JAMA Network Open

Original Investigation | Neurology

Sudden Deaths From Aneurysmal Subarachnoid Hemorrhage and Proximity to Neurosurgical Tertiary Care

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Abstract

IMPORTANCE A substantial proportion of deaths due to aneurysmal subarachnoid hemorrhage (SAH) occur without admission to neurosurgical units. Whether this proportion varies by geographic region is unclear.

OBJECTIVE To determine the proportion of SAH deaths without neurosurgical unit admission across hospital districts in 2 high-income countries.

DESIGN, SETTING, AND PARTICIPANTS This retrospective, population-based cohort study used 2 externally validated nationwide administrative data collections in all 41 hospital districts and 10 neurosurgical units in Finland and New Zealand from January 1, 2001, to December 31, 2017. Participants included all hospitalized and fatal nonhospitalized cases with SAH. Data were analyzed from July 1, 2024, to September 7, 2026.

EXPOSURES Hospital district of residence and its distance to the designated neurosurgical referral center, grouped into 4 zones.

MAIN OUTCOMES AND MEASURES The primary outcome was the death-based proportion of all 30-day deaths after SAH that occurred without neurosurgical unit admission (prehospital deaths plus deaths within 30 days after admission to a nonneurosurgical unit divided by all 30-day deaths from SAH). This proportion was estimated across 41 hospital districts and demographic groups, with age- and sex-adjusted risk ratios (RRs) and 95% CIs.

RESULTS A total of 12 912 patients with SAH (7856 in Finland and 5056 in New Zealand; median age, 58 [IQR, 49-69] years; 7924 [61.4%] women) were included. Of all 5418 SAH deaths, 3819 (70.5%) occurred without neurosurgical unit admission: 2203 of 3114 (70.7%) in Finland (interdistrict range, 403 of 644 [62.6%] to 5 of 5 [100%]) and 1616 of 2304 (70.1%) in New Zealand (interdistrict range, 111 of 190 [58.4%] to 22 of 23 [95.7%]). Compared with districts containing a neurosurgical unit (1723 of 2602 [66.2%]), the death-based proportions were higher in close-distance (1-130 km; 796 of 1129 [70.5%]; RR, 1.07 [95% CI, 1.02-1.12]), middle-distance (131-157 km; 469 of 599 [78.3%]; RR, 1.18 [95% CI, 1.12-1.24]), and far-distance (158-371 km; 831 of 1088 [76.4%]; RR, 1.15 [95% CI, 1.10-1.20]) zones. This proportion increased by 6.7% (95% CI, 4.9%-8.5%) for each additional 100 km to a neurosurgical unit. The proportions decreased in both countries over time.

CONCLUSIONS AND RELEVANCE In this cohort study of 12 912 patients with SAH, most deaths occurred without neurosurgical unit admission, and this proportion increased with distance to the

(continued)

Key Points

Question What proportion of deaths within 30 days after aneurysmal subarachnoid hemorrhage (SAH) occur in patients not admitted to a neurosurgical unit, and does this proportion vary by proximity to the designated tertiary care center?

Findings In this cohort study of 12 912 patients with SAH, more than 70% of all 30-day deaths occurred without neurosurgical unit admission. This proportion increased with the distance from a neurosurgical referral center, reaching 100% in the most remote districts.

Meaning These findings suggest that improving prevention and early prehospital management of SAH may be a more effective way to reduce its overall mortality than focusing on tertiary care alone.

+ Supplemental content

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Abstract (continued)

neurosurgical referral center. Prevention and early management outside tertiary care may therefore warrant priority in reducing SAH mortality.

JAMA Network Open. 2026;9(11):e2644245. doi:10.1001/jamanetworkopen.2026.44245

Introduction

Aneurysmal subarachnoid hemorrhage (SAH) is a life-threatening stroke requiring urgent neurosurgical tertiary care.[1] Systematic reviews[2,3] indicate that around one-third of patients die within the first month, with only modest improvements during the early 21st century. Based on previous nationwide studies from Finland and New Zealand, one contributing factor may be that more than half of these deaths occur before neurosurgical admission, and thus cannot benefit from tertiary care improvements.[4,5] However, reports from single urban regions describe substantially lower out-of-hospital death rates.[6-12] While part of the variation may be attributed to regional differences in autopsy rates for prehospital sudden deaths, limited availability of neurosurgical services may also partly contribute to the large proportions of people with SAH who never reach neurosurgical tertiary care. Nevertheless, investigations in regions without direct access to tertiary care centers are lacking.

Finland and New Zealand are similar-sized countries (approximately 5.5 million people with land area of approximately 300 000 km^2) with universal public health care and low population density outside a few urban centers.[13,14] Moreover, both show substantial geographic variation in SAH case fatality rates (CFRs).[4,5,15] However, to our knowledge, the impact of neurosurgical hospitalization status has not yet been explored. We therefore determined the proportion of patients with SAH who died without neurosurgical unit admission across the 41 hospital districts of Finland and New Zealand from January 1, 2001, to December 31, 2017, hypothesizing that most SAH deaths occur among patients not admitted to neurosurgical units and that this proportion is greater in districts without a tertiary care center. If so, the high and persistent CFR of SAH cannot be substantially reduced by improving neurosurgical care alone.

