

Utility of the Gamma Knife in a Johannesburg Private Hospital, South Africa

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Abstract

Background: Gamma Knife Stereotactic Radiosurgery (SRS) is an established modality for treating a range of neurosurgical and oncological conditions. However, utilisation pattern in low- and middle-income countries (LMICs) remains poorly described. This study characterises the use of Leksell Gamma Knife at a private hospital in Johannesburg, South Africa.

Methods: A retrospective review of all adult patients who underwent Gamma Knife between April 2017 and December 2023 was undertaken. A total of 1,414 records were analysed. Descriptive statistics summarised patient demographics and disease characteristics, while subgroup analyses of patients with brain metastases explored treatment patterns.

Results: The mean age of patients was 54.3 ± 14.3 years, and 59.3% were females. The majority (97.5%) resided in South Africa, with referrals from all nine provinces. Benign conditions represented 55.0% of cases, followed by malignant lesions. The most frequently treated conditions were meningioma (23.7%), brain metastases (21.8%), vestibular schwannoma (16.5%), and pituitary adenoma (14.8%). Among patients with brain metastases, breast (37.1%), lung cancer (25.9%) and melanoma (18.4%) cancers predominated. Multiple metastases were more common than solitary lesions (66.1% vs 33.9%). A statistically significant association was observed between metastatic volume and number of lesions ($p = 0.01$). No significant differences were identified for dose prescription ($p = 0.479$) or retreatment frequency ($p = 0.902$). Most patients (90.9%) received single fraction treatment.

Conclusion This study provides the first description of the utilisation of Gamma Knife radiosurgery in South Africa, demonstrating broad diagnostic and sustained multi-provincial referrals. The findings characterise service use rather than treatment outcomes, and patterns likely reflect both clinical demand and structural constraints within the health system. Expanded stereotactic radiotherapy access will require coordinated service planning and integration across sectors.

INTRODUCTION

Stereotactic Radiosurgery (SRS), introduced by Leksell in the 1950s, has evolved into a precise, minimally invasive technique for treating a range of neurosurgical and oncological conditions.(1) Modern systems such as Leksell Gamma Knife deliver high dose, conformal radiation to well-defined targets while sparing surrounding tissues (2, 3) This has broadened the therapeutic landscape for malignant, benign, functional vascular disorders.(4)

Although gamma Gamma Knife SRS (GKSRS) is widely established in high income countries (HICs), such as the United States, Canada, Europe and parts of Asia.(5–8), global access remains uneven (6,9), with profound disparities in equipment distribution, imaging availability and specialist expertise. (4,6,10,11) Most LMICs lack sufficient SRS capacity (10)and published utilisation data from African are limited.(12) Within Southern Africa, The Gamma Knife unit based at a private hospital in Johannesburg, represents the only dedicated system, operating as a national referral centre.

There is a paucity of data utilisation of the Gamma Knife in the delivery of SRS in Africa; with no published data available in the Southern African context. (6,8,9). Understanding utilisation patterns is critical for planning service expansion, optimising resource allocation, and improving equitable access. Therefore, this study aimed to characterise the demographic profile, referral patterns, treated pathologies and examine temporal trends of treated with Leksell Gamma Knife SRS in South Africa.

METHODS

Study design and setting: A retrospective descriptive review of hospital records was conducted for all adult patients who underwent Gamma Knife treatment between April 2017 and 31 December 2023 at private hospital in Johannesburg, South Africa.

The Gamma Knife Unit (GKU) is based at a private hospital in South Africa. It is located in the suburb of Western Parktown, Johannesburg. Situated in the economic hub of Gauteng province, it is one of the oldest private hospitals in Johannesburg with 346 beds including 95 beds allocated to intensive care and high care units.

Study Population: All patients aged 18 years and older who received treatment during the study period were included GKSRS. A total of 1,414 patient records were reviewed.

Data Collection and Analysis: Demographic variables, funding source, place of residence, referring region and clinical characteristics were extracted. Pathologies were categorised as benign, malignant, vascular, functional or other. Descriptive statistics were used to summarise data. Categorical variables were compared using the Pearson-Chi-squared test or Fisher's Exact test where appropriate. Continuous variables were summarised as mean and standard deviations (SD) or median with interquartile ranges (IQR) depending on data distribution. Images were presented using a flow chart and a bar graph. A p-value of <0.05 was considered statistically significant. The analysis was performed using Stata (version 16; StataCorp Ltd., College Station, TX, USA).

