EDITOR'S CHOICE

ORIGINAL RESEARCH

Treatment of ruptured and unruptured cerebral aneurysms in the USA: a paradigm shift

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ABSTRACT

Background Integration of data from clinical trials and advancements in technology predict a change in selection for treatment of patients with cerebral aneurysm.

Objective To describe patterns of use and in-hospital mortality associated with surgical and endovascular treatments of cerebral aneurysms over the past decade.

Materials and methods The data are 34 899 hospital discharges with a diagnosis of ruptured or unruptured cerebral aneurysm from 1998 to 2007 identified from the Nationwide Inpatient Sample (NIS). The rates of endovascular coiling and surgical clipping and in-hospital mortality among patients with an aneurysm are examined over a decade by hospital and patient demographic characteristics.

Results From 1998 to 2007, 20 134 discharges with a ruptured aneurysm and 14 765 discharges with an unruptured aneurysm were identified. Over this decade, the number of patients discharged with a ruptured aneurysm was stable while the number discharged with an unruptured aneurysm increased significantly. The use of endovascular coiling increased at least twofold for both groups of patient ($p<0.001$) with the majority of unruptured aneurysms treated with coiling by 2007. Although whites were more likely than non-whites to undergo coiling versus clipping for a ruptured aneurysm (OR=1.30; 95% CI 1.13 to 1.48) and men with unruptured aneurysms were more likely than women to undergo coiling (OR=1.26; 95% CI 1.13 to 1.40), by 2007 differences in treatment selection by gender and racial subgroups were decreased or statistically non-significant. Over time the use of coiling spread from primarily large, teaching hospitals to smaller, non-teaching hospitals.

Conclusions The majority of unruptured aneurysms in the USA are now treated with endovascular coiling. Although surgical clipping is used for treatment of most ruptured aneurysms, its use is decreasing over time. Dissemination of endovascular procedures appears widespread across patient and hospital subgroups.

INTRODUCTION

Cerebral aneurysms are estimated to affect approximately 2% of the population worldwide.[1 2] Rupture of a cerebral aneurysm results in subarachnoid hemorrhage (SAH) and is associated with substantial mortality and morbidity. The rupture rate of an aneurysm is thought to vary with its size,[3 4] location[4] and morphological characteristicss[5 6] as well as a patient's personal and family medical history,[4 7 8] and these variables help to guide the clinical management of these lesions. For those aneurysms requiring treatment, two primary methods are used: microsurgical clipping or endovascular coiling. In 2002, outcomes for patients with ruptured cerebral aneurysms were reported in the International Subarachnoid Aneurysm Trial (ISAT), a randomized, controlled clinical trial that compared the mortality and clinical outcomes of patients with aneurysmal SAH treated with either surgical clipping or endovascular coiling. The study reported that patients who underwent coiling had lower mortality and better outcome at 1 year than those who had open surgery. As a result of this trial, a change in practice pattern within the USA was likely with more ruptured aneurysms treated endovascularly.[9 10] Although a previous effort to assess this trend through 2003 was presented by Andaluz *et al* (2008), only now has sufficient time passed since the publication of the ISAT trial results to allow for a formal examination of treatment practice patterns for cerebral aneurysms, both ruptured and unruptured, within the USA. In addition, use of coiling may not be uniform for patients in different demographic subgroups and in hospitals located in different geographic areas. Using data from the Nationwide Inpatient Sample (NIS), we present trends in treatment selection for patients with cerebral aneurysms over the past decade and the associated clinical outcomes.

METHODS

Data were obtained from the NIS, a component of the Healthcare Cost and Utilization Project (HCUP) sponsored by the Agency for Healthcare Research and Quality and the US Department of Health and Human Services and the largest all-payer inpatient care database in the USA. It contains data on eight million discharges from more than 1000 hospitals each year, which approximates to a 20% stratified sample of all US community hospitals.[11] The NIS and other administrative databases have been extensively used to analyze trends of practice in various medical fields in the USA, such as cardiology,[12] psychiatry,[13 14] gastrointestinal surgery[15] and spinal surgery.[16] Here we conducted a retrospective cohort study on data extracted from the NIS to describe trends in treating cerebral aneurysms in the USA.

Table 1 Descriptive statistics for treated aneurysm discharges from national inpatient sample, 1998–2007

