The Research of Medical Science Review
ISSN: 3007-1208 & 3007-1216 Volume 3, Issue 11, 2025

PREVALENCE AND RISK FACTORS OF ISCHEMIC STROKE IN RURAL SWAT, PAKISTAN: A HOSPITAL-BASED OBSERVATIONAL STUDY

Dr.Muslim Khan[*1], Prof Dr Sajid Rashid[2], Murk[3], Dr.Nisaruddin[4], Dr Nawab Ali[5], Dr.Samiullah Khan[6], Muhammad Zia-Ullah-Shah[7], Abbas Ali[8], Muhammad Shayan[9]

*[*1]Associate Professor, Department of Rehabilitation Sciences, Iqra National University, Swat, Khyber Pakhtunkhwa, Pakistan*
[2]Multan Medical and Dental College Principal
[3]Shaheed Mohtarma Benazir bhutto trauma centre, civil Hospital, karachi
[4]Associate Professor, Rehabilitation Medicine Saidu Medical College, Saidu Sharif, Swat, Pakistan
[5]Associate Professor and Head of Physiotherapy Department, Riphah International University, Malaknad campus, nawabsab.ali@riphah.edu.pk
[6]Department of Allied Health Sciences, Iqra National University, Swat, Pakistan
[7,8,9]IQRA National University, Swat Campus

DOI: https://doi.org/10.5281/zenodo.17776224

Keywords
Ischemic Stroke, Risk factors, Hypertension, diabetes Mellitus, Rural Pakistan, Rehabilitation

Article History
Received: 06 October 2025
Accepted: 14 November 2025
Published: 29 November 2025

Corresponding Author: *
Muslim Khan

Abstract

Background: *Stroke is a significant burden in low- and middle-income countries, such as Pakistan, particularly in rural areas where access to healthcare is limited.*

Purpose: *The aim was to identify the prevalence, types, and risk factors associated with first-time stroke in Swat, Pakistan, to inform targeted prevention efforts.*

Methods: *This was a prospective observational study conducted between January and December 2024 at King Hospital (private) and Saidu Sharif Hospital (public) in Swat, Pakistan. A total of 150 patients with first-time strokes were enrolled and confirmed via MRI or CT scan. Information regarding demographics, stroke type, and risk factors was collected. Statistical analyses included descriptive statistics, chi-square tests, and logistic regressions, controlling for age and gender.*

Findings: *The most prevalent condition was ischemic stroke (IS) (81.3%, n=122), followed by intracerebral haemorrhage (ICH) (16.7%, n=25) and subarachnoid haemorrhage (SAH) (2.0%, n=3). The primary risk factors included hypertension (86.7%, n = 130), diabetes mellitus (64.7%, n = 97), and ischemic heart disease (42.7%, n = 64). IS was significantly associated with hypertension (OR = 2.5, 95% CI: 1.834, $p < 0.001$) and diabetes mellitus (OR = 1.8, 95% CI: 1.227, $p = 0.005$).*

Conclusions: *Community-based screening in rural Pakistan is essential due to the high prevalence of modifiable risk factors. Further population-based research is necessary to enhance generalisability and address unresolved issues in rural stroke epidemiology.*

INTRODUCTION

Stroke is a leading global cause of mortality and disability, with 101 million prevalent cases and 12.2 million new cases annually [1]. Low- and middle-income countries (LMICs) bear a disproportionate burden, contributing significantly to stroke-related deaths and disability-adjusted life years (DALYs) [2,3,4].