Procedure

The delivery of GKSRS at the Gamma Knife Unit requires a multi-disciplinary team approach including a neurosurgeon, radiation oncologist, physicist and radiotherapist.

The workflow for treating a patient using GKSRS [Figure 1] first involves a planning MRI – using a predefined scan protocol and double contrast. This can be done before the day of treatment for a smoother workflow. On the day of treatment, one begins with installation of an Immobilisation device– most commonly a frame. The Leksell frame is placed under local anaesthesia using four posts and screws. In the case of previous surgery resulting in surgical defects in the skull, the use of three screws might be warranted. For multi-fraction treatment, a thermoplastic mask can be used.

The target volumes are reviewed jointly by the neurosurgeon and radiation oncologist, and once approved, a 3-dimensional treatment plan is finalised. The plan depicts the dose in the form of isodoses (lines outlining the same dose) and advances in treatment planning allowing for inverse planning using a predefined prescription and the input of certain dose constraints to critical structures. In some instances, mostly with brain metastases, the plan evaluation is done solely by the radiation oncologist.

Following plan evaluation, final positioning is confirmed using cone beam CT and treatment is delivered. Given the precision required, stringent quality assurance procedures are essential.

Patients are referred to the GKU by different treating practitioners from across the country. Remote planning facilities are available in other areas of the country – the Free State Province and Eastern Cape province- allowing for improved ease of access for the primary treating practitioner.

Ethical Consideration

This study was approved by the University of the Witwatersrand Human Research Ethics Committee (Medical) (M240653), and by the research operations committee of the hospital (UNIV-2024-0035). This study was conducted in accordance with the ethical standards of the institutional research committee and with the principles of the Declaration of Helsinki as revised in 2013, and all relevant guidelines and regulations applicable to retrospective clinical research.

RESULTS

Demographic Profile of Patients Treated

Over the seven-year period, 1, 414 adults were treated at the Gamma Knife Unit (GKU). The mean age at treatment was 54 ± 14.3 years (range: 18 -88) (Table 1). Females comprised 59.3% (838) of patients. As shown in Table 1, most patients (68.2%, n = 914) were employed, and the majority (96.4%, n = 1363) were funded through medical insurance, with referrals from all nine provinces. The Eastern Cape province (5.2%) and the Free State Province (5.2%) contributed the highest proportions of out-of-province referrals (both 5.2%).The variation in regional referral patterns is further illustrated in Figure 2. Thirty-six patients (2.5%) travelled from the Southern African Development Community (SADC) countries, n = 17 (1.2%) and the rest from non-SADC countries, n = 19 (1.3%).

Table 1: Sociodemographic Characteristics of Patients Treated with Gamma Knife at a Private Hospital, Johannesburg, 2017 -2023

Characteristics	Total, N = 1414 (%)
Age in years, Mean ± SD	54.0 ± 14.3
Gender	
Male	576 (40.7)
Female	838 (59.3)
Employment	
Employed	914 (68.2)
Unemployed	426 (31.8)
Funding	
Medical Aid	1363 (96.4)
Self-funded	51 (3.6)
Country	
South Africa	1378 (97.5)
SADC*	17 (1.2)
Non-SADC	19 (1.3)

Missing: Employment status (n =70)

Abbreviations:

SD (standard deviation)

*SADC = Southern African Development Community– countries include Angola, Botswana, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, Tanzania, Zambia and Zimbabwe.

Procedure volumes increased from 2017 to 2019 (Figure 3) and subsequently plateaued, averaging 16 procedures per month.

Characteristics of Conditions Treated

Across all procedures, benign accounted form 55.2% (778) of cases, followed by malignant (32.7%, n=463), functional (4.5%, n=63) vascular (3.2%, n=46), and other lesions (4.4%, n= 62) (Table 2). The most frequently treated pathologies were meningioma (23.7%, n=334), brain metastases (21.7%, n= 307), vestibular schwannoma (16.5%, n= 232), and pituitary adenoma 208(14.7%).