Factors	Ruptured (n=20 134)	Unruptured (n=14 765)	p Value
Age (years)			
Mean±SD	53.3±13.9	53.0±14.0	0.02
Median	53.0	54.0	
Sex			
Female	13 839 (68.7)	10 665 (72.2)	<0.001
Male	6259 (31.1)	4005 (27.1)	
Race			
White	9073 (45.1)	7658 (51.9)	<0.001
Black	2297 (11.4)	1011 (6.8)	
Other (Hispanic, Asian or Native American)	2243 (11.1)	1129 (7.6)	
Unknown	6521 (32.4)	4967 (33.6)	
Income quartile (%)			
<25 000	3626 (18.0)	2511 (17.0)	0.006
25 000–34 999	5002 (24.8)	3687 (25.0)	
35 000–44 999	5110 (25.4)	3979 (26.9)	
≥45 000	5732 (28.5)	4234 (28.7)	
Healthcare coverage			
Private insurance	10 412 (51.7)	8504 (57.6)	<0.001
Public (Medicare or Medicaid)	6923 (34.4)	5225 (35.4)	
Self-pay	1797 (8.9)	431 (2.9)	
Charlson comorbidity score			
Mean±SD	0.47±0.73	0.39±0.65	<0.001
Admission source			
Emergency room	9695 (48.2)	1020 (6.9)	<0.001
Hospital/facility transfer	6048 (30.0)	690 (4.7)	
Elective	3786 (18.8)	12 622 (85.5)	
Treatment method			
Clipping	14 514 (72.1)	7597 (51.5)	<0.001
Coiling	5620 (27.9)	7168 (48.5)	
Hospital location			
Northeast	3326 (16.5)	2595 (17.6)	<0.001
Midwest	4303 (21.4)	3523 (23.9)	
South	7976 (39.6)	5686 (38.5)	
West	4529 (22.5)	2961 (20.1)	
Hospital size			
Small	970 (4.8)	879 (6.0)	<0.001
Medium	3019 (15.0)	1988 (13.5)	
Large	16 131 (80.1)	11 894 (80.6)	
Hospital type			
Non-teaching	3810 (18.9)	1902 (12.9)	<0.001
Teaching	16 310 (81.0)	12 859 (87.1)	

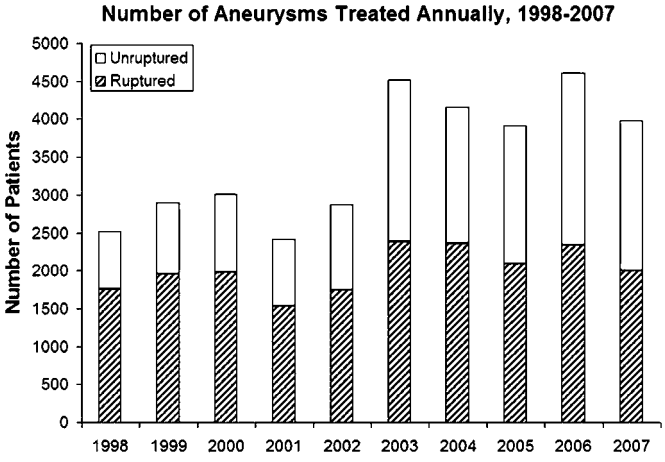

Figure 1 The number of ruptured and unruptured cerebral aneurysms treated annually in the USA, 1998–2007. Although the yearly presentation of ruptured aneurysms was stable, the number of unruptured aneurysms treated in the USA increased significantly during this period.

Approval for the project was obtained from the Partners/Brigham and Women's Hospital Institutional Review Board. Annual NIS data files from 1998 to 2007 were obtained from the HCUP Central Distributor (Rockville, Maryland, USA). The *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*)[17] codes were used to define diagnostic as well as treatment groups. Ruptured aneurysms were defined by code 430.0 (SAH) or 431.0 (intracerebral hemorrhage) and unruptured aneurysms by code 437.3 (cerebral artery aneurysm, not ruptured). Patients with both a ruptured and unruptured aneurysm in one hospitalization were included in the ruptured group. The *ICD-9-CM* procedure code 39.51 has long been established for microsurgical clipping and was used to categorize those treated by open surgery. For endovascular therapies, dedicated procedure codes 39.72 (endovascular repair or occlusion of head and neck vessels) and 39.79 (other endovascular procedures on head and neck vessels) were defined in 2001. Before that time, 39.52 (other repair of aneurysm) was used to identify endovascular treatment for a cerebral aneurysm. As the code 39.52 might also include open surgical treatments such as wrapping, in our analyses, patients with code 39.52 were also required to carry a code of 88.41 (angiography of cerebral arteries) and not any procedure codes indicating open craniotomy in the same hospitalization to be categorized as having endovascular coiling. These methods were similar to those described in other investigations of neurosurgical patients.[9 10 18] Only patients with an aneurysm who underwent treatment were included; those who carried diagnostic codes for cerebral aneurysms but not procedure codes for either surgical clipping or endovascular coiling were excluded from analyses. Data from the year 1998, when the NIS sampling and weighting strategy was redesigned to improve national representativeness,[19] up to the year 2007, the latest database publicly available, were included in the analyses. This period therefore included the 5 years before as well as after publication of the ISAT results.