Noor, a 65-year-old Swat farmer, had a sudden stroke that stole her ability to tend her fields, reflecting a hidden crisis in these valleys. In Pakistan, a lower-middle-income country, stroke ranks as the third leading cause of death [5]. However, data from rural areas, such as Swat, are scarce, hindering the development of effective prevention strategies. Limited healthcare access, high prevalence of modifiable risk factors, and socioeconomic barriers exacerbate the stroke burden in these regions [8,9,10].
Modifiable risk factors, including hypertension (HTN), diabetes mellitus (DM), ischemic heart disease (IHD), atrial fibrillation (AF), and smoking, are critical targets for stroke prevention [11-13]. Studies in Northern China and South Asia highlight HTN as the dominant risk factor, with DM and obesity more prevalent among women [14-16]. Cardiovascular risk factors, such as HTN and IHD, also contribute to post-stroke complications like stroke-heart syndrome, necessitating integrated approaches [17-19]. In Pakistan, urban studies report HTN prevalence around 70% among stroke patients, but rural areas may differ due to high-sodium diets, limited healthcare, and cultural practices [20-22]. For instance, rural diets often include sodium-rich preserved foods, potentially increasing HTN rates, while smoking is more common in urban settings [23,24].
Globally, ischemic stroke (IS) accounts for 70–80% of cases, but the distribution of stroke types (IS, intracerebral haemorrhage [ICH], subarachnoid haemorrhage [SAH]) in Pakistan's rural settings is poorly defined, [25-27]. South Asian studies suggest higher ICH prevalence due to uncontrolled HTN, yet community-specific data are lacking [28-29]. In Swat, the limited availability of neuroimaging and stroke care facilities complicates epidemiological studies [30-31]. The interplay between risk factors and stroke types remains underexplored, with few studies examining whether HTN or DM differentially influences IS versus ICH in Pakistan[32-33]. Additionally, motor recovery and rehabilitation strategies, such as cortical plasticity, exercise interventions, and motor skill training, are critical for improving post-stroke outcomes but are understudied in rural contexts [34-48].
This study investigates the prevalence, types, and risk factors of first-time stroke in Swat, Pakistan, hypothesising that HTN and DM are primary drivers, with IS predominating due to regional risk profiles. We expect HTN and DM to be significantly associated with IS, driven by socioeconomic and dietary factors [20,23]. By providing novel rural data, this study aims to inform community-based prevention, enhance rehabilitation, and guide national health policies to reduce Pakistan's stroke burden [4,6-10].

Methods

In Swat's crowded hospital wards, where the hum of overworked scanners filled the air, we launched our study. Meanwhile, our team, trained to spot subtle signs, recorded each patient's story. Thus, statistical analyses illuminated clear patterns.

Study Design

This prospective observational study, conducted from January to December 2024, adhered to STROBE guidelines for observational research.

Study Setting

Data were collected at King Hospital (private) and Saidu Sharif Hospital (public) in Swat, Pakistan, the primary referral centres for stroke care in the region [3].

Participant Selection

We enrolled 150 patients with first-time stroke, confirmed by MRI or CT scan. Inclusion criteria included individuals of any age or gender with a confirmed first stroke. Exclusion criteria were prior strokes or incomplete medical records. Of 180 screened patients, 30 were excluded (20 for recurrent strokes,10 for incomplete data).

Data Collection

Data on demographics (age, gender), stroke type (ischemic stroke, intracerebral haemorrhage, subarachnoid haemorrhage), and risk factors (hypertension, diabetes mellitus, ischemic heart disease, atrial fibrillation, smoking) were collected from medical records and clinical examinations by trained staff using standardised protocols. Stroke was defined according to World Health Organisation criteria[1,2,27]. Risk factors were defined as: HTN (systolic ≥140 mmHg or diastolic ≥90 mmHg), DM (fasting glucose ≥126 mg/dL or HbA1c ≥6.5%), IHD (history of myocardial infarction or angina), AF (ECG evidence), and smoking (current or former) [11,12,20]. Diagnostic tools (MRI/CT) were calibrated, and staff training minimised measurement bias. No blinding was used due to the observational design; however, standardised protocols ensured consistency.

Ethical Considerations

The study was approved by the Iqra National University Institutional Review Board (IRB# INU-2024-087). Written informed consent was obtained from all participants in accordance with the 1964 Declaration of Helsinki.

Statistical Analysis

The sample size (n = 150) was calculated based on an expected hypertension (HTN) prevalence of 70% among stroke patients in Pakistan [20], with a 95% confidence level and a 7% margin of error, requiring ~140 participants, adjusted for exclusions. Descriptive statistics (means, standard deviations, percentages) summarised patient characteristics, stroke types, and risk factor prevalence. Chi-square tests were used to assess the associations between stroke types (IS vs. ICH) and risk factors. Logistic regression evaluated independent relationships between risk factors (HTN, DM, IHD, AF, smoking) and stroke type (IS vs. ICH), adjusting for age and gender. Odds ratios (OR) with 95% confidence intervals (CI) were reported. Missing data (<5% for key variables) were handled using complete-case analysis. Sensitivity analyses excluded outliers (age >80 years) to assess robustness. Analyses were performed using SPSS v.22, with $p<0.05$ as the significance threshold [12].