Table 2: Summary of conditions treated at the Gamma Knife Unit in a private hospital in Johannesburg 2017- 2023

Lesion	N = 1410*	Percentage (%)
Benign		55.2%
Vestibular Schwannoma	232	16.5
Pituitary Adenoma	208	14.7
Meningioma	334	23.7
Craniopharyngioma	4	0.3
Vascular		3.2%
AVM	17	1.2
Cavernous Malformation	29	2.0
Malignant		32.7%
Uveal Melanoma	67	4.8
Lymphoma	3	0.2
Glioblastoma	46	3.3
Astrocytoma	34	2.4
Nasopharyngeal Carcinoma	4	0.3
Brain Metastases	307	21.7
Functional		4.5%
Trigeminal neuralgia	56	4.0
Essential tremor	7	0.5
Other		4.4%
Ependymoma	10	0.7
Haemangioma	27	1.9
Glomus Tumour	25	1.8
Total	1410*	100

*Missing (n=4) – choroid plexus papilloma, epidermoid cyst, medulloblastoma, parameningeal RMS

Abbreviations:

AVM = Arteriovenous Malformations.

Subset Analysis: Brain Metastases

A total of 307 patients were treated for brain metastases as summarised in Table 3. Breast (37.1%, n=109), lung cancer (25.9%, n= 76) and melanoma (18.4%, n=54) were the predominant primary diagnosis with brain metastases. Multiple metastases were more common with solitary lesions (66.1% vs 33.9%). The average number of brain metastases treated was 6.0 ± 9.8 , with a maximum of 100.

A statistically significant association was observed between metastatic volume and number of lesions ($p = 0.01$, Table 3). However, no significant differences were observed in prescribed dose category ($p = 0.508$), immobilisation methods ($p=0.815$) or retreatment frequency ($p =0.902$). Most patients (90.9%) were treated in a single fraction (Table 3).

Table 3: Treatment Characteristics of Patients with Brain Metastases Treated with Gamma Knife at a Private Hospital, Johannesburg, 2017 -2023

Characteristic	Total, n = 307 (%)	Single brain metastasis, n=104 (%)	Multiple brain metastasis, n=203 (%)	P value
Primary Diagnosis				0.157*
Breast	109 (37.1)	31(31.3)	78(40.0)	
Lung	76 (25.9)	22(22.2)	54(27.7)	
Melanoma	54 (18.4)	19(19.2)	35(18.0)	
Colon/Rectum	19 (6.4)	9(9.1)	10(5.1)	
Gyn-Cervix/Endometrium	6 (2.0)	3(3.1)	3(1.5)	
RCC	6 (2.0)	2(2.0)	4(2.1)	
Other	24 (8.2)	13(13.1)	11(5.6)	
BM, median (IQR)	1 (1-1)	1 (1-1)	5(2-10)	<0.001
BM. Mean ± SD	6.0 ± 9.8	1.0±0.0	8.5±11.3	<0.001
BM volume (cm3):				0.001
<= 5	115 (37.5)	49 (47.1)	66 (32.5)	
6 - 10	45 (14.7)	19 (18.3)	26 (12.8)	
11 - 15	42 (13.7)	16 (15.4)	26 (12.8)	
>15	105 (34.2)	20 (19.2)	85 (41.9)	
Dose (Gy)				0.508*
<18	67 (21.8)	22 (21.2)	45 (22.2)	
18- 24	237 (77.2)	80 (76.9)	157 (77.3)	
>24	3 (1.0)	2 (1.9)	1 (0.5)	
Fractionation				0.144
1	279 (90.9)	98 (94.2)	181 (89.2)	
2-5	28 (9.1)	6 (5.8)	22 (10.8)	
Immobilisation				0.815
Frame	177 (57.6)	59 (56.7)	118 (58.1)	
Mask	130(42.4)	45 (43.3)	85(41.9)	
Retreatment				0.902

Yes	46 (15)	16 (15.4)	30 (14.9)
No	260 (85)	88 (84.6)	172 (85.1)

☐ missing (n=13) – primary diagnosis not captured.

*Fisher’s Exact test

Abbreviations: BM = Brain Metastases, Gy = Gray, IQR = interquartile range, SD = standard deviation

DISCUSSION

This seven-year retrospective review provides the first national overview of the utilisation of the Gamma Knife in South Africa, offering insight into referral pathways, care mix patterns and operational trends. The predominance of benign conditions, particularly meningiomas, vestibular schwannomas and pituitary adenomas is consistent with global reports from both high-income settings and LMIC contexts. However, as with similar utilisation studies, these findings reflect patterns of service use rather than the underlying epidemiology of intracranial disease (2,4, 7, 9, 22).