Differences in demographic and hospital characteristics by diagnostic and treatment groups were examined using χ^2 and t tests for binary and continuous variables, respectively. Multivariable logistic regression was used to calculate the ORs and 95% CIs for the likelihood of using endovascular treatment as well as in-hospital mortality for both SAH and unruptured aneurysm groups after adjusting for age, sex, race (white, black and other), household income quartile, comorbidity score, geographic region, hospital size and hospital teaching status. Medical comorbidity stratification was performed using the Charlson comorbidity index[20] adapted for use on *ICD-9-CM* codes.[21 22]

Multivariable linear regression was used to examine the association of the above-mentioned variables with postoperative length of stay and total charge for the hospitalization. The NIS categorizes hospital bed size as small, medium and large, based on the hospital's region, location and teaching status, so that approximately one-third of the hospital in a given region, location and teaching status combination would fall into each category.[11] The NIS database provides information only on the total charge for the inpatient hospitalization, which represents the sum of all charges during the hospitalization except for professional fees. Logarithmic transformation was used for

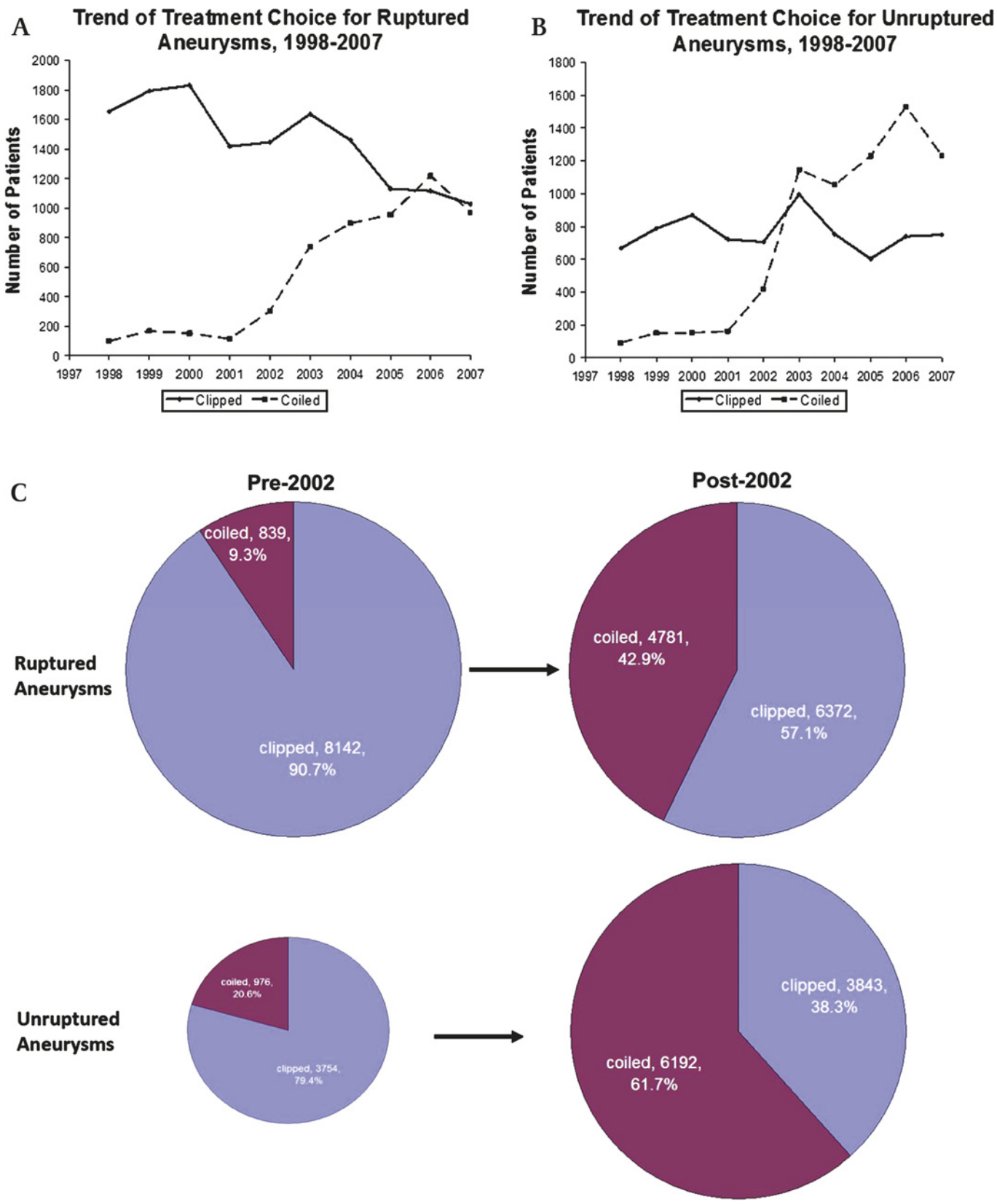

Figure 2 Changes of treatment selection for ruptured and unruptured cerebral aneurysms in the USA before and after the publication of the International Subarachnoid Aneurysm Trial (2002). Increased use of coiling was found for both ruptured aneurysms (A) and unruptured cerebral aneurysms (B) from 1998 to 2007. There was a twofold increase in the use of coiling for both aneurysm types after 2002 (C).