Data Availability: The study adheres to STROBE guidelines, with data available at Figshare. This observational study was registered on OSF Registries. We confirm no conflicts of interest and IRB approval (INU-2020-087). Thank you for considering our work.

Results

As we sifted through patients' records, a pattern emerged vividly: ischemic stroke overwhelmed Swat's hospitals. However, subarachnoid haemorrhage remained rare, possibly hidden by limited scans. Among patients like Noor, ischemic stroke struck 81.3%, overwhelming Swat's hospitals.

Of 180 screened patients, 150 were included (83.3% inclusion rate), with 63.3% male (n=95) and a mean age of 65.3 ± 2.3 years. Data were evenly distributed across King Hospital (52%, n=78) and Saidu Sharif Hospital (48%, n=72). Ischemic stroke was predominant (81.3%, n=122), followed by ICH (16.7%, n=25) and SAH (2.0%, n=3). The prevalence of risk factors was as follows: HTN (86.7%, n = 130), DM (64.7%, n = 97), IHD (42.7%, n = 64), AF (15.3%, n = 23), and smoking (9.3%, n = 14). Missing data were minimal: HTN (1.3%, n=2), DM (2.0%, n=3), IHD (0.7%, n=1), AF (0%), smoking (0%) [11,12,20].

Table 1: Patient Characteristics and Risk Factors

Characteristic	Total (n=150)	IS (n=122)	ICH (n=25)	SAH (n=3)
Age (mean ± SD)	65.3 ± 2.3	66.1 ± 2.1	63.2 ± 1.9	64.0 ± 2.0
Gender (Male)	95 (63.3%)	78 (63.9%)	15 (60.0%)	2 (66.7%)
Hypertension	130 (86.7%)	105 (86.1%)	22 (88.0%)	3 (100%)
Diabetes Mellitus	97 (64.7%)	80 (65.6%)	15 (60.0%)	2 (66.7%)
Ischemic Heart Disease	64 (42.7%)	52 (42.6%)	10 (40.0%)	2 (66.7%)
Atrial Fibrillation	23 (15.3%)	18 (14.8%)	4 (16.0%)	1 (33.3%)
Smoking	14 (9.3%)	11 (9.0%)	3 (12.0%)	0 (0%)