Methods

Ethical Consideration

This cohort study was approved by the New Zealand Ministry of Health, the Northern Health and Disability Ethics Committee of New Zealand, the Finnish Institute for Health and Welfare, and Statistics Finland. Because both datasets were retrospective analyses of administratively collected data without personal identifiers, informed consent was not required and was therefore waived by these institutions. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Study Cohort

The details of both administrative datasets and their external case validation have been described previously.[15,16] Briefly, both cohorts drew on 2 nationwide hospital discharge and cause of death collections. Using codes I60.0 to I60.9 from the *International Statistical Classification of Diseases, Tenth Revision*, the hospital data (Care Register for Health Care in Finland and the National Minimum Dataset in New Zealand) captured all publicly funded inpatient episodes with SAH as a primary or secondary diagnosis. As the Finnish dataset spanned 1998 to 2017 and the New Zealand dataset spanned 2001 to 2018, we analyzed the overlapping years 2001 to 2017, with cause of death linkage until December 31, 2018. Both datasets underwent external case validation. Validation compared the administrative cases with the imaging-verified in-house SAH register of Helsinki University

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Hospital[17] and with the prospectively collected population-based Auckland Regional Community Stroke Studies III and IV in New Zealand.[18,19] After exclusion of false-positive cases,[15,16] both cohorts had high case identification accuracies, especially among patients admitted to the neurosurgical units with 99.8% positive predictive value in the Finnish dataset and 96.0% in the New Zealand dataset. Among prehospital deaths, the SAH diagnosis was based on autopsy in 1717 of 1881 cases (91.3%) in Finland and 414 of 610 (67.9%) in New Zealand. The remaining cases were certified without postmortem examination, based on antemortem brain imaging, a known intracranial aneurysm, or the clinical circumstances of the death, which our data did not distinguish.

Demographic Data

For all cases, we extracted age, sex, municipality of residence, date of SAH, and survival until 365 days after SAH; for fatal cases, the place of death and the means of cause of death determination. Following previous studies,[4,5] we categorized cases into 3 age groups: young (<40 years), middle-aged (40-64 years [reference group]), and older (≥65 years). In New Zealand, ethnicity was self-identified by patients at hospital registration or reported by next of kin at death registration and was extracted from the national collections. Using the Statistics New Zealand categorization,[20] we assigned 1 ethnicity per case, applying its prioritization sequence in case of multiple ethnicities: Asian, European or other (reference group; including African, Latin American, and Middle Eastern ethnicities), Māori, and Pacific. Ethnicity was not available in the Finnish cohort, where approximately 5% of the population identifies as non-Finnish (approximately 2% as non-European and 0.2% as the Indigenous Sámi).[21] We collected ethnicity data because substantial ethnic disparities in SAH incidence and case fatality have previously been reported in New Zealand.[15] By domicile at the time of SAH, we categorized patients into 21 Finnish and 20 New Zealand hospital districts covering the entire land area of both countries. Every district hospital provides emergency care, but SAH tertiary care is centralized to 5 neurosurgical units per country (10 in total). In both countries, patients with SAH are admitted to a neurosurgical unit when treatment can offer an acceptable prognosis or organ donation is considered.

Outcome Assessment

We defined 3 mutually exclusive patient groups by admission status: (1) prehospital deaths (deaths outside an inpatient ward, including at home or work, in an ambulance, or in an emergency department), (2) admissions to a nonneurosurgical unit (admissions to a ward not capable of microsurgical or endovascular aneurysm occlusion, which are provided exclusively in the 10 neurosurgical units), and (3) admissions to a neurosurgical unit (admissions to a unit capable of operative aneurysm treatment). We defined 2 primary outcomes for deaths occurring without neurosurgical unit admission within 30 days of SAH: (1) the death-based proportion (share of 30-day deaths) and (2) the case-based proportion (share of all cases). Specifically, the death-based proportion was defined as prehospital deaths plus deaths within 30 days following admission to a nonneurosurgical unit, divided by all 30-day deaths from SAH; the case-based proportion comprised the same numerator divided by all cases of SAH. We estimated these death- and case-based proportions by country, sex, age group, and ethnicity. We also compared these death- and case-based proportions between individual hospital districts and grouped all districts into quartiles by road or ferry distance in kilometers from each district's largest hospital to its primary neurosurgical referral unit (eFigure 1 in Supplement 1): immediate zone (0 km), close-distance zone (1-130 km), middle-distance zone (131-157 km), and far-distance zone (158-371 km). As the secondary outcome, we reported 30-day all-cause CFRs among patients admitted to each of the 10 neurosurgical units.

Statistical Analysis

To compare the differences in death- and case-based proportions of 30-day deaths without admission to a neurosurgical unit between hospital districts and different demographic groups, we used a Poisson regression model to calculate crude, as well as age- and sex-adjusted risk ratios (RRs)

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with 95% CIs. Because we focused on within-country differences, the districts of the highest-volume unit in each country (Helsinki in Finland and Auckland in New Zealand) served as reference categories in the geographic comparisons. Moreover, we used the Poisson regression model to calculate the mean annual changes of death rates (percentages with 95% CIs) on national, regional, and hospital-specific levels between 2001 and 2017. We also reported 3-year mean estimates during the first (2001-2003) and the last (2015-2017) 3 years of our study period to illustrate overall temporal changes.[4,5,15] The correlation between hospital regions' distance to a neurosurgical center and the death-based proportion of deaths from SAH occurring outside neurosurgical units was assessed using Pearson correlation. Similarly, the correlation between regional case-based proportions and the population-wide prevalence of smoking, hypertension, and living alone was assessed using Spearman correlation. Two-sided $P < .05$ was considered statistically significant. We performed all statistical analyses using Stata, version 17.1 (StataCorp LLC). Data were analyzed from July 1, 2024, to September 7, 2026.