Table 2 Factors associated with coiling use in ruptured and unruptured aneurysms, NIS 1998–2007

Factors	Ruptured aneurysms			Unruptured aneurysms		
	Clipping (n=14 514)	Coiling (n=5620)	OR* (95% CI)	Clipping (n=7597)	Coiling (n=7168)	OR* (95% CI)
Age (years)						
Mean±SD	52.88±13.4	54.55±15.2	1.01 (1.005 to 1.01)†	53.3±11.8	52.7±16.1	0.99 (0.99 to 1.00)†
Sex						
Female	10 065 (69.4)	3774 (67.4)	1	5665 (74.8)	5000 (70.4)	1
Male	4437 (30.6)	1822 (32.6)	1.09 (0.99 to 1.21)	1906 (25.2)	2099 (29.6)	1.26 (1.13 to 1.40)
Race						
Black	1812 (12.5)	485 (8.6)	1	548 (7.2)	463 (6.5)	1
White	6641 (45.8)	2432 (43.3)	1.30 (1.13 to 1.48)	4050 (53.3)	3608 (50.3)	1.10 (0.94 to 1.29)
Other (Hispanic, Asian, or Native American)	1642 (11.3)	601 (10.7)	1.01 (0.85 to 1.19)	511 (6.7)	618 (8.6)	1.22 (0.99 to 1.51)
Income quartile (%)						
<25 000	2372 (16.9)	1254 (23.0)	0.79 (0.69 to 0.91)	1029 (13.9)	1482 (21.1)	0.95 (0.82 to 1.10)
25 000–34 999	3626 (25.8)	1376 (25.3)	0.93 (0.81 to 1.06)	1967 (26.5)	1720 (24.6)	0.87 (0.76 to 0.99)
35 000–44 999	3764 (26.8)	1346 (24.8)	0.88 (0.78 to 1.00)	2155 (29.1)	1824 (26.1)	0.86 (0.75 to 0.97)
≥45 000	4272 (30.4)	1460 (26.9)	1	2261 (30.5)	1973 (28.2)	1
Healthcare coverage						
Private insurance	7697 (53.2)	2715 (48.5)	1	4572 (62.7)	3932 (57.3)	1
Public (Medicare or Medicaid)	4794 (33.1)	2129 (37.9)	1.14 (1.03 to 1.27)	2468 (33.9)	2757 (40.1)	1.44 (1.30 to 1.60)
Self-pay	1315 (9.1)	482 (8.5)	0.86 (0.72 to 1.02)	250 (3.4)	181 (2.6)	0.88 (0.66 to 1.18)
Charlson comorbidity score						
Mean±SD	0.44±0.70	0.54±0.79	1.18 (1.11 to 1.25)	0.38±0.65	0.39±0.66	0.86 (0.80 to 0.92)
Admission source						
Emergency room	7556 (53.7)	2139 (39.2)	1	626 (8.5)	394 (5.6)	1
Hospital/facility transfer	3920 (27.9)	2128 (39.0)	1.64 (1.48 to 1.83)	336 (4.6)	363 (5.2)	1.52 (1.15 to 2.01)
Elective	2591 (18.4)	1195 (21.8)	1.37 (1.21 to 1.55)	6401 (86.9)	6221 (89.2)	1.36 (1.13 to 1.63)
Hospital location						
Northeast	2434 (16.8)	892 (15.9)	1	1364 (17.9)	1231 (17.2)	1
Midwest	3109 (21.4)	1194 (21.3)	1.20 (1.03 to 1.40)	1683 (22.2)	1840 (25.7)	1.70 (1.45 to 1.99)
South	5794 (39.9)	2182 (38.8)	1.12 (0.98 to 1.27)	3090 (40.7)	2596 (36.2)	1.13 (1.00 to 1.28)
West	3177 (21.9)	1352 (24.0)	1.15 (0.99 to 1.33)	1460 (19.2)	1501 (20.9)	1.28 (1.11 to 1.49)
Hospital size						
Small	746 (5.1)	224 (4.0)	1	583 (7.7)	296 (4.1)	1
Medium	2346 (16.2)	673 (12.0)	0.71 (0.56 to 0.90)	1147 (15.1)	841 (11.7)	1.03 (0.82 to 1.31)
Large	11 408 (78.7)	4723 (84.0)	1.11 (0.90 to 1.37)	5863 (77.2)	6031 (84.2)	2.28 (1.88 to 2.76)
Hospital type						
Non-teaching	3125 (21.5)	685 (12.2)	1	1175 (15.5)	727 (10.1)	1
Teaching	11 375 (78.5)	4935 (87.8)	1.34 (1.18 to 1.52)	6418 (84.5)	6441 (89.9)	1.69 (1.46 to 1.97)
Year						
1998	1656	100	1	668	92	1
1999	1793	168	1.62 (1.14 to 2.29)	788	151	1.39 (0.95 to 2.04)
2000	1830	153	1.27 (0.89 to 1.82)	870	153	1.09 (0.73 to 1.63)
2001	1417	115	1.29 (0.89 to 1.89)	722	162	2.00 (1.38 to 2.90)
2002	1446	303	3.20 (2.28 to 4.47)	706	418	4.80 (3.37 to 6.84)
2003	1637	740	7.92 (5.84 to 10.75)	995	1146	8.71 (6.26 to 12.7)
2004	1461	897	11.58 (8.53 to 15.7)	754	1054	10.76 (7.71 to 15.0)
2005	1131	956	15.00 (11.1 to 20.3)	604	1229	15.37 (11.0 to 21.5)
2006	1116	1218	20.62 (15.2 to 28.0)	740	1530	18.72 (13.3 to 26.3)
2007	1027	970	16.64 (12.2 to 22.7)	750	1233	12.77 (9.10 to 17)

*ORs were adjusted for age, sex, race, income quartile, primary payer, admission source, treatment year, Charlson comorbidity score and hospital characteristics (location, size and teaching status).
†OR per year increase.

length of stay and total charges when performing the analyses because of the significant positive skew of the data. Statistical significance was defined as a type I error <0.05. Statistical analyses were performed using the unweighted data with SAS version 9.2 (SAS Institute Inc, Cary, North Carolina, USA).

