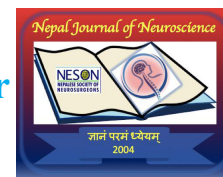


Bridging The Neurovascular Care Gap In A Small Island Nation: Five-Year Experience From The First Dedicated Neuroendovascular Center In The Maldives



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Abstract

Introduction: Neuroendovascular therapy has significantly advanced the management of cerebrovascular disorders; however, access to specialized neurointerventional services remains limited in geographically isolated and resource-constrained healthcare systems. The Maldives established its first dedicated neuroendovascular center in 2019. This study describes the five-year development of the service and evaluates patient characteristics, disease spectrum, procedural patterns, and temporal growth of neurovascular care delivery. **Materials & Methods:** A single-center retrospective observational cohort study was conducted at Abdul Rahman Dhon Kaleyfaanu (ADK) Hospital, Malé, Maldives, including all consecutive patients undergoing diagnostic or therapeutic neuroendovascular procedures between January 2019 and October 2023. Data were obtained through retrospective review of the institutional neurovascular database, cerebral angiography reports, procedural records, and electronic medical records. Demographic characteristics, diagnostic categories, procedure types, and annual procedural volumes were analyzed. Descriptive statistics and inferential analyses, including chi-square tests, independent-samples t-tests, one-way analysis of variance, and linear regression analysis, were performed.

Results: A total of 321 neuroendovascular procedures were included. The mean age of patients was 51.8 ± 15.7 years, with an equal distribution of males and females. Cerebral aneurysms (36.8%) and ischemic cerebrovascular disease (32.1%) were the most common indications. Diagnostic cerebral angiography accounted for 72.0% of procedures, while therapeutic interventions comprised 28.0%, including flow diversion (6.2%), mechanical thrombectomy (4.4%), and intrasaccular aneurysm treatment (3.7%). Annual procedural volume increased from 2 procedures in 2019 to 139 procedures in 2023. Linear regression demonstrated a significant upward trend in procedural volume (coefficient of determination = 0.89, $P = 0.016$). Significant associations were observed between diagnostic categories and patient sex ($P < 0.001$) and age group ($P < 0.001$).

Conclusion: Establishment of a dedicated neuroendovascular center in the Maldives resulted in rapid expansion of comprehensive neurovascular services and reduced dependence on overseas referral. This experience demonstrates that advanced neurointerventional programs can be successfully developed in small island healthcare systems through coordinated infrastructure development, specialist training, multidisciplinary collaboration, and sustainable healthcare financing.

Keywords: Neuroendovascular Procedures; Cerebrovascular Disorders; Intracranial Aneurysm; Stroke; Digital Subtraction Angiography; Health Services Accessibility

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Introduction

Cerebrovascular diseases remain major causes of global mortality, disability, and healthcare burden. Stroke, intracranial aneurysms, arteriovenous malformations, and other vascular disorders contribute substantially to neurological morbidity worldwide^{1,2}. Advances in neuroendovascular surgery have transformed management through minimally invasive diagnostic and therapeutic approaches. Digital subtraction angiography remains the reference standard for cerebrovascular imaging, while mechanical thrombectomy, flow diversion, intrasaccular devices, and embolization techniques have expanded treatment options for complex lesions.³⁻¹³

Despite these advances, access to neuroendovascular care remains unequal, particularly in low-resource and geographically isolated healthcare systems due to limited specialist availability, restricted angiographic facilities, financial barriers, and challenges in maintaining expertise.¹⁶⁻¹⁹

The Maldives, an archipelagic nation of approximately 1,190 islands, faces unique challenges in providing specialized medical services due to geographic dispersion.^{20, 21}

Neurosurgical services developed recently, with continuous care established in 2014, the first neurointerventional procedure in 2017, and a dedicated 24-hour neuroendovascular service

Methods

Study Design and Setting

This retrospective single-center observational cohort study was conducted using the neurovascular registry of Abdul Rahman Dhon Kaleyfaanu (ADK) Hospital, Malé, Maldives, the country's first dedicated neuroendovascular center. All consecutive patients undergoing diagnostic or therapeutic neuroendovascular procedures between January 2019 and October 2023 were included.