Results

General Characteristics

Between 2001 and 2017, we identified 12 912 cases of SAH (7856 in Finland and 5056 in New Zealand) (**Table 1**), of whom 8853 (68.6%) were admitted to a neurosurgical unit and 5418 (42.0%) died within 30 days. Most cases occurred in women (7924 [61.4%] compared with 4988 men

Table 1. Death-Based Proportions of Subarachnoid Hemorrhage Occurring Without Admission to Neurosurgical Units Within 30 Days[a]

Characteristic	Finland			New Zealand		
	Death-based proportion, No./total No. (%)	RR (95% CI)		Death-based proportion, No./total No. (%)	RR (95% CI)	
		Crude	Adjusted[b]		Crude	Adjusted[b]
Overall	2203/3114 (70.7)	NA	NA	1616/2304 (70.1)	NA	NA
Sex[c]						
Men	1003/1411 (71.1)	1 [Reference]	1 [Reference]	556/762 (73.0)	1 [Reference]	1 [Reference]
Women	1200/1703 (70.5)	0.99 (0.95-1.04)	0.96 (0.92-1.01)	1060/1542 (68.7)	0.94 (0.89-1.00)	0.92 (0.87-0.97)
Age, y[d]						
<40	102/148 (68.9)	1.02 (0.91-1.14)	1.02 (0.91-1.14)	106/157 (67.5)	1.10 (0.97-1.23)	1.09 (0.97-1.23)
40-64	1016/1502 (67.6)	1 [Reference]	1 [Reference]	648/1051 (61.7)	1 [Reference]	1 [Reference]
≥65	1085/1464 (74.1)	1.10 (1.05-1.15)	1.10 (1.05-1.16)	862/1096 (78.6)	1.28 (1.21-1.35)	1.28 (1.21-1.36)
Ethnicity[e]						
Asian	NA	NA	NA	81/118 (68.6)	0.94 (0.83-1.07)	0.96 (0.85-1.09)
European or other[f]	NA	NA	NA	1205/1654 (72.9)	1 [Reference]	1 [Reference]
Māori	NA	NA	NA	254/399 (63.7)	0.87 (0.81-0.95)	0.96 (0.88-1.04)
Pacific	NA	NA	NA	49/91 (53.8)	0.74 (0.61-0.90)	0.79 (0.65-0.96)
Missing[g]	NA	NA	NA	27/42 (64.3)	0.88 (0.70-1.11)	0.86 (0.69-1.07)
Region's distance to a neurosurgical unit[d]						
Immediate zone	1082/1632 (66.3)	1 [Reference]	1 [Reference]	641/970 (66.1)	1 [Reference]	1 [Reference]
Close-distance zone (1-130 km)	278/384 (72.4)	1.09 (1.02-1.17)	1.09 (1.01-1.17)	518/745 (69.5)	1.05 (0.99-1.12)	1.07 (1.00-1.14)
Middle-distance zone (131-157 km)	400/508 (78.7)	1.19 (1.12-1.26)	1.19 (1.12-1.25)	69/91 (75.8)	1.15 (1.01-1.30)	1.15 (1.01-1.30)
Far-distance zone (158-371 km)	443/590 (75.1)	1.13 (1.07-1.20)	1.13 (1.07-1.20)	388/498 (77.9)	1.18 (1.10-1.26)	1.19 (1.11-1.27)

Abbreviations: NA, not applicable; RR, risk ratio.

[a] Death-based proportions are calculated as the sum of prehospital deaths and deaths within 30 days after admission to a nonneurosurgical unit divided by all deaths within 30 days of subarachnoid hemorrhage.

[b] Adjusted for age and sex.

[c] $P = .11$ for heterogeneity in Finland and $P = .002$ for heterogeneity in New Zealand.

[d] $P < .001$ for heterogeneity in Finland and New Zealand.

[e] $P = .08$ for heterogeneity in New Zealand.

[f] Includes African, Latin American, Middle Eastern, and other.

[g] Includes do not know, refused to answer, response unidentifiable, or not stated.

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[38.6%]), regardless of whether patients were admitted to neurosurgery (5531 of 8853 [62.5%]) or not (2393 of 4059 [59.0%]). The median age was 58 (IQR, 49-69) years; neurosurgery-admitted patients were younger (median, 55 [IQR, 47-65] years) than those not admitted (median, 65 [IQR, 54-78] years). Helsinki University Hospital (1940 of the 5456 Finnish admissions [35.6%]) and Auckland City Hospital (1455 of the 3397 New Zealand admissions [42.8%]) had the largest unit caseloads (**Table 2**). Overall, 4059 patients (31.4%) (2400 [30.5%] in Finland and 1659 [32.8%] in New Zealand) were never admitted to a neurosurgical unit due to prehospital death (1881 [23.9%] in Finland and 610 [12.1%] in New Zealand) or conservative treatment in a nonneurosurgical unit (519 [6.6%] in Finland and 1049 [20.7%] in New Zealand). Of these 1568 patients treated in a nonneurosurgical unit, 240 (1.9% of all cases) survived beyond 30 days.