RESULTS

From 1998 to 2007, 34 899 discharges associated with the treatment of a cerebral aneurysm were identified, including 20 134 ruptured and 14 765 unruptured aneurysms (table 1). The mean age was 53.2 years. The majority of patients were Caucasian and women outnumbered men by at least twofold. Men and non-whites were more likely than women and whites to present as ruptured. Most treatments took place at large medical centers and those with teaching responsibilities. The South had the greatest number of treated patients and private insurance was the most commonly reported payment type.

Table 3 Trend of factors associated with coiling use in ruptured and unruptured aneurysms, NIS 1998–2007

Factors	Ruptured aneurysms		Unruptured aneurysms	
	Before 2002 OR* (95% CI)	After 2002 OR* (95% CI)	Before 2002 OR* (95% CI)	After 2002 OR* (95% CI)
Age	1.01 (1.002 to 1.018)†	1.00 (1.00 to 1.01)†	1.00 (0.99 to 1.01)†	0.99 (0.99 to 1.00)†
Sex				
Female	1	1	1	1
Male	1.38 (1.04 to 1.59)	1.05 (0.94 to 1.17)	1.20 (0.96 to 1.50)	1.27 (1.12 to 1.43)
Race				
Black	1	1	1	1
White	1.68 (1.21 to 2.33)	1.23 (1.06 to 1.43)	1.42 (0.99 to 2.03)	1.01 (0.84 to 1.21)
Other minorities	1.76 (1.17 to 2.64)	0.91 (0.75 to 1.09)	2.16 (1.37 to 3.43)	1.05 (0.83 to 1.33)
Income quartile				
<25 000	1.28 (0.85 to 1.94)	0.78 (0.67 to 0.90)	0.79 (0.46 to 1.34)	0.95 (0.81 to 1.12)
25 000 to 34 999	0.85 (0.65 to 1.11)	0.96 (0.83 to 1.12)	0.92 (0.71 to 1.20)	0.86 (0.74 to 1.01)
35 000 to 44 999	0.77 (0.60 to 1.00)	0.92 (0.79 to 1.07)	0.82 (0.64 to 1.05)	0.88 (0.76 to 1.03)
≥45 000	1	1	1	1
Healthcare coverage				
Private insurance	1	1	1	1
Public	1.16 (0.91 to 1.47)	1.14 (1.02 to 1.29)	1.52 (1.21 to 1.91)	1.41 (1.25 to 1.60)
Self-pay	0.80 (0.51 to 1.26)	0.87 (0.72 to 1.05)	0.80 (1.41 to 1.59)	0.91 (0.65 to 1.26)
Charlson comorbidity score	1.28 (1.12 to 1.45)	1.17 (1.09 to 1.25)	1.03 (0.88 to 1.21)	0.84 (0.77 to 0.91)
Admission source				
ER	1	1	1	1
Other facility	1.66 (1.31 to 2.09)	1.65 (1.47 to 1.86)	2.41 (1.40 to 4.14)	1.27 (0.91 to 1.76)
Elective	1.40 (1.07 to 1.83)	1.36 (1.19 to 1.57)	1.56 (1.05 to 2.32)	1.28 (1.03 to 1.58)
Hospital location				
Northeast	1	1	1	1
Midwest	1.83 (1.31 to 2.56)	1.04 (0.86 to 1.24)	2.58 (1.89 to 3.52)	1.44 (1.20 to 1.74)
South	1.51 (1.10 to 2.08)	1.05 (0.92 to 1.21)	1.29 (0.95 to 1.75)	1.08 (0.94 to 1.24)
West	1.63 (1.17 to 2.27)	1.04 (0.89 to 1.22)	1.80 (1.31 to 2.47)	1.14 (0.97 to 1.35)
Hospital size				
Small	1	1	1	1
Medium	0.90 (0.52 to 1.58)	0.61 (0.46 to 0.81)	0.62 (0.35 to 1.08)	1.11 (0.85 to 1.45)
Large	2.24 (1.43 to 3.50)	0.87 (0.67 to 1.11)	2.41 (1.62 to 3.61)	2.14 (1.72 to 2.67)
Hospital type				
Non-teaching	1	1	1	1
Teaching	2.72 (2.02 to 3.66)	1.09 (0.95 to 1.26)	2.62 (1.90 to 3.61)	1.44 (1.21 to 1.72)

*ORs were adjusted for age, sex, race, income quartile, primary payer, admission source, treatment year, Charlson comorbidity score and hospital characteristics (location, size and teaching status).
†OR per year increase.