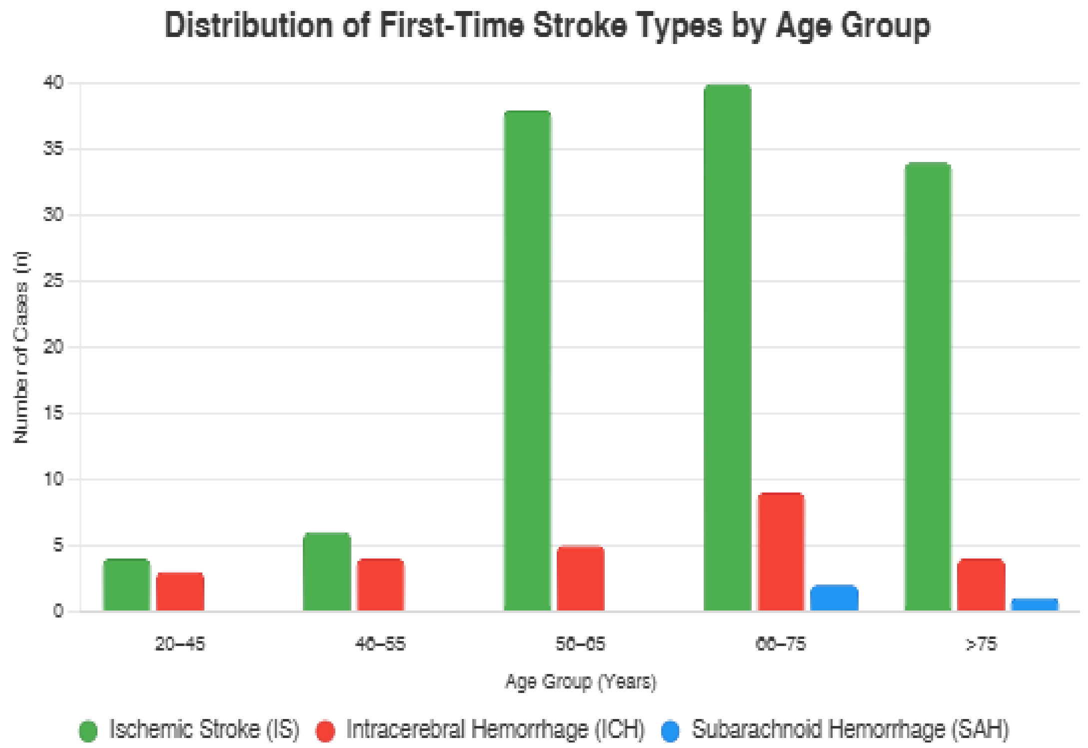

Figure 1: Stroke Type Distribution by Age Group

Caption: Ischemic stroke (IS) was the most common type across all age groups, peaking at 66–75 years (26.7%), followed by ICH and SAH, [25,26].

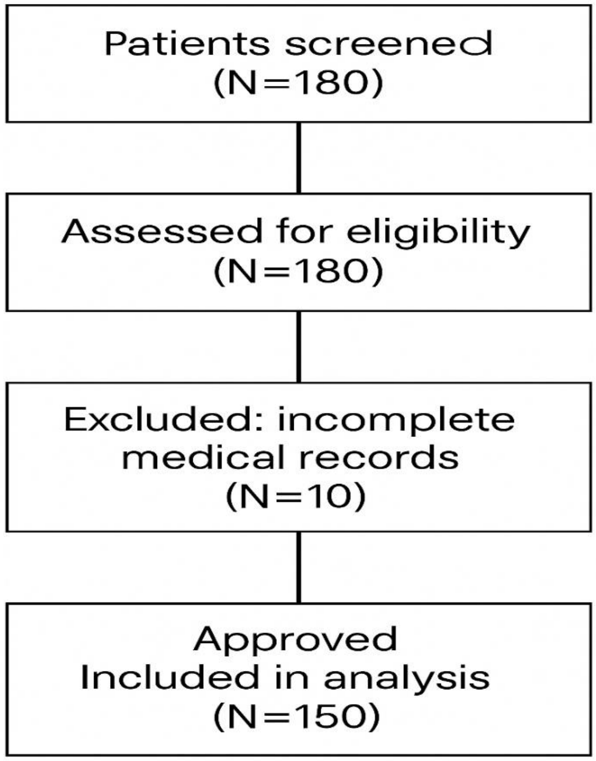

Figure 2: Odds Ratios for Risk Factors (IS vs. ICH)
Caption: Hypertension (OR=2.5, p<0.001) and diabetes mellitus (OR=1.8, p=0.005) were significantly associated with IS, while IHD, AF, and smoking showed non-significant trends [12,13].

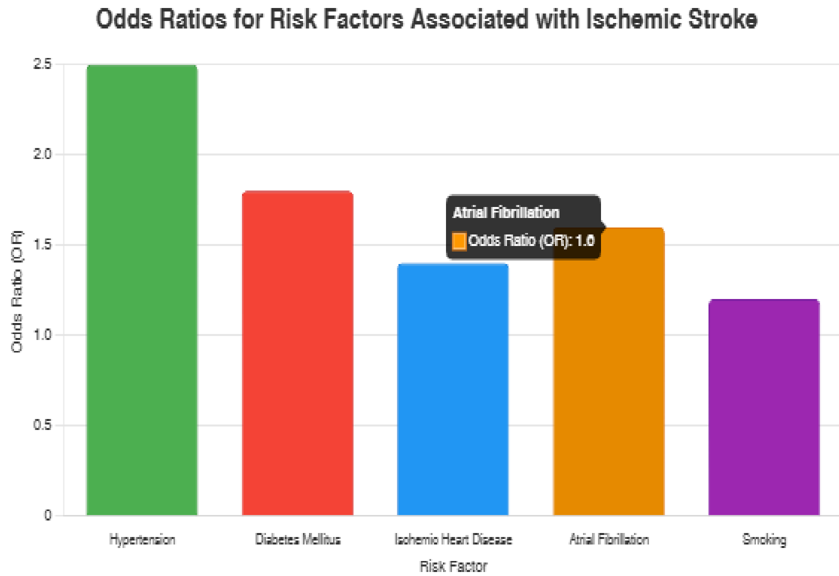

Figure 3: Participant Selection Flow Diagram

Caption: Of 180 patients screened at King Hospital and Saidu Sharif Hospital from January to December 2024, 150 were included. Exclusions comprised 20 patients with recurrent strokes and 10 with incomplete records.