Case Fatalities by Demographic Groups

Overall, the case-based proportion (deaths occurring without neurosurgical unit admission divided by all SAH cases) was 3819 (29.6%) (2203 [28.0%] in Finland and 1616 [32.0%] in New Zealand), and the death-based proportion (deaths occurring without neurosurgical unit admission divided by all SAH deaths) was 3819 of 5418 (70.5%) (2203 of 3114 [70.7%] in Finland and 1616 of 2304 [70.1%] in

Table 2. Crude 30-Day CFRs for Cases of Subarachnoid Hemorrhage Who Were Admitted to a Neurosurgical Unit

Characteristic	Finland			New Zealand		
	Crude CFR, No./total No. (%)	RR (95% CI)		Crude CFR, No./total No. (%)	RR (95% CI)	
		Crude	Adjusted[a]		Crude	Adjusted[a]
Overall	911/5456 (16.7)	NA	NA	688/3397 (20.3)	NA	NA
Sex[b]						
Men	408/2205 (18.5)	1 [Reference]	1 [Reference]	206/1117 (18.4)	1 [Reference]	1 [Reference]
Women	503/3251 (15.5)	0.84 (0.74-0.94)	0.72 (0.64-0.82)	482/2280 (21.1)	1.15 (0.99-1.33)	1.05 (0.91-1.22)
Age, y[c]						
<40	46/493 (9.3)	0.67 (0.50-0.90)	0.67 (0.50-0.89)	51/417 (12.2)	0.68 (0.52-0.89)	0.68 (0.52-0.89)
40-64	486/3499 (13.9)	1 [Reference]	1 [Reference]	403/2233 (18.0)	1 [Reference]	1 [Reference]
≥65	379/1464 (25.9)	1.86 (1.65-2.10)	1.95 (1.73-2.21)	234/747 (31.3)	1.74 (1.51-1.99)	1.72 (1.50-1.98)
Ethnicity[d]						
Asian	NA	NA	NA	37/197 (18.8)	0.95 (0.70-1.28)	1.00 (0.75-1.34)
European or other[e]	NA	NA	NA	449/2268 (19.8)	1 [Reference]	1 [Reference]
Māori	NA	NA	NA	145/668 (21.7)	1.10 (0.93-1.29)	1.33 (1.12-1.57)
Pacific	NA	NA	NA	42/189 (22.2)	1.12 (0.85-1.48)	1.27 (0.96-1.68)
Missing[f]	NA	NA	NA	15/75 (20.0)	1.01 (0.64-1.60)	1.04 (0.67-1.60)
Neurosurgical unit						
Finland[g]						
Helsinki	315/1940 (16.2)	1 [Reference]	1 [Reference]	NA	NA	NA
Tampere	190/1111 (17.1)	1.05 (0.89-1.24)	1.00 (0.86-1.18)	NA	NA	NA
Turku	102/548 (18.6)	1.15 (0.94-1.40)	1.04 (0.85-1.27)	NA	NA	NA
Oulu	127/828 (15.3)	0.94 (0.78-1.14)	0.90 (0.75-1.09)	NA	NA	NA
Kuopio	177/1029 (17.2)	1.06 (0.90-1.25)	1.04 (0.88-1.22)	NA	NA	NA
New Zealand[h]						
Auckland	NA	NA	NA	275/1455 (18.9)	1 [Reference]	1 [Reference]
Waikato	NA	NA	NA	118/465 (25.4)	1.34 (1.11-1.62)	1.32 (1.09-1.58)
Wellington	NA	NA	NA	163/785 (20.8)	1.10 (0.92-1.31)	1.08 (0.91-1.27)
Christchurch	NA	NA	NA	50/471 (10.6)	0.56 (0.42-0.75)	0.53 (0.41-0.70)
Dunedin	NA	NA	NA	82/221 (37.1)	1.96 (1.60-2.40)	1.94 (1.59-2.36)

Abbreviations: CFR, case fatality rate; NA, not applicable; RR, risk ratio.

[a] Adjusted for age and sex.

[b] $P < .001$ for heterogeneity in Finland and $P = .49$ for heterogeneity in New Zealand.

[c] $P < .001$ for heterogeneity in Finland and New Zealand.

[d] $P = .08$ for heterogeneity in New Zealand.

[e] Includes African, Latin American, Middle Eastern, and other.

[f] Includes do not know, refused to answer, response unidentifiable, or not stated.

[g] $P = .72$ for heterogeneity in Finland.

[h] $P < .001$ for heterogeneity in New Zealand.

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New Zealand) (Table 1 and eTable 1 in Supplement 1). Among patients with SAH admitted to a neurosurgical unit, the 30-day all-cause CFR was 1599 of 8853 (18.1%) (911 of 5456 [16.7%] in Finland and 688 of 3397 [20.3%] in NZ) (Table 2). Both within and outside neurosurgical units, CFR increased with age and was higher in men than women, except there was no sex difference among neurosurgery-admitted patients in New Zealand (Table 2 and eTables 1-3 in Supplement 1). By ethnicity, Pacific ethnic groups had the lowest age- and sex-adjusted case-based and death-based proportions, whereas among neurosurgery-admitted patients, Māori and Pacific groups had the highest 30-day CFRs (Tables 1 and 2 and eTable 1 in Supplement 1). Between the 2001-2003 and 2015-2017 periods, the case-based proportion declined by 20% (95% CI, 11%-30%) in Finland and 18% (95% CI, 8%-26%) in New Zealand after age and sex adjustment (eTable 4 in Supplement 1). During the same period, the CFR of neurosurgery-admitted patients decreased by 26% (95% CI, 10%-39%) in Finland but was stable in New Zealand (eTable 5 in Supplement 1).