The number of aneurysms treated yearly increased significantly during the study period, with treatment of unruptured aneurysms accounting for the majority of the increase (figure 1). For both ruptured and unruptured aneurysms, the trend was toward an increased use of coiling (figures 2A,B). This increase was particularly notable after 2002 when there was a twofold increase in the use of coiling for both aneurysm types. Before 2002, 90.7% of ruptured aneurysms were treated with clipping versus 57.1% after 2002 (OR=7.3; 95% CI 6.7 to 7.9). For unruptured aneurysms, 79.4% were treated with clipping before 2002 versus 38.3% after 2002 (OR=6.2; 95% CI 5.7 to 6.7) (figure 2C). The number of unruptured aneurysms treated with surgical clipping remained stable over time while the number of ruptured aneurysms that were surgically treated decreased.

We examined factors related to coiling use by rupture status. Across the decade, older age, white race, higher income level, public healthcare coverage, later year of presentation, Midwest location, hospital type (teaching), higher Charlson comorbidity score and non-emergency presentation were significantly associated with coiling for ruptured aneurysms (table 2). In particular, Caucasians who presented with a ruptured aneurysm were more likely to be coiled than blacks (OR=1.30; 95% CI 1.13

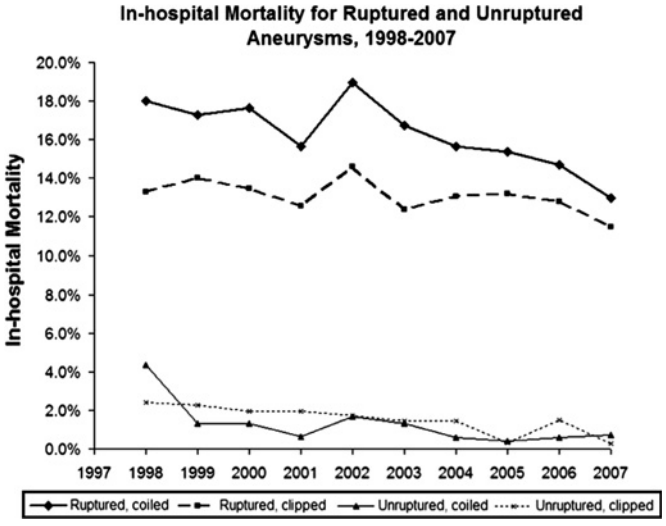

Figure 3 Changes of in-hospital mortality for treated ruptured and unruptured cerebral aneurysms in the USA from 1998 to 2007. Regardless of ruptured status and treatment choice, mortality nationwide decreased steadily over time.

Table 4 In-hospital mortality according to patient and hospital factors, NIS 1998–2007

Factors	Ruptured aneurysms (20 134)		Unruptured aneurysms (n=14 765)	
	No. of events (%)	OR* (95% CI)	No. of events(%)	OR* (95% CI)
Age				
Mean±SD	59.0 (15.1) versus 52.9 (14.1)†	1.03 (1.02 to 1.03)	58.1 (14.4) versus 52.6 (13.8)†	1.05 (1.03 to 1.07)
Sex				
Female	1976 (14.3)	1	125 (1.17)	1
Male	789 (12.7)	0.88 (0.79 to 0.99)	52 (1.30)	1.24 (0.87 to 1.77)
Race				
White	1315 (14.5)	1	80 (1.05)	1
Black	261 (11.5)	0.83 (0.71 to 1.00)	17 (1.68)	1.63 (0.91 to 2.91)
Other (Hispanic, Asian, or Native American)	294 (13.2)	0.93 (0.80 to 1.08)	15 (1.33)	1.43 (1.21 to 1.70)
Income quartile				
<25 000	504 (14.0)	1.14 (0.97 to 1.34)	36 (1.44)	1.25 (0.68 to 2.31)
25 000–34 999	698 (14.0)	1.10 (0.95 to 1.27)	42 (1.14)	1.11 (0.63 to 1.97)
35 000–44 999	704 (13.8)	1.08 (0.94 to 1.25)	53 (1.33)	1.18 (0.68 to 2.04)
≥45 000	761 (13.3)	1	42 (0.99)	1
Healthcare coverage				
Private insurance	1163 (11.2)	1	79 (0.93)	1
Public (Medicare or Medicaid)	1221 (17.7)	1.24 (1.12 to 1.37)	87 (1.67)	1.16 (0.73 to 1.85)
Self-pay	261 (14.6)	1.51 (1.29 to 1.76)	6 (1.39)	1.26 (0.53 to 2.96)
Charlson comorbidity score				
Mean±SD	0.56 (0.81) versus 0.45 (0.71)†	1.10 (1.03 to 1.18)	0.47 (0.85) versus 0.37 (0.65)†	1.23 (0.95 to 1.59)
Admission source				
Emergency room	1485 (15.4)	1.29 (1.12 to 1.50)	27 (2.65)	2.90 (1.78 to 5.03)
Hospital/facility transfer	750 (12.5)	0.98 (0.83 to 1.15)	20 (2.87)	2.79 (1.42 to 5.52)
Elective	456 (12.1)	1	120 (0.95)	1
Treatment selection				
Clipping	1902 (13.2)	1	117 (1.54)	1
Coiling	864 (15.4)	1.31 (1.16-1.47)	60 (0.84)	0.52 (0.37-0.73)
Hospital location				
Northeast	480 (14.4)	1	26 (1.00)	1
Midwest	565 (13.1)	1.05 (0.88 to 1.25)	35 (0.99)	0.93 (0.52 to 1.65)
South	1069 (13.5)	0.83 (0.72 to 0.96)	93 (1.64)	1.21 (1.09 to 1.34)
West	652 (14.4)	0.95 (0.81 to 1.12)	23 (0.78)	0.65 (0.35 to 1.12)
Hospital size				
Small	95 (9.80)	0.73 (0.58 to 0.93)	16 (1.82)	1.69 (0.97 to 2.95)
Medium	450 (15.0)	1.14 (1.01 to 1.28)	24 (1.21)	2.03 (1.75 to 2.34)
Large	2219 (13.8)	1	136 (1.15)	1
Hospital type				
Non-teaching	595 (15.8)	1	25 (1.33)	1
Teaching	2169 (13.3)	0.86 (0.77 to 0.96)	151 (1.17)	1.09 (0.63 to 1.91)