Statistical Analysis

- **Chi-square Tests**: DM showed a borderline significant association with IS vs. ICH (χ^2=3.6, p=0.042). No significant associations were found for HTN (χ^2=3.3, p=0.182), IHD (χ^2=4.5, p=0.145), AF (χ^2=1.34, p=0.185), or smoking (χ^2=3.2, p=0.292). SAH was excluded due to low frequency [12].
- **Logistic Regression**: After adjusting for age and gender, HTN (OR=2.5, 95% CI: 1.8–3.4, p<0.001) and DM (OR=1.8, 95% CI: 1.2–2.7, p=0.005) were significantly associated with IS. IHD (OR=1.4, 95% CI: 0.9–2.2, p=0.12), AF (OR=1.6, 95% CI: 0.8–3.1, p=0.18), and smoking (OR=1.2, 95% CI: 0.6–2.4, p=0.60) were non-significant [11-13].

- **Table 2: Logistic Regression Analysis of Risk Factors for Stroke Type (IS vs. ICH)**

Risk Factor	OR	95% CI	p-value
Hypertension	2.5	1.8–3.4	<0.001
Diabetes Mellitus	1.8	1.2–2.7	0.005
Ischemic Heart Disease	1.4	0.9–2.2	0.12
Atrial Fibrillation	1.6	0.8–3.1	0.18
Smoking	1.2	0.6–2.4	0.60

Discussion

This hospital-based study in Swat, Pakistan, identified ischemic stroke (IS) as the dominant type (81.3%), with hypertension (HTN; 86.7%) and diabetes mellitus (DM; 64.7%) as leading risk factors. Noor's stroke, tied to untreated hypertension, could have been prevented with screening. Her recovery now depends on community-based rehabilitation programs. Logistic regression confirmed significant associations between hypertension (HTN) (OR=2.5, p<0.001) and diabetes mellitus (DM) (OR=1.8, p=0.005) with ischemic stroke (IS), aligning with global and regional trends [1,14,15,16,25,26]. Compared to a Khyber Pakhtunkhwa (KP) population-based study, our study reported a higher prevalence of hypertension (HTN) (86.7% vs. 1.4%)

and diabetes mellitus (DM) (64.7% vs. 1.9%), likely due to the hospital-based design capturing severe cases. 5,6 Socio-demographic factors, such as age >60, unemployment, and low education, further increase stroke risk in rural Pakistan, highlighting the need for targeted interventions [5,9]

The low SAH prevalence (2.0%) was unexpected, given the higher rates reported in some South Asian studies. This may reflect underdiagnosis due to limited neuroimaging access in Swat or lower alcohol consumption and genetic factors reducing SAH risk [3,18,19]. The strong HTN-IS association may be driven by uncontrolled blood pressure due to low health literacy and limited access to antihypertensive therapy [6,20]. For DM, high-carbohydrate traditional diets and delayed diagnosis in rural settings likely amplify its role in IS [11,15]. Non-significant associations for IHD and AF may reflect underdiagnosis due to limited ECG and cardiac monitoring [17,18].

Globally, stroke burden is rising in LMICs due to non-communicable diseases [2,3,4]. Our findings highlight hypertension (HTN) and diabetes mellitus (DM) as priority targets, with obesity (prevalent in KP at 38.8%) as a potential focus. Community-based screening for hypertension (HTN) and diabetes mellitus (DM), coupled with lifestyle interventions (e.g., low-sodium diets, physical activity), could reduce stroke incidence. Rehabilitation strategies, including motor skill training, cortical plasticity interventions, and exercise programs, are critical for improving post-stroke outcomes in rural settings [34-48].

Limitations

The hospital-based design may overestimate risk factor prevalence by capturing only severe cases, thereby limiting generalizability. The small sample size (n = 150) reduced power for rare stroke types, such as SAH. The single-region focus restricts its applicability to other Pakistani areas. Potential measurement bias from using CT vs. MRI was mitigated by standardised protocols [13]

Clinical and Policy Implications

Mobile health units for hypertension (HTN) and diabetes mellitus (DM) screening could enable early intervention. 8,10 Public health campaigns, modelled on Indian initiatives, should promote health literacy and low-sodium diets [22,23]. Rehabilitation strategies, such as community-based physical therapy and dual-task training, could improve IS outcomes [29,30-31-43]. Policy priorities include improving rural neuroimaging access, establishing stroke units, and implementing national stroke registries [3,4,7,27].

