosis Study. JAMA 1995;273:1421-8.
11. Gillum RF. Epidemiology of carotid endarterectomy and cerebral arteriography in the United States. Stroke 1995;26:1724-8.
12. To T, Kucey DS, Naylor CD. Variations in selected surgical procedures and medical diagnoses by year and region: carotid endarterectomy. In: Goel V, Anderson GM, Blackstein-Hirsch P, Fooks C, Naylor CD, eds. Patterns of health care in Ontario: the ICES practice atlas. 2nd ed. Ottawa, Ont.: Canadian Medical Association, 1996:85-9.
13. The international classification of diseases, 9th rev., clinical modification: ICD-9-CM. Ann Arbor, Mich.: Commission on Professional and Hospital Activities, 1992.
14. Canadian classification of diagnostic, therapeutic, and surgical procedures. Ottawa, Ont.: Minister of Industry, Science, and Technology, 1993.
15. Hennekens CH, Buring JE. Epidemiology in medicine. Boston: Little, Brown, 1987.
16. Beebe HG, Clagett GP, DeWeese JA, et al. Assessing risk associated with carotid endarterectomy: a statement for health professionals by an Ad Hoc Committee on Carotid Surgery Standards of the Stroke Council, American Heart Association. Circulation 1989;79:472-3.
17. Rosner BA. Fundamentals of biostatistics. 4th ed. Belmont, Calif.: Duxbury Press, 1995.
18. SAS software/computer program, version 6.11. Cary, N.C.: SAS Institute, 1996.
19. Chassin MR, Brook RH, Park RE, et al. Variations in the use of medical and surgical services by the Medicare population. N Engl J Med 1986; 314:285-90.
20. Wennberg JE. Dealing with medical practice variations: a proposal for action. Health Aff (Millwood) 1984;3(2):6-32.
21. Goldstein LB, Bonito AJ, Matchar DB, et al. US national survey of physician practices for the secondary and tertiary prevention of ischemic stroke: design, service availability, and common practices. Stroke 1995;26: 1607-15.