*ORs were adjusted for age, sex, race, income quartile, primary payer, admission source, treatment selection, Charlson comorbidity score and hospital characteristics (location, size and teaching status).
†Mean±SD for those who died in hospital versus did not die in-hospital.

to 1.48) and patients with public insurance were more likely to be coiled than those covered by private payers (OR=1.14; 95% CI 1.03 to 1.27). For unruptured aneurysms, similar parameters were identified during multivariable analyses except race and Charlson comorbidity score (table 2). In addition, male patients with an unruptured aneurysm were more likely to be coiled than female subjects (OR=1.26; 95% CI 1.13 to 1.40).

We further investigated whether the above variables associated with coiling usage changed over the decade (table 3). For ruptured aneurysms, the significance of a number of factors lessened over time; in particular, although men were more likely than women (OR=1.38; 95% CI 1.04 to 1.59) and whites more likely than blacks (OR=1.68; 95% CI 1.21 to 2.33) to be coiled before 2002, differences associated with sex (OR=1.05; 95% CI 0.94 to 1.17) and race (OR=1.23; 95% CI 1.06 to 1.43) had disappeared or reduced, respectively, after 2002. While large, teaching hospitals performed most of the coiling procedures for ruptured aneurysms before 2002, smaller non-teaching hospitals were equally as likely to perform these procedures after that year. Similar trends were found for unruptured aneurysms, although the tendency for coiling rates to become uniform was less prominent across patient and hospital demographic subgroups over time. For instance, after 2002 men remained more likely than women to be coiled (OR=1.27; 95% CI 1.12 to 1.43) and coiling was still more frequently performed in large (OR=2.14; 95% CI 1.72 to 2.67), teaching (OR=1.44; 95% CI 1.21 to 1.72) and mid-west (OR=1.44; 95% CI 1.20 to 1.74) hospitals, although the importance of these factors decreased compared with pre-2002 OR values (table 3).

Overall, in-hospital mortality was 1.2% for patients with an unruptured aneurysm and 13.7% for patients with SAH. Regardless of rupture status and treatment choice, mortality

for treated aneurysms nationwide decreased steadily over time (figure 3). Among patients with ruptured aneurysms, increased mortality was associated with female sex, non-private insurance, higher Charlson comorbidity score, coiling usage and non-teaching hospitals. For unruptured aneurysms, non-elective admission and clipping were associated with a higher mortality (table 4).

DISCUSSION

In this retrospective cohort study, data from the NIS were used to investigate trends in aneurysm treatment patterns in the USA for the 10-year interval centered around the publication of ISAT in 2002.[23] A marked change in treatment selection from surgical clipping to endovascular coiling was noted for both ruptured (the focus of the ISAT trial) and unruptured aneurysms after publication of the trial results. The relative increase in coiling usage was greater for patients with SAH than for those with unruptured aneurysms, as the number of ruptured aneurysms treated with surgery decreased while the number of unruptured aneurysms treated with surgery remained stable. The increased use of coiling for both ruptured and unruptured aneurysms is consistent with previous reports,[9 10 18 24–26] and the large decrease in surgical clipping volume for ruptured aneurysms was recently reported.[25]

These data collectively suggest a paradigm shift for the treatment of cerebral aneurysms within the USA with the majority being treated with endovascular coiling in recent years. While the trend towards more coiling had already occurred in the late 1990s,[9] publication of the ISAT results markedly accelerated this process in the USA. The trial served to increase the awareness and acceptance of endovascular coiling as a treatment option for cerebral aneurysms in the general public and in the medical community. In 2003, the Center for Medicare and Medicaid Services created a new DRG code (DRG528) for the treatment of intracranial hemorrhage including those caused by aneurysm rupture and both surgical clipping and endovascular coiling were listed as therapeutic options. This addition helped to streamline the billing of coil embolization and may have encouraged its use.