Case Fatalities by Hospital Districts

Across the 41 districts, the case-based proportion ranged from 26 of 135 (19.3%) to 218 of 531 (41.1%) in Finland and from 111 of 442 (25.1%) to 22 of 43 (51.2%) in New Zealand. The death-based proportion ranged from 403 of 644 (62.6%) to 5 of 5 (100%) and from 111 of 190 (58.4%) to 22 of 23 (95.7%), respectively (**Figure 1** and eTables 6 and 7 in Supplement 1). The highest proportions occurred in remote districts with archipelago (Åland, Finland) or mountainous (West Coast, New Zealand) terrain (Figure 1). Relative to the immediate-distance zone (1723 of 2602 deaths [66.2%]), the age- and sex-adjusted death-based proportion was higher in the close-distance (796 of 1129 [70.5%]; RR, 1.07 [95% CI, 1.02-1.12]), middle-distance (469 of 599 [78.3%]; RR, 1.18 [95% CI, 1.12-1.24]), and far-distance (831 of 1088 [76.4%]; RR, 1.15 [95% CI, 1.10-1.20]) zones, increasing by 6.7% (95% CI, 4.9%-8.5%) per additional 100 km, with a moderate distance-proportion correlation (Pearson r = 0.52 [95% CI, 0.25-0.71]; P < .001) (Table 1 and **Figure 2**). The gradient was similar in both countries and across sexes and, in New Zealand, more pronounced in middle-aged and non-European patients (Table 1 and eTables 8-10 in Supplement 1). In New Zealand but not Finland, regional proportions tended to correlate with the prevalence of smoking (Spearman ρ = 0.42 [95% CI, −0.05 to 0.74]; P = .06), hypertension (ρ = 0.46 [95% CI, −0.003 to 0.76]; P = .05), and living alone (ρ = 0.51 [95% CI, 0.06 to 0.79]; P = .02) (eTable 11 in Supplement 1). Between the 2001-2003 and 2015-2017 periods, the death-based proportion declined in the Finnish close-distance zone, from 50 of 67 deaths (74.6%) to 30 of 58 (51.7%) and trended downward in the far-distance zones of both countries (**Table 3**).

Case Fatalities by Neurosurgical Units

Across the 10 neurosurgical units, 30-day CFRs did not differ significantly among the Finnish centers (127 of 828 [15.3%] at Oulu to 102 of 548 [18.6%] at Turku) but ranged widely in New Zealand (50 of 471 [10.6%] at Christchurch to 82 of 221 [37.1%] at Dunedin) (Table 2); the New Zealand differences persisted after age and sex adjustment (Table 2). Unit-level differences were also present within age groups and, in New Zealand, across ethnic groups and by sex (eTables 12-14 in Supplement 1). Between the 2001-2003 and 2015-2017 periods, the 30-day CFR decreased at Helsinki, from 86 of 431 (20.0%) to 35 of 260 (13.5%), and trended down at Oulu, from 31 of 172 (18.0%) to 15 of 125 (12.0%), while no New Zealand unit showed a declining trend (eTable 5 in Supplement 1).

Discussion

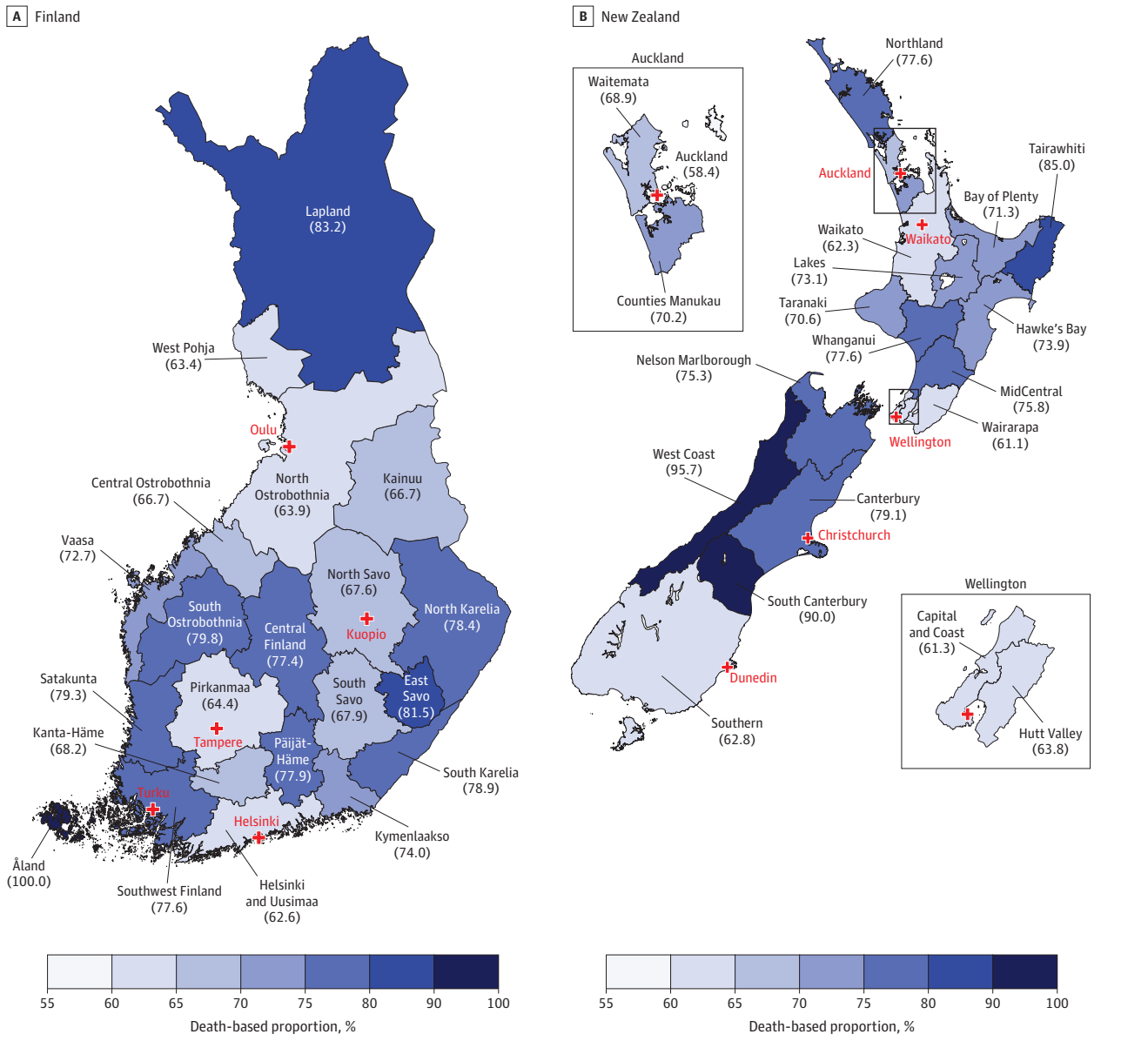
In this international, population-based cohort study including 12 912 hospitalized and fatal nonhospitalized cases with SAH from Finland and New Zealand, more than 70% of deaths within 30 days occurred among those not admitted to a neurosurgical unit. This proportion was lowest in urban districts containing a neurosurgical unit and greatest in remote districts with geographically challenging environments (mountainous or archipelago regions), reaching 95.7% in New Zealand and