The neuroendovascular program was established in 2019 after progressive development of neurosurgical services, beginning with continuous neurosurgical care in 2014 and the first neurointerventional procedure in 2017. The service operates through a dedicated biplane digital subtraction angiography suite with multidisciplinary support, specialist expertise, structured referral pathways, and national health insurance coverage.

Study Population and Data Collection

All 321 consecutive neuroendovascular procedures performed during the study period were included. Data were retrospectively collected from the neurovascular database, angiography reports, procedural records, and electronic medical records. Variables analyzed included patient demographics, diagnosis category, procedure type, and annual procedural volume.

Diagnostic and Procedure Classification

Neurovascular diagnoses were classified as cerebral aneurysm, ischemic cerebrovascular disease, arteriovenous malformation/dural arteriovenous fistula, hemorrhagic cerebrovascular disease, venous disorders, tumor-related vascular lesions, and other conditions.

Procedures were categorized as diagnostic or therapeutic. Diagnostic procedures included cerebral digital subtraction angiography, while therapeutic interventions included flow diversion, aneurysm embolization, intrasaccular devices, mechanical thrombectomy, embolization procedures, arterial stenting, and other neuroendovascular treatments.

Outcome Measures and Statistical Analysis

Primary outcomes included demographic characteristics, diagnostic distribution, procedural profile, and annual service volume. Statistical analysis was performed using IBM SPSS Statistics (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean $\pm$ standard deviation or median with interquartile range, and categorical variables as frequencies and percentages. Associations were assessed using chi-square tests, group differences using t-tests and ANOVA, and annual procedural trends using linear regression. Statistical significance was defined as a two-sided P value <0.05 .

Results

Study Population

A total of 321 consecutive neuroendovascular procedures were analyzed (January 2019–October 2023). The mean age was 51.8 ± 15.7 years (median 54 years; IQR 37–64; range 11–84 years). (Table 1).

Table 1: Baseline demographic characteristics of the study population

Variable	Value
Total neuroendovascular procedures	321
Patients with available age data	320
Mean age $\pm$ SD (years)	51.8 ± 15.7
Median age (years)	54
Interquartile range (years)	37–64
Age range (years)	11–84
Male patients, n (%)	160 (49.8)
Female patients, n (%)	160 (49.8)

Most procedures were performed in middle-aged and older adults, with 68.9% of patients aged 41–80 years. Pediatric and very elderly patients accounted for 2.2% and 1.6%, respectively. (Table 2).

Table 2: Age distribution of patients undergoing neuroendovascular procedures

Age group	Number of procedures (%)
<18 years	7 (2.2)
18–40 years	55 (17.1)
41–60 years	110 (34.3)
61–80 years	111 (34.6)
>80 years	5 (1.6)
Missing age data	1 (0.3)
Total	321 (100)

Sex distribution was balanced, with 160 male (49.8%) and 160 female (49.8%) patients; sex was unavailable in one case (0.3%) (Table 3).

Table 3: Sex distribution of the study population

Sex	Number of procedures (%)
Male	160 (49.8)
Female	160 (49.8)
Missing	1 (0.3)
Total	321 (100)

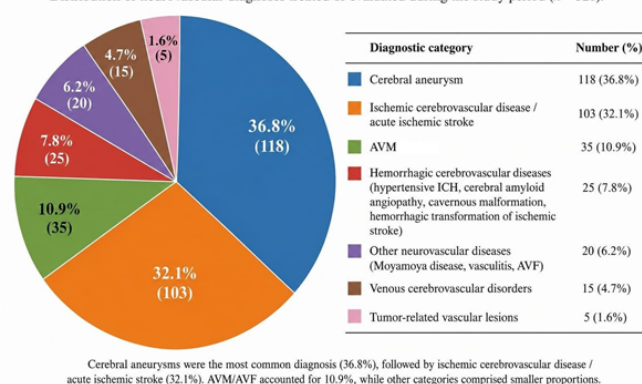
Distribution of Neurovascular Diagnoses

Cerebral aneurysms (36.8%) and ischemic cerebrovascular disease (32.1%) were the leading indications, comprising 68.9% of procedures. AVM/AVF (10.9%) and hemorrhagic disease (7.8%) were other common indications. (Table 4; Figure 1).