Other factors related to the shift in treatment selection include subsequent technologic advances such as more prevalent usage of stent-assistant coiling, increased availability of endovascular procedures, a shift toward observation rather than surgical intervention for some unruptured aneurysms associated with publication of ISUIA[4] (hence a different underlying case mix of patients who present for treatment) and financial considerations. Previous analyses by Johnston *et al*[27–29] suggest that patients with unruptured aneurysms treated by coiling have fewer adverse events, lower mortality, shorter hospital stay and smaller hospital charge. Hoh *et al*[24] also analyzed data from NIS and showed that clipping compared with coiling is associated with significantly longer lengths of stay and higher total hospital charges for patients with ruptured and unruptured aneurysms. Our analyses (not shown) produced similar results, which could influence treatment selection and allocation of hospital resources.

Two studies focusing on the treatment trend for ruptured[25] and unruptured[26] aneurysms separately have been published in the past year. Our analyses yielded largely consistent results that the use of endovascular treatment increased considerably for cerebral aneurysms, regardless of rupture status. Furthermore, this study examined practice patterns across race and gender and investigated the changes of these factors over time, both of which had not been previously performed for patients with an aneurysm in these data. Minorities have traditionally been shown to have poorer access to interventional procedures such as carotid endarterectomy[30 31] and coronary angiogram,[32] which may explain the gap in coiling use between whites and blacks. Men with unruptured aneurysms were more likely to be coiled than women in our analyses, which may potentially be explained by practitioners' tendency to refer women for clipping because female gender is a known risk factor for aneurysm growth and rupture in natural history studies.[7 33] However, for the treatment of patients with a ruptured aneurysm, the importance of a number of patient (including sex and race) and hospital demographic factors reduced over time, suggesting a more uniform delivery of care for ruptured patients and a move towards an equitable assignment of treatment across gender and racial subgroups. With respect to hospital demographic characteristics, the use of coiling was seen to spread from more specialized large teaching hospitals to smaller hospitals and across all geographic regions, suggesting a dissemination of this technology away from specialized university-based centers.

Endovascular coiling was associated with lower in-hospital mortality for patients with unruptured aneurysms after adjustment for age, sex and other demographic and hospital factors, although the mortality for either treatment is low. For the SAH group, coiling was found to be associated with higher in-hospital mortality and the difference was consistent over the 10-year study period (figure 3). This finding could be explained by the difference of age and preoperative clinical conditions between the two treatment groups. Patients with SAH who underwent coiling were significantly older ($p<0.0001$) and had a higher Charlson comorbidity score ($p<0.0001$) than those who were clipped (table 4). Another counterintuitive finding for the SAH group was that mortality was lower for patients at small hospitals than for those at medium and large hospitals, which was probably because small hospitals usually transfer higher-grade, more complex patients to large, tertiary medical centers.

Caveats for our analyses include the fact that the NIS does not provide specific clinical information on admission, such as the presenting neurological condition, Hunt and Hess grade, or the size and location of the aneurysm and therefore these factors are not included in any analyses. The rationale for treatment

Key messages

- A change in practice pattern for the treatment of cerebral aneurysms was likely after the publication of the results of the International Subarachnoid Aneurysm Trial (ISAT) in 2002.
- Sufficient time has passed to allow for a formal examination of treatment practice patterns for both ruptured and unruptured aneurysms within the USA.
- Before 2002, 90.7% of ruptured aneurysms and 79.4% of unruptured aneurysms were treated with clipping, compared with 57.1% and 38.3% after 2002, respectively.
- Older age, higher income level, public healthcare coverage, teaching hospital admission and non-emergency presentation were associated with a higher likelihood of coiling for both ruptured and unruptured aneurysms.
- Over the past decade, the use of coiling has spread from large, teaching hospitals to smaller hospitals and across all geographic regions. The delivery of care for patients in all gender and racial subgroups has become more uniform over time.

selection is not known, and no correction was made for associated biases of non-random assignment to treatment. Coding inaccuracies remain a concern for any outcome study using NIS data and *ICD-9-CM* identifiers[34]; however, the large size and well-established nationwide representativeness made NIS a standard tool for large-sample analyses in multiple medical fields and the codes used here have been previously validated and generally used in examination of treatment of patients with an aneurysm. One difference in our study relative to previous groups is the inclusion of patients with the diagnostic code 431.0 (intracerebral hemorrhage) who also had a procedure code for either clipping or coiling. This group comprised <10% of the sample and permitted more complete inclusion of all patients with an aneurysm than previous investigations.

CONCLUSION

In conclusion, our analyses of the NIS data from 1998 to 2007 highlight the marked increase in coiling use for both ruptured and unruptured aneurysms in the USA, with the majority of unruptured aneurysms now treated with coiling rather than clipping. Endovascular coiling has become more widely available across multiple patient and hospital demographic subgroups.

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