Our case mix aligns closely with the Leksell Gamma Knife Society review, which highlights benign tumours, especially meningiomas and vestibular schwannomas, as common indications for radiosurgery (22). Concordant with our findings, Iraq’s experience reported a high frequency of meningioma treatment; however, brain metastases were treated less often there than at our centre, diverging from both our cohort and broader global patterns (22,28). By contrast, the Colombian series described a benign-predominant profile but with a comparatively higher proportion of vascular lesions, particularly arteriovenous malformations than we observed, underscoring how local referral pathways, service configuration and health-system capacity shape utilisation (7). These cross-country comparisons highlight the value of country-specific evidence to guide scalable implementation models in LMICs (4,7,9,22).

Within our cohort, patients with brain metastases constituted 21.7% of cases, and multiple lesions were more common than solitary disease. The observed association between number of lesions and intracranial metastatic volume is consistent with evolving practice patterns whereby SRS increasingly replaces whole-brain radiotherapy for patients with numerous lesions (24-27). While SRS was historically reserved for up to four brain metastases (24), contemporary series and practice guidelines support treatment of substantially higher lesion counts often 10-30 in appropriately selected patients (25-27). Our operational experience included instances of very high lesion numbers, facilitated by multi-isocentric techniques, albeit at the expense of longer treatment times relative to mono-isocentric approaches (25-26).

The Johannesburg Gamma Knife Unit (GKU) operates as a centralised national service embedded within distributed clinical care. Although definitive treatment is delivered at a single facility, patients can undergo pretreatment MRI and receive longitudinal follow-up with local clinicians. Notably, 358 patients

(25.98%) from within South Africa travelled from outside the province for treatment, suggesting that a structured referral model augmented by remote planning capacity can extend radiosurgical access across geographies (10,13,14). Similar benefits of telemedicine, remote contouring and virtual tumour boards have been demonstrated elsewhere, particularly as enablers for quality assurance and skills transfer in settings with limited specialist availability (4,29).

Technology selection for stereotactic radiosurgery in resource-constrained settings must balance clinical performance, case volume and health-system context. Although the Leksell Gamma Knife is the only dedicated SRS platform, comparable stereotactic capability can be achieved with linear accelerator linac-based systems (15,30). International cost-effectiveness analyses indicate that dedicated SRS units are most sustainable in higher-volume environments, whereas linac-based SRS may be more cost-effective where demand is lower (13,16). Our seven-year activity of 1,414 procedures places the GKU within a moderate–high-volume range by LMIC standards, supporting the viability of a dedicated GK system in the South African private sector, while reinforcing the need for system-level integration to optimise utilisation and equity (7,13,16,30). The documented cost advantages of SRS over open surgery for selected intracranial pathologies, including vestibular schwannoma and brain metastases further support the appropriateness of our case mix (23).

Referral patterns demonstrate substantial inter-provincial variability, suggesting uneven access and potentially fragmented care pathways. The concentration of treatment at a single private-sector facility likely reflects structural constraints, including limited public-sector stereotactic infrastructure and insurance-dependent access (17,18). As nearly all patients were privately funded, these findings represent a subset of the population with financial means to access specialised care, rather than overall national need. Similar constraints were reported in other fragile or resource-limited systems, for example, in Iraq, where advanced cancer services are shaped by workforce shortages, institutional silos, and disrupted infrastructure. (17) These findings reinforce the importance of conceptualising SRS not as a standalone technological intervention, but as part of an integrated neurosurgical and oncological ecosystem supported by coordinated referral networks and governance structures. (18)

Policy and financing models will be pivotal to expanding equitable access. In South Africa, the proposed National Health Insurance (NHI) framework provides an avenue to reduce access barriers, while innovative affordability mechanisms such as India's "Gamma Knife for Life" model demonstrate practical approaches to improve affordability ($p = 0.026$) through a fixed-fee structure (20-21). International experiences suggest that volume consolidation and regionalisation, supported by telemedicine and remote planning, can improve sustainability in LMICs, whereas judicious deployment of linac-based SRS can broaden reach where dedicated units are not feasible (13, 14, 23, 29, 30).

In nutshell, our data situate South Africa's first documented GK utilisation within global and LMIC patterns: a benign-predominant case mix with substantial treatment of brain metastases; a centralised service model leveraging remote workflows; and technology choices shaped by volume and system context. These comparisons underscore the need for coordinated planning across sectors, strengthened

referral networks, and outcome- and cost-effectiveness research to guide sustainable expansion of stereotactic radiosurgery services in South Africa and comparable LMIC settings (13-16, 18-23, 29, 30).