Table 4: Distribution of neurovascular diagnoses

Diagnostic category	Number of procedures (%)
Cerebral aneurysm	118 (36.8)
Ischemic cerebrovascular disease/ acute ischemic stroke	103 (32.1)
Arteriovenous malformation (AVM)	35 (10.9)
Hemorrhagic cerebrovascular disease (Hypertensive ICH, cerebral amyloid angiopathy, cavernous malformation, hemorrhagic transformation of ischemic stroke)	25 (7.8)
Other neurovascular conditions	20 (6.2)
Venous cerebrovascular disorders	15 (4.7)
Tumor-related vascular lesions	5 (1.6)
Total	321 (100)

Figure 1. Distribution of Neurovascular Diagnostic Categories
Distribution of neurovascular diagnoses treated or evaluated during the study period (n = 321).



Distribution of Neuroendovascular Procedures

A broad range of neuroendovascular procedures was performed, with diagnostic cerebral angiography being the most common (72.0%). Therapeutic procedures accounted for 28.0% of cases and included aneurysm treatment, thrombectomy, vascular malformation embolization, and tumor-related interventions. Flow diverter placement (6.2%), mechanical thrombectomy (4.4%), and intrasaccular aneurysm devices (3.7%) were the leading advanced interventions.

Other therapeutic procedures included:

- Middle meningeal artery embolization: 8 procedures (2.5%)
- Carotid artery stenting: 7 procedures (2.2%)
- AVM embolization: 6 procedures (1.9%)
- Intracranial internal carotid artery stenting: 4 procedures (1.2%)
- Tumor embolization: 3 procedures (0.9%)
- Other endovascular procedures: 16 procedures (5.0%)

(Table 5)

Table 5: Distribution of neuroendovascular procedures

Procedure type	Number of procedures (%)
Diagnostic cerebral angiography	231 (72.0)
Flow diverter placement	20 (6.2)
Mechanical thrombectomy	14 (4.4)
Intrasaccular aneurysm device placement	12 (3.7)
Middle meningeal artery embolization	8 (2.5)
Carotid artery stenting	7 (2.2)
AVM embolization	6 (1.9)
Intracranial internal carotid artery stenting	4 (1.2)
Tumor embolization	3 (0.9)
Other therapeutic neuroendovascular procedures	16 (5.0)
Total	321 (100)

Annual Growth of the Neuroendovascular Service

Neuroendovascular volume increased markedly after service establishment, rising from 2 procedures in 2019 to 139 procedures in the first 10 months of 2023, with major growth observed in 2022. (Table 6).

Table 6: Annual neuroendovascular procedural volume (2019–2023)

Year	Number of procedures	Percentage of total procedures (%)
2019	2	0.6
2020	11	3.4
2021	38	11.8
2022	131	40.8
2023*	139	43.3
Total	321	100

Overall, procedural activity increased approximately 70-fold between 2019 and 2023 (Figure 1). This increase coincided with expansion of institutional referral pathways, development of specialist expertise, increased availability of advanced neurointerventional procedures, and improved awareness among referring clinicians.

Temporal Trend Analysis

Linear regression showed a significant increase in annual procedural volume, with an estimated rise of 39.4 procedures/year ($R^2=0.89$, $P=0.016$), reflecting progressive service growth. (Figure 2).

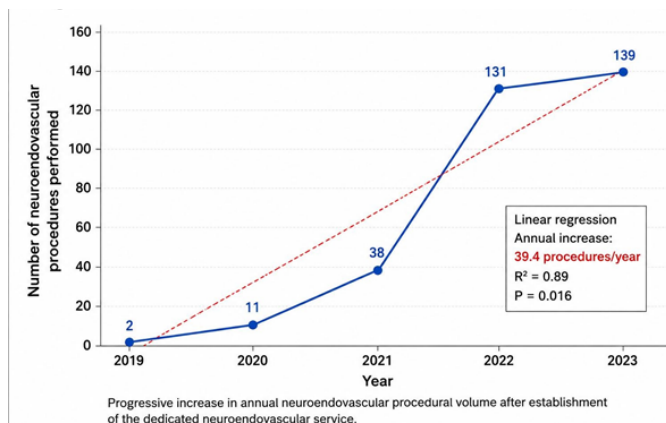


Figure : 2 Annual Growth of Neuroendovascular Procedural Volume (2019-2023)