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100% in Finland. Given that most patients who die from SAH do not reach neurosurgical units, even substantial improvements in the tertiary care of SAH may not have a major impact on its high CFR. In other words, health care planning and future investigations aiming to reduce deaths among patients with SAH outside neurosurgical units should likely be prioritized.

Our findings highlight the very early phase as a critical window for future improvement. Specifically, 70.5% of SAH deaths occurred before hospitalization or after admission to a nonneurosurgical unit. Although many of these deaths are likely immediately fatal, some may be preventable by faster symptom recognition, earlier access to computed tomography of the brain, and streamlined transfer to tertiary care, where shorter delays have been associated with better outcomes.[22] It is possible that some transfer policies, especially in remote regions, result in

Figure 1. Maps of Regional Death-Based Proportions of Deaths Following Subarachnoid Hemorrhage (SAH) Occurring Without Admission to Neurosurgical Units Within 30 Days After SAH



Death-based proportion is calculated as the sum of prehospital deaths plus deaths within 30 days after admission to a nonneurosurgical unit divided by all deaths within 30 days of SAH. The number of deaths underlying each regional proportion is reported in eTable 7 in Supplement 1. Geographic categorization is based on the domicile of the cases at the time of SAH. Crosses indicate location of a neurosurgical unit providing operative treatment for SAH.

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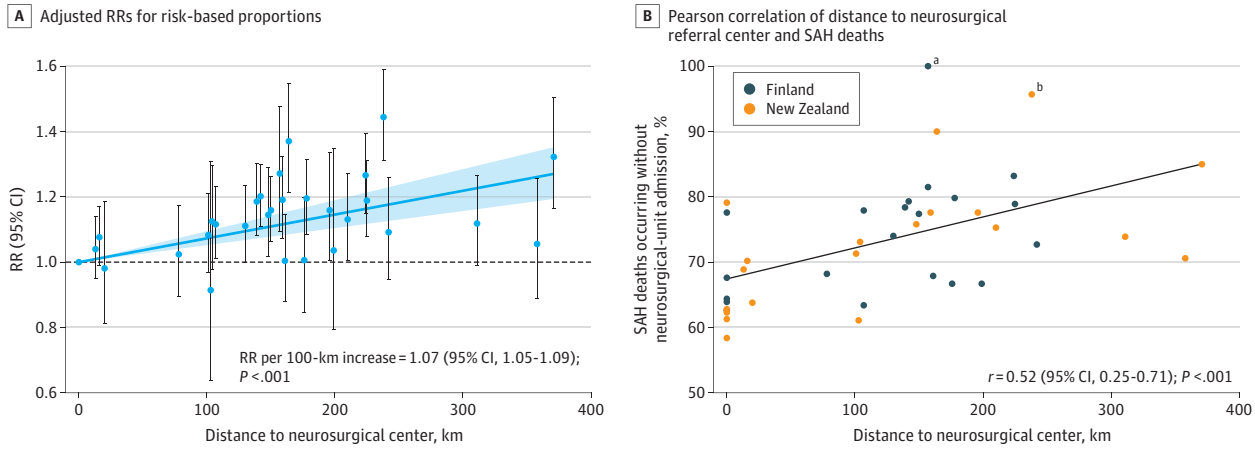
preventable delays that increase the risk of rebleeding before neurosurgical care (eg, overnight stays in remote hospitals with suboptimal blood pressure control). Moreover, in New Zealand but not Finland, districts with the highest proportions had the highest population-wide prevalence of smoking, hypertension, and living alone, known risk factors for prehospital SAH death (eTable 11 in Supplement 1).[23] Future studies should be undertaken to quantify the relative contributions of immediately fatal or moribund SAH, potentially modifiable delays, and underlying risk factor burden, because these imply different prevention and health-system priorities.

While CFRs did not differ significantly among the 5 Finnish units, there was a 4-fold variation between the 2 South Island units in New Zealand. This most likely relates to Dunedin Hospital (highest CFR) not providing a 24/7 comprehensive treatment program for SAH (eg, no out-of-hours neurosurgical care or onsite endovascular treatment). Consequently, many patients with Glasgow Coma Scale scores greater than 12 suitable for operative treatment are transferred directly to Christchurch, the center with the lowest observed CFR. Since the combined CFR of these 2 centers (132 of 692 [19.1%]) did not differ from the New Zealand mean (20.3%), the observed differences may reflect service configuration rather than care quality.