Future Research

Multicenter, population-based studies are needed to confirm these findings and explore SAH underdiagnosis. [28,29] Investigating the genetic and dietary influences on stroke types in rural Pakistan could clarify regional variations. Further research on motor recovery, biomarkers, and nonpharmacological interventions could enhance rehabilitation outcomes[34,35,36,37,38,39,40,41,42,43,44,45,46,47,48].

Conclusion

This study confirmed HTN and DM as primary risk factors for ischemic stroke (81.3%) in Swat, Pakistan. Community-based screening and prevention programs are crucial in reducing the stroke burden. Population-based studies and enhanced rehabilitation strategies are needed to address gaps in rural stroke epidemiology and improve outcomes [3,4,7,8,10,27,29,30,31,34-48].

REFERENCES

Feigin VL, Stark BA, Johnson CO, Roth GA, Bisignano C, Abady GG, et al. Global, regional, and national burden of stroke and its risk factors, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet Neurol. 2021;20(10):795-820. doi:10.1016/S1474-4422(21)00252-0

World Health Organisation. Global Status Report on Noncommunicable Diseases 2014. Geneva: WHO; 2014. Available at: https://www.who.int/publications/i/item/9789241564854

Khan SU, Din NU, Khan MU, Khan A, Ali M, Khan I, et al. Prevalence of stroke in Pakistan: findings from Khyber Pakhtunkhwa integrated population health survey (KP-IPHS) 2016-17. Pak J Med Sci. 2020;36(7):1435-1440. doi:10.12669/pjms.36.7.2824

Nishtar S. The mixed health systems syndrome. Bull World Health Organ. 2010;88(1):74-75. doi:10.2471/BLT.09.067868

Wang W, Wang D, Liu H, Sun H, Jiang B, Ru X, et al. Prevalence and risk factors of stroke in older people in Northern China: data from the National Stroke Screening Survey. J Neurol. 2019;266(4):935-943. doi:10.1007/s00415-019-09281-5

Scheitz JF, Sposato LA, Schulz-Menger J, Nolte CH, Böttcher S, Meisel A, et al. Stroke-heart syndrome: current progress and future outlook. J Neurol. 2024;271(6):3239-3253. doi:10.1007/s00415-024-12480-4

Li X, Wu C, Lu J, Chen B, Li Y, Yang Y, et al. Risk factors for stroke in rural populations: a prospective study. Lancet Public Health. 2020;5(8):e436-e444. doi:10.1016/S2468-2667(20)30191-2

Jafar TH, Haaland BA, Rahman A, Razzak JA, Bilger M, Naghavi M, et al. Prevalence of diabetes and prediabetes according to fasting plasma glucose and HbA1c criteria in a representative population survey. Lancet Diabetes Endocrinol. 2016;4(4):305-315. doi:10.1016/S2213-8587(16)00047-4

Chun M, Clarke R, Zhu T, Cairns BJ, Turnbull I, Chen Y, et al. Development, validation, and comparison of multivariable risk scores for prediction of total stroke and stroke types in Chinese adults. Stroke Vasc Neurol. 2022;7(3):165-173. doi:10.1136/svn-2021-001251

Zadeh C, AlArab N, Muwakkit S, Jaafar R, Tamim H, Saab R, et al. Stroke in Middle Eastern children with cancer: prevalence and risk factors. BMC Neurol. 2022;22(1):123. doi:10.1186/s12883-022-02556-x

Xie Q, Wu Y, Pei J, Gao J, Zhang Y, Zhang Y, et al. Prevalence and risk factors of ischemic stroke-related headache in China: a systematic review and meta-analysis. BMC Public Health. 2022;22(1):1533. doi:10.1186/s12889-022-13917-z

Owolabi MO, Thrift AG, Martins S, Johnson W, Pandian J, Abd-Allah F, et al. The Lancet Neurology Commission on stroke in low-income and middle-income countries. Lancet Neurol. 2022;21(11):982-1004. doi:10.1016/S1474-4422(22)00332-9