Diagnostic and Therapeutic Procedures

Diagnostic cerebral angiography comprised 72.0% of procedures, while therapeutic interventions accounted for 28.0%. (Table 7A, 7B; Figure 3).

Table 7 A. Diagnostic and therapeutic procedure distribution

Procedure classification	Number of procedures (%)
Diagnostic cerebral angiography	231 (72.0)
Therapeutic neuroendovascular intervention	90 (28.0)
Total	321 (100)

Table 7 B. Therapeutic intervention categories

Therapeutic procedure	Number (%) of all procedures
Flow diversion	20 (6.2)
Mechanical thrombectomy	14 (4.4)
Intrasaccular device placement	12 (3.7)
Middle meningeal artery embolization	8 (2.5)
Carotid artery stenting	7 (2.2)
AVM embolization	6 (1.9)
Intracranial arterial stenting for Intracranial Atherosclerotic Disease (ICAD)	4 (1.2)
Tumor embolization	3 (0.9)
Other therapeutic interventions	16 (5.0)
Total therapeutic procedures	90 (28.0)

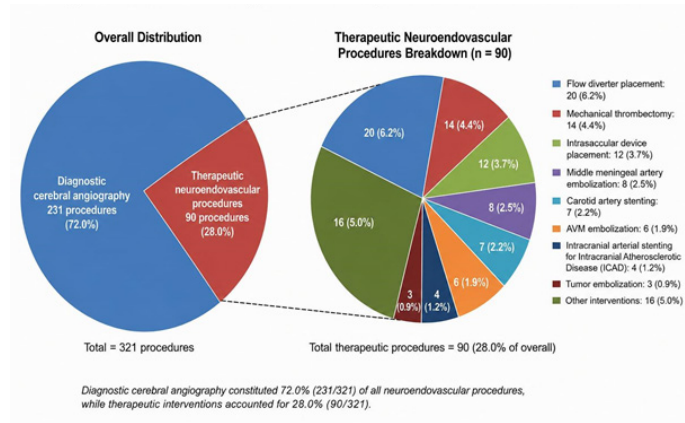


Figure : 2 Distribution of diagnostic and therapeutic neuroendovascular procedures

Early service activity was dominated by diagnostic angiography, with increasing therapeutic interventions as expertise and infrastructure developed. Procedures included flow diversion, thrombectomy, aneurysm treatment, stenting, AVM/AVF embolization, MMA embolization, and tumor embolization.

The increasing proportion of therapeutic procedures demonstrates the transition of the center from a predominantly diagnostic angiographic service into a comprehensive neurointerventional program capable of managing a broad spectrum of cerebrovascular disorders.

Inferential Statistical Analysis

Diagnosis was significantly associated with sex ($\chi^2=45.43$, $P<0.001$), with aneurysms/AVM/AVF more common in females and ischemic disease in males. Age was significantly associated with diagnostic categories ($\chi^2=87.12$, $P<0.001$), with younger patients having more vascular malformations and older patients more ischemic/atherosclerotic disease. Procedure type showed no association with age or sex. Males were older than females ($P=0.0045$), and mean age differed significantly across diagnostic groups (ANOVA $F=12.08$, $P<0.001$).