Apart from Helsinki and Oulu, no unit showed a meaningful 30-day CFR decline. This may partly reflect the reported 2-fold rise in patients with Glasgow Coma Scale scores less than 13,[24] who previously died before admission but now reach neurosurgical care with a poor prognosis. Consistent with this, the case-based proportion dying outside neurosurgical units decreased across most demographic groups and districts in both countries. Potential explanations for such favorable trends include declining smoking prevalence,[25] increasing computed tomographic use,[26] improved physician awareness of SAH,[27] shorter treatment delays,[3] improved access to neurocritical care,[12] and rising detection and preventive treatment of unruptured aneurysms, including those at high risk of prehospital death after rupture.[26,28,29] Nevertheless, considering the high and stagnant CFRs in many regions, disparities in ambulance care, interhospital transfer, risk-factor prevention, timely diagnostics, and in-hospital complications remain critical avenues for investigation.

The case-based proportions dying without neurosurgical admission (28.0% in Finland and 32.0% in New Zealand) substantially exceeded prehospital death rates from population-based cohorts in Australia (5%-19%), the US (2%-6%), the United Kingdom (5%-19%), and Sweden

Figure 2. Dot Plot of Age- and Sex-Adjusted Risk Ratios (RRs) for Death-Based Proportions of Subarachnoid Hemorrhage (SAH) Deaths and Scatterplot of Pearson Correlations With Hospital Districts' Distance to a Neurosurgical Referral Center



Death-based proportions are calculated as the sum of prehospital deaths and deaths within 30 days after admission to a nonneurosurgical unit divided by all 30-day SAH deaths. Points with whiskers show RRs with 95% CI for hospital districts (hospital districts containing a neurosurgical unit were used as reference). The solid lines represent a log-linear trend using a Poisson regression model, with the shaded area indicating the 95% CI.

[a] Indicates a challenging archipelago environment (Åland, Finland).

[b] Indicates a challenging mountainous environment (West Coast, New Zealand).

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Table 3. Temporal Changes in Death-Based Proportions of Subarachnoid Hemorrhage Occurring Without Admission to Neurosurgical Units Within 30 Days After Subarachnoid Hemorrhage[a]

Characteristic	Finland				New Zealand			
	Death-based proportion, crude No./total No. (%)		Adjusted RR (95% CI)[b]	Adjusted mean annual decrease, % (95% CI)[b]	Death-based proportion, crude No./total No. (%)		Adjusted RR (95% CI)[b]	Adjusted mean annual decrease, % (95% CI)[b]
	2001-2003	2015-2017			2001-2003	2015-2017		
Overall	431/617 (69.9)	296/433 (68.4)	0.96 (0.88 to 1.04)	0.6 (0.1 to 1.0)	374/491 (76.2)	271/388 (69.8)	0.91 (0.84 to 0.99)	0.4 (−0.1 to 0.9)
Sex								
Men	212/286 (74.1)	129/195 (66.2)	0.88 (0.77 to 0.99)	0.9 (0.2 to 1.6)	126/160 (78.8)	97/129 (75.2)	0.96 (0.84 to 1.09)	0.2 (−0.6 to 1.0)
Women	219/331 (66.2)	167/238 (70.2)	1.04 (0.93 to 1.16)	0.2 (−0.4 to 0.9)	248/331 (74.9)	174/259 (67.2)	0.89 (0.80 to 0.99)	0.6 (−0.1 to 1.2)
Age, y								
<40	23/40 (57.5)	8/12 (66.7)	1.19 (0.71 to 2.00)	−1.7 (−4.2 to 0.8)	28/38 (73.7)	15/23 (65.2)	0.83 (0.59 to 1.17)	0.9 (−1.2 to 3.0)
40-64	221/328 (67.4)	116/170 (68.2)	1.02 (0.90 to 1.16)	0.1 (−0.6 to 0.9)	154/221 (69.7)	120/189 (63.5)	0.91 (0.79 to 1.05)	0.5 (−0.4 to 1.4)
≥65	187/249 (75.1)	172/251 (68.5)	0.91 (0.82 to 1.02)	0.9 (0.3 to 1.6)	192/232 (82.8)	136/176 (77.3)	0.93 (0.85 to 1.03)	0.3 (−0.3 to 0.9)
Ethnicity								
Asian	NA	NA	NA	NA	13/15 (86.7)	60.0 (18/30)	0.69 (0.47 to 1.00)	2.1 (−0.3 to 4.3)
European or other[c]	NA	NA	NA	NA	304/387 (78.6)	188/257 (73.2)	0.92 (0.84 to 1.01)	0.4 (−0.2 to 1.0)
Māori	NA	NA	NA	NA	43/69 (62.3)	54/80 (67.5)	1.07 (0.84 to 1.36)	−0.7 (−2.2 to 0.8)
Pacific	NA	NA	NA	NA	8/10 (80.0)	6/15 (40.0)	0.52 (0.27 to 1.01)	5.0 (1.1 to 8.7)
Missing[d]	NA	NA	NA	NA	6/10 (60.0)	5/6 (83.3)	1.20 (0.62 to 2.30)	0.1 (−3.7 to 3.8)
Region's distance to a neurosurgical unit								
Immediate zone	209/339 (61.7)	159/232 (68.5)	1.11 (0.98 to 1.25)	−0.2 (−1.0 to 0.5)	159/220 (72.3)	117/173 (67.6)	0.93 (0.81 to 1.05)	0.2 (−0.7 to 1.0)
Close-distance zone (1-130 km)	50/67 (74.6)	30/58 (51.7)	0.68 (0.51 to 0.90)	1.9 (0.5 to 3.3)	130/162 (80.2)	84/118 (71.2)	0.89 (0.78 to 1.02)	0.7 (−0.2 to 1.6)
Middle-distance zone (131-157 km)	82/101 (81.2)	48/65 (73.8)	0.88 (0.74 to 1.04)	1.5 (0.5 to 2.5)	11/14 (78.6)	10/13 (76.9)	0.97 (0.65 to 1.45)	0.5 (−1.9 to 2.9)
Far-distance zone (158-371 km)	90/110 (81.8)	59/78 (75.6)	0.88 (0.75 to 1.02)	1.0 (0.0 to 1.9)	74/95 (77.9)	60/84 (71.4)	0.92 (0.78 to 1.09)	0.6 (−0.4 to 1.5)

Abbreviations: NA, not applicable; RR, risk ratio.