LIMITATIONS

This study has several limitations. First, it reports service utilisation only and does not include treatment outcomes such as local control, survival or toxicity; therefore, no conclusion can be drawn about clinical effectiveness.

Second, the study was conducted at a single private-sector Gamma Knife unit, limiting generalisability and underrepresenting patients who lack private medical insurance or access to specialist referral pathways.

Third, referral bias is likely, as patients with better functional status, limited disease burden or ability to travel may be preferentially referred. This could influence the observed case mix and may not reflect the true population-level distribution of indications for radiosurgery. Fourth, the absence of data on linac-based SRS means the findings do not reflect overall stereotactic radiotherapy in South Africa

Fifth, no costing or economic analyses were performed, limiting assessment of affordability or sustainability in resource-constrained settings.

Finally, as a retrospective review of routinely collected clinical data, findings may be affected by missing variables or incomplete.

Conclusion

The study provides the first comprehensive description of Leksell Gamma Knife stereotactic radiosurgery utilisation in South Africa, documenting 1414 procedures over seven years (2017 -2023). The Gamma Knife unit treated a diverse range of benign, malignant, vascular and functional conditions, with sustained referrals from across the country. These findings offer insight into how a centralised SRS service is used within a mixed public-private health system but reflect utilisation patterns rather than clinical outcomes. Expanding equitable access to stereotactic radiosurgery will require coordinated planning, strengthened referral pathways and consideration of public-sector consideration. Further research, including outcome analyses, cost analyses and system-level evaluations is needed to guide sustainable expansion of SRS services in South Africa and comparable LMIC settings.

Declarations

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Consent to participate

Not applicable

Availability of data and materials

The generated dataset for the current study is not publicly available due to the proprietary nature of the dataset.

Consent for Publication

Not applicable.

Competing Interests

The authors declare that they have no competing interests.

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Contributions

All authors have read and approved the final manuscript.

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Figures

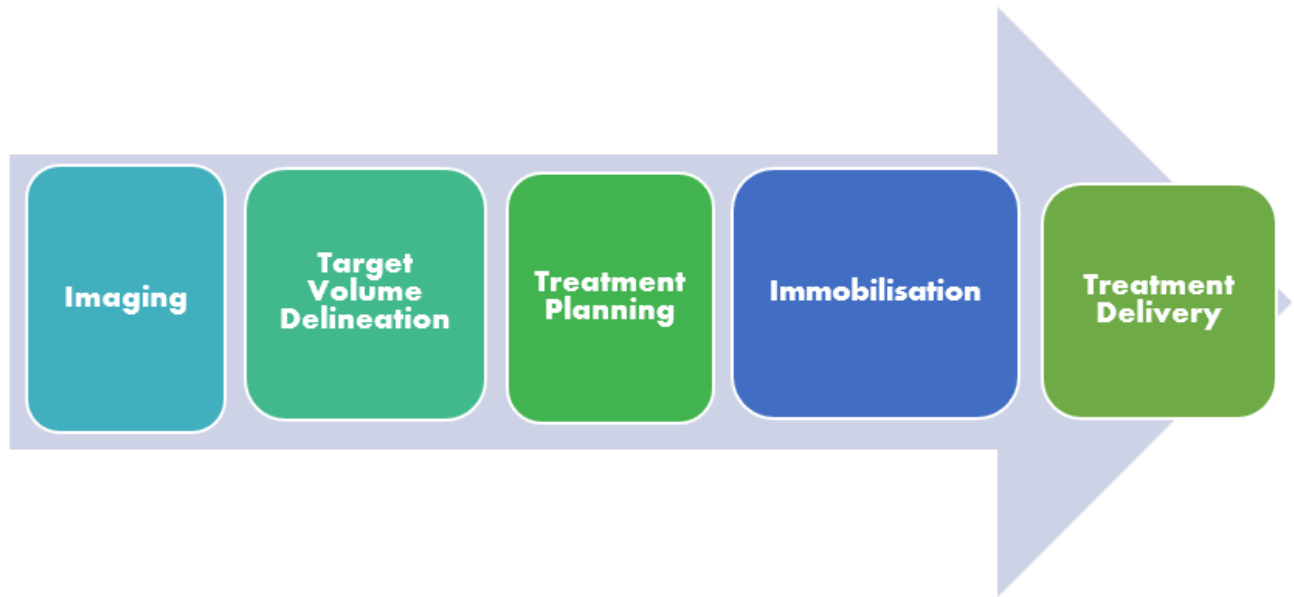


Figure 1

Workflow for the delivery of Gamma Knife Stereotactic Radiosurgery at a Johannesburg Private Hospital