Table 8: Summary of inferential statistical analyses

Analysis	Statistical test	Result	P value
Diagnosis category vs sex	Chi-square test	$\chi^2 = 45.43$	<0.001
Diagnosis category vs age group	Chi-square test	$\chi^2 = 87.12$	<0.001
Procedure type vs sex	Chi-square test	$\chi^2 = 0.001$	1.00
Procedure type vs age group	Chi-square test	$\chi^2 = 3.74$	0.44
Mean age difference between male and female patients	Independent samples t-test	$t = 2.86$	0.0045
Mean age difference between diagnostic and therapeutic procedures	Independent samples t-test	$t = -1.92$	0.056
Mean age difference among diagnostic categories	One-way ANOVA	$F = 12.08$	<0.001
Annual procedural volume trend	Linear regression	$R^2 = 0.89$; annual increase = 39.4 procedures/year	0.016

Discussion

Development of Neuroendovascular Services in a Small Island Healthcare System

This study demonstrates the feasibility of establishing a comprehensive neuroendovascular service within a geographically isolated island healthcare system. During the five-year study period, 321 neuroendovascular procedures were performed, reflecting the transition from an initial diagnostic angiography service to a center capable of delivering advanced therapeutic interventions.

The major findings include the predominance of cerebral aneurysms and ischemic cerebrovascular disease, rapid growth in procedural volume after establishment of dedicated infrastructure, successful implementation of advanced endovascular procedures, and significant demographic differences among neurovascular disease categories.

Establishing neuroendovascular capability requires advanced imaging infrastructure, specialized devices, trained operators, multidisciplinary collaboration, and institutional commitment. Continuous availability of angiography facilities, anesthesia support, intensive care resources, emergency pathways, and coordinated stroke teams remains essential but challenging in healthcare systems with limited specialist workforce and procedural volume.^{16–18, 24, 25}

In geographically isolated healthcare systems, patients with complex cerebrovascular disorders often require overseas referral, which may result in treatment delays, increased healthcare expenditure, logistical challenges, and fragmented continuity of care.^{17–19, 21, 22} The Maldives presents additional challenges due to its dispersed island population. Development of local neuroendovascular capability therefore represents an important advancement in improving accessibility and reducing dependence on international referral.

The increase in annual procedural volume from 2 procedures in 2019 to 139 procedures in 2023 demonstrates rapid service maturation. Similar experiences from developing healthcare systems indicate that locally established neurointerventional programs can improve access to time-sensitive therapies when supported by infrastructure, training, and multidisciplinary organization.^{16–18, 26, 29}

Establishment and Sustainability of Neurovascular Care in the Maldives

The development of neuroendovascular services in the Maldives resulted from progressive expansion of neurosurgical capability, specialist expertise, institutional investment, and national healthcare support. Continuous neurosurgical services were established in 2014, followed by the first neurointerventional procedure in 2017 with visiting specialist support and establishment of a dedicated 24-hour service in 2019.

Successful neurointerventional programs require more than technological acquisition; they depend on workforce development, structured training, multidisciplinary collaboration, emergency protocols, and continuous quality improvement.^{24, 25} The availability of a dedicated biplane angiography suite at ADK Hospital enabled management of a broad spectrum of vascular conditions, including aneurysms, stroke, arteriovenous malformations, vascular stenosis, and tumor-related lesions.

Government-supported insurance coverage for

neurointerventional procedures contributed significantly to accessibility by reducing financial barriers and dependence on overseas referral. Financial limitations remain an important challenge for equitable access to advanced cerebrovascular therapies worldwide.^{18, 19, 21}

Spectrum of Neurovascular Disease and Procedures

Cerebral aneurysm was the most common indication, accounting for 36.8% of procedures. This reflects the established role of endovascular therapy in contemporary aneurysm management following evidence demonstrating favorable outcomes of endovascular approaches compared with surgical clipping in selected patients.⁹ Advances including flow diversion and intrasaccular devices have further expanded treatment options for complex aneurysms.^{10–12, 26–28}

Flow diversion was the most frequently performed advanced therapeutic procedure in this cohort, demonstrating successful adoption of modern aneurysm treatment strategies within a newly developed neurovascular service.