[a] Death-based proportions are calculated as the sum of prehospital deaths and deaths within 30 days after admission to a nonneurosurgical unit divided by all deaths within 30 days of subarachnoid hemorrhage.

[b] Adjusted for age and sex.

[c] Includes African, Latin American, Middle Eastern, and other.

[d] Includes do not know, refused to answer, response unidentifiable, or not stated.

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(4%-21%) (eFigure 2 in Supplement 1). These comparisons warrant caution, as most prior reports included prehospital deaths only, whereas our definition also included deaths after admission to nonneurosurgical units, and all previous cohorts differed in methodology, coverage years, and health care organization and were restricted to urban populations with direct access to neurosurgical units (eFigure 2 in Supplement 1). Such urban reports likely underestimate nationwide proportions, as our findings in remote regions suggest. Moreover, the between-country variation in population-wide autopsy rates for prehospital deaths may also explain some of the observed differences. For example, autopsies are performed less often for prehospital deaths in the US (9%)[30] than in Finland (50%)[21] or New Zealand (26%).[20] Of note, despite differences in ethnic composition and terrain, the death-based proportions of Finland and New Zealand were nearly identical, differing only in whether the deaths occurred before admission or in a nonneurosurgical unit, which likely relates to autopsy and registry differences (eTable 15 in Supplement 1).

Strengths and Limitations

Despite being the first international study, to our knowledge, to report nationwide, long-term, population-based, and subgroup-specific proportions of deaths occurring with and without admission to neurosurgical units, our study has several limitations. First, our administrative datasets lacked individual-level data on symptoms, comorbidities, clinical and radiological severity, diagnostic and treatment modalities, and treatment decisions and delays, and we therefore cannot directly evaluate the quality of neurosurgical care or explain why most SAH deaths occur before neurosurgical admission. Second, although our external validation provides evidence that cases of SAH treated in neurosurgical departments were identified accurately, data on prehospital deaths and conservatively treated cases may include some misclassification. For instance, we were not able to validate such data from Finland, and not all prehospital deaths in New Zealand were identified in its validation cohorts. However, since 2131 of 2491 prehospital SAH deaths (85.5%) underwent autopsy and patients with SAH treated in nonneurosurgical units who did not die within the first 30 days after SAH comprised only 240 (1.9%) of all cases, the number of misclassified cases and their effect on findings is likely minimal. Third, some patients in the most remote regions in Finland, such as Lapland and Åland, may have received neurosurgical care abroad (eg, Stockholm or Tromsø) and are thus not included in our cohort. This can possibly contribute to the extreme estimates in those regions, although the number of such cases is most likely negligible. Fourth, the distance from each district's largest hospital to its referral center was our only accessibility proxy. Therefore, future work should incorporate travel time, terrain, traffic, and subdistrict remoteness in analyses. Fifth, emergency transport was reorganized nationally in Finland during the study period and in New Zealand afterward, so our findings may not reflect current service configurations. However, distances and the centralization of aneurysm occlusion to the same 10 units are unchanged.

Conclusions

In this international population-based cohort study, 70.5% of SAH deaths occurred among patients not admitted to neurosurgical units, and this proportion was greater in remote regions than in urban centers. Although the proportion declined during the early 21st century, future studies are required to determine whether improved management outside tertiary care leads to timelier diagnostics, shorter delays, and lower CFRs.

ARTICLE INFORMATION

Accepted for Publication: September 15, 2026.

Published: November 16, 2026. doi:10.1001/jamanetworkopen.2026.44245

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Obtained funding: Barker-Collo, Exeter, Douwes, Te Ao, Rautalin.

Administrative, technical, or material support: Korja, Exeter, Nair, Te Ao, Rautalin.

Supervision: Korja, Correia, Feigin, Rautalin.

Conflict of Interest Disclosures: Dr Exeter reported receiving grant support from the Health Research Council of New Zealand and the Auckland Medical Research Foundation during the conduct of the study. No other disclosures were reported.

Funding/Support: The study was funded by grant HRC-20/680 from the Health Research Council of New Zealand and grant 5553 from the Finnish Medical Foundation. Dr Asikainen was supported by research grants from the Juho Vainio Foundation, the Päivikki and Sakari Sohlberg Foundation, the Maire Taponen Foundation, the Orion Research Foundation, the Paavo Nurmi Foundation, and the Paulo Foundation. Dr Rautalin was supported by grants from the Sigrid Juselius Foundation, the Finnish Medical Foundation, the Sakari Alhopuro Foundation, the Finnish Foundation for Cardiovascular Research, the Juho Vainio Foundation, and the Maud Kuistila Foundation. Dr Ranta was supported by grants from the New Zealand Health Research Council and the Ministry of Health. Dr Douwes was supported by grants from the New Zealand Health Research Council and the New Zealand Royal Society Marsden Fund.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Data Sharing Statement: See Supplement 2.

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SUPPLEMENT 1.

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SUPPLEMENT 2.
Data Sharing Statement

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