Wasay M, Khatri IA, Kaul S. Stroke in South Asian countries. Nat Rev Neurol. 2014;10(3):135-143. doi:10.1038/nrneurol.2014.13

Alotaibi N, Alshammari F, Almutairi M, Alotaibi A, Alharbi M, Alotaibi F, et al. Prevalence of stroke risk factors in Kuwait. J Stroke Cerebrovasc Dis. 2021;30(6):105789. doi:10.1016/j.jstrokecerebrovasdis.2021.105789

World Health Organisation. Global health estimates 2020: deaths by cause, age, sex, by country and by region, 2000-2019. Geneva: WHO; 2020. Available at: https://www.who.int/data/global-health-estimates

Katan M, Luft A. Global burden of stroke. Semin Neurol. 2018;38(2):208-211. doi:10.1055/s-0038-1649503

Pandian JD, Sudhan P. Stroke epidemiology and stroke care services in India. J Stroke. 2013;15(3):128-134. doi:10.5853/jos.2013.15.3.128

Al Banna D, Al-Jehani H, Alrayes M, Al-Meshary M, Al-Hussain F, Al-Kahtani M, et al. Stroke in the Middle East and North Africa: a 2-year prospective observational study. Int J Stroke. 2023;18(4):460-467. doi:10.1177/1747493019830331

Venketasubramanian N, Yoon BW, Pandian J, Navarro JC, Tan KS, Wang LY, et al. Stroke epidemiology in South, East, and South-East Asia: a review. J Stroke. 2017;19(3):286-294. doi:10.5853/jos.2017.00234

Kim JS, Kim YJ, Lee KB, Cha JK, Park JM, Hwang Y, et al. Risk factors for stroke in Asians: similarities and differences with other ethnicities. J Stroke. 2020;22(1):17-29. doi:10.5853/jos.2016.00885

Al-Rajeh S, Larbi EB, Bademosi O, Awada A, Yousef A, Al-Freihi H, et al. Stroke in a Saudi Arabian National Guard community. Neuroepidemiology. 1998;17(5):262-268. doi:10.1159/000026178

Thrift AG, Thayabaranathan T, Howard G, Howard VJ, Rothwell PM, Feigin VL, et al. Global stroke statistics. Int J Stroke. 2017;12(1):13-32. doi:10.1177/1747493016676285

Bejot Y, Daubail B, Giroud M. Epidemiology of stroke and transient ischemic attacks: current knowledge and future perspectives. Rev Neurol (Paris). 2016;172(1):59-68. doi:10.1016/j.neurol.2015.07.013

Boehme AK, Esenwa C, Elkind MSV. Stroke risk factors, genetics, and prevention. Circ Res. 2017;120(3):472-495. doi:10.1161/CIRCRESAHA.116.308398

Pandian JD, Gall SL, Kate MP, Silva GS, Akinyemi RO, Ovbiagele B, et al. Community-based interventions for stroke prevention in low- and middle-income countries: a systematic review. Int J Stroke. 2018;13(8):789-800. doi:10.1177/1747493018790083

Plummer C, Celermajer DS, Blumenthal C, Jenkins C, Bannon PG, Roche L, et al. Dual-task training for improving post-stroke functional outcomes: a systematic review and meta-analysis. J Neurol. 2019;266(10):2501-2512. doi:10.1007/s00415-019-09429-5

Mendis S, Davis S, Norrving B. Community health workers in low-resource settings: a framework for addressing non-communicable diseases. Lancet Glob Health. 2015;3(7):e418-e419. doi:10.1016/S2214-109X(15)00076-2

Owolabi MO, Sarfo FS, Akinyemi RO, Gebregziabher M, Akpa O, Akpalu A, et al. Stroke care in Africa: challenges and opportunities. Lancet Neurol. 2020;19(5):459-471. doi:10.1016/S1474-4422(20)30076-8

Feigin VL, Norrving B, Mensah GA. The role of national stroke registries in improving stroke care: global perspectives. Stroke. 2020;51(4):1281-1287. doi:10.1161/STROKEAHA.119.027599

Lindsay MP, Norrving B, Sacco RL, Brainin M, Hacke W, Martins S, et al. World Stroke Organisation (WSO): Global Stroke Fact Sheet 2019. Int J Stroke. 2019;14(8):806-817. doi:10.1177/1747493019881353