Ischemic cerebrovascular disease accounted for 32.1% of procedures. Mechanical thrombectomy has transformed acute ischemic stroke management, with randomized trials demonstrating improved functional outcomes for patients with large vessel occlusion treated with endovascular thrombectomy.^{4–8} Although thrombectomy represented 4.4% of procedures in this early period, establishing this capability represents an important milestone in comprehensive stroke care. Successful thrombectomy programs require coordinated stroke pathways, rapid imaging, emergency referral systems, and multidisciplinary collaboration.^{4, 14, 29, 34}

Role of Diagnostic Angiography in Service Development

Diagnostic cerebral angiography accounted for 72% of procedures, reflecting the expected developmental pathway of a newly established neuroendovascular service. Digital subtraction angiography remains essential for definitive vascular diagnosis, treatment planning, evaluation of arteriovenous lesions, and post-treatment assessment.^{3, 30}

The observed transition from predominantly diagnostic procedures toward increasing therapeutic activity represents progressive maturation of the service. Gradual expansion of procedural complexity allows development of operator expertise while maintaining safety and sustainability.^{24, 25}

Training, Challenges, and Future Sustainability

Long-term sustainability of neuroendovascular services depends on specialist training, continuous professional development, international collaboration, and multidisciplinary education.^{24, 25} Small healthcare systems face challenges related to limited population size, procedural volume, specialist retention, device availability, and maintaining technical expertise.

For island nations, regional collaboration, structured training networks, simulation-based education, and quality monitoring may help overcome limitations associated with smaller healthcare systems. Despite geographic challenges and resource constraints, the Maldives experience demonstrates that advanced neurovascular services can be successfully developed through coordinated institutional leadership, workforce development, and healthcare planning.

Clinical and Health System Implications

The establishment of local neuroendovascular capability reduces dependence on overseas referral and improves access to time-sensitive interventions. This experience demonstrates that small healthcare systems can successfully implement complex medical technologies when infrastructure development is combined with specialist expertise, multidisciplinary collaboration, and sustainable healthcare financing.

Stroke systems of care and equitable access to reperfusion therapies remain global priorities; however, implementation strategies must be adapted according to local geography, population characteristics, workforce availability, and healthcare financing structures.^{14, 19, 29} The Maldives model may provide useful lessons for other small island nations and geographically isolated healthcare systems.

Limitations

This study has several limitations. It represents a single-center retrospective analysis, limiting generalizability. The study primarily evaluated procedural volume, diagnostic distribution, demographic characteristics, and service development rather than detailed clinical outcomes.

Functional outcomes, modified Rankin Scale scores, procedure-related complications, mortality, and long-term angiographic outcomes were not consistently available and therefore were not analyzed. Additionally, some advanced procedures, particularly mechanical thrombectomy and flow diversion, had relatively small sample sizes, limiting procedure-specific outcome assessment.

The observed increase in procedural volume reflects both increasing clinical demand and maturation of healthcare infrastructure and should not be interpreted solely as increased disease incidence. Future prospective studies should evaluate clinical outcomes, cost-effectiveness, quality indicators, patient satisfaction, and regional referral patterns.

Conclusion

The establishment of a dedicated neuroendovascular service in the Maldives demonstrates that comprehensive cerebrovascular intervention can be successfully developed within a geographically isolated healthcare system. Over five years, 321 procedures were performed, with cerebral aneurysms and ischemic cerebrovascular disease representing the predominant indications.

The service evolved from diagnostic angiography-based practice into a comprehensive neurovascular center capable of providing advanced interventions including flow diversion, mechanical thrombectomy, aneurysm treatment, vascular stenting, and embolization procedures.

Successful development was supported by coordinated infrastructure investment, specialist expertise, multidisciplinary collaboration, emergency pathways, and sustainable healthcare financing. The Maldives experience demonstrates that small island nations can establish advanced neurovascular services and may provide a valuable model for other resource-limited and geographically isolated healthcare systems.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Ethical Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. ADK Hospital is a tertiary clinical care center and does not currently have a formal Institutional Review Board or independent Research Ethics Committee. Accordingly, the study protocol and methodology were reviewed and approved by the Department of Neurosurgery, ADK Hospital, in accordance with the institution's practice for retrospective clinical research. The study involved a retrospective review of anonymized clinical and procedural records without direct patient contact or intervention. All patient identifiers were removed prior to data extraction and analysis, and strict confidentiality was maintained throughout the study. The research was conducted in compliance with institutional policies and applicable national ethical and methodological standards governing retrospective observational research.

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