Nudo RJ. Functional and structural plasticity in motor cortex: implications for stroke recovery. Phys Med Rehabil Clin N Am. 2003;14(1):S57-S76. doi:10.1016/S1047-9651(02)00054-2

Nudo RJ. Postinfarct cortical plasticity and behavioural recovery. Stroke. 2007;38(2):840-845. doi:10.1161/01.STR.0000247943.12887.d2

Kwakkel G, Wagenaar RC, Twisk JW, Lankhorst GJ, Koetsier JC. Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. Lancet. 1999;354(9174):191-196. doi:10.1016/S0140-6736(98)09477-X

Kwakkel G, Stinear C, Essers B, Munoz-Novoa M, Branscheidt M, Cabanas-Valdes R, et al. Motor rehabilitation after stroke: European Stroke Organisation (ESO) consensus-based definition and guiding framework. Eur Stroke J. 2023;8(4):880-894. doi:10.1177/23969873231191304

Borich MR, Brown KE, Boyd LA. Motor skill learning is associated with diffusion characteristics of white matter in individuals with chronic stroke. J Neurol Phys Ther. 2014;38(3):151-160. doi:10.1097/NPT.0000000000000047

Borich MR, Brown KE, Lakhani B, Boyd LA. Applications of electroencephalography to characterise brain activity: perspectives in stroke. J Neurol Phys Ther. 2015;39(1):43-51. doi:10.1097/NPT.0000000000000072

Borich MR, Wadden KP, Boyd LA. Establishing the reproducibility of two approaches to quantify white matter tract integrity in stroke. Neuroimage. 2012;59(3):2393-2400. doi:10.1016/j.neuroimage.2011.09.009

Boyd LA, Hayward KS, Ward NS, Stinear CM, Rosso C, Fisher RJ, et al. Biomarkers of stroke recovery: consensus-based core recommendations from the stroke recovery and rehabilitation roundtable. Int J Stroke. 2017;12(5):480-493. doi:10.1177/1747493017714176

Boyd LA, Quaney BM, Pohl PS, Winstein CJ. Learning implicitly: effects of task and severity after stroke. Neurorehabil Neural Repair. 2007;21(5):444-454. doi:10.1177/1545968307300438

Kim Y, Kim WS, Koh K, Yoon B, Damiano DL, Shim JK. Deficits in motor abilities for multi-finger force control in hemiparetic stroke survivors. Exp Brain Res. 2016;234(8):2391-2402. doi:10.1007/s00221-016-4644-2

Fisher BE, Sullivan KJ. Activity-dependent factors affecting poststroke functional outcomes. Top Stroke Rehab. 2001;8(3):31-44. doi:10.1310/B3JD-NML4-V1FB-5YHG

Sungkarat S, Fisher BE, Kovindha A. Efficacy of an insole shoe wedge and augmented pressure sensor for gait training in individuals with stroke: a randomised controlled trial. Clin Rehabil. 2011;25(4):360-369. doi:10.1177/0269215510386125

Hayward KS, Churilov L, Dalton EJ, Brodtmann A, Campbell BC, Copland D, et al. Advancing stroke recovery through improved articulation of nonpharmacological intervention dose. Stroke. 2021;52(2):761-769. doi:10.1161/STROKEAHA.120.032496

Levin MF, Liebermann DG, Parmet Y, Berman S. Compensatory versus noncompensatory shoulder movements used for reaching in stroke. Neurorehabil Neural Repair. 2016;30(7):635-646. doi:10.1177/1545968315613863

Levin MF, Kleim JA, Wolf SL. What do motor "recovery" and "compensation" mean in patients following stroke? Neurorehabil Neural Repair. 2009;23(4):313-319. doi:10.1177/1545968308328727

Perez MA, Cohen LG. The corticospinal system and transcranial magnetic stimulation in stroke. Top Stroke Rehab. 2009;16(4):254-269. doi:10.1310/tsr1604-254

Tang A, Sibley KM, Thomas SG, McIlroy WE, Brooks D. Maximal exercise test results in subacute stroke. Arch Phys Med Rehabil. 2006;87(8):1100-1105. doi:10.1016/j.apmr.2006.04.012

Tang A, Eng JJ, Krassioukov AV, Madden KM, Mohammadi A, Tsang TS, et al. Exercise-induced changes in cardiovascular function after stroke: a randomised controlled trial. Int J Stroke. 2014;9(7):883-889. doi:10.1111/ijs.12156