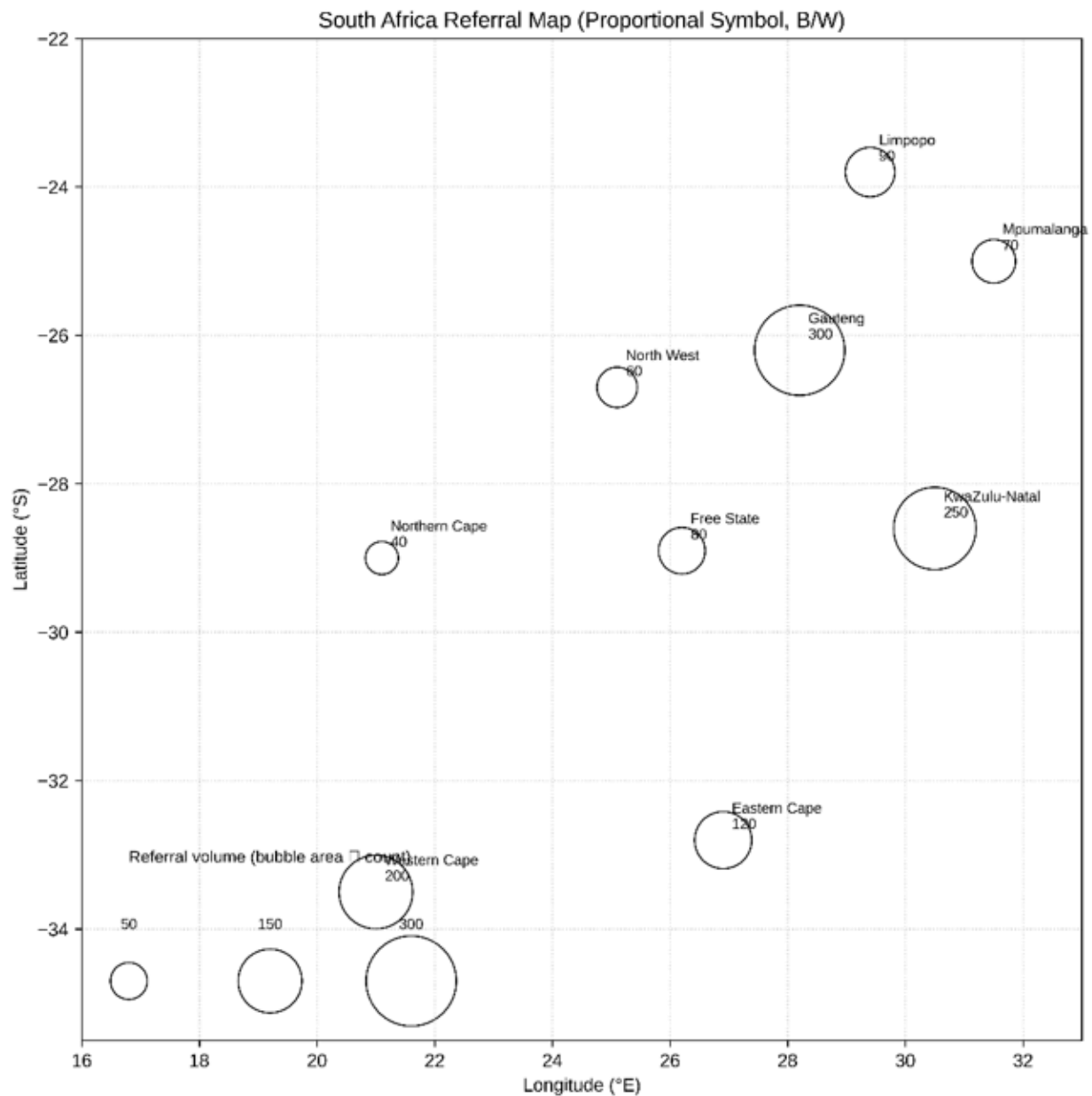


Figure 2

Choropleth map of provincial referral patterns for Gamma Knife stereotactic radiosurgery in South Africa. Provincial referral rates were expressed as the number of treated patients per million -population, over the study period 2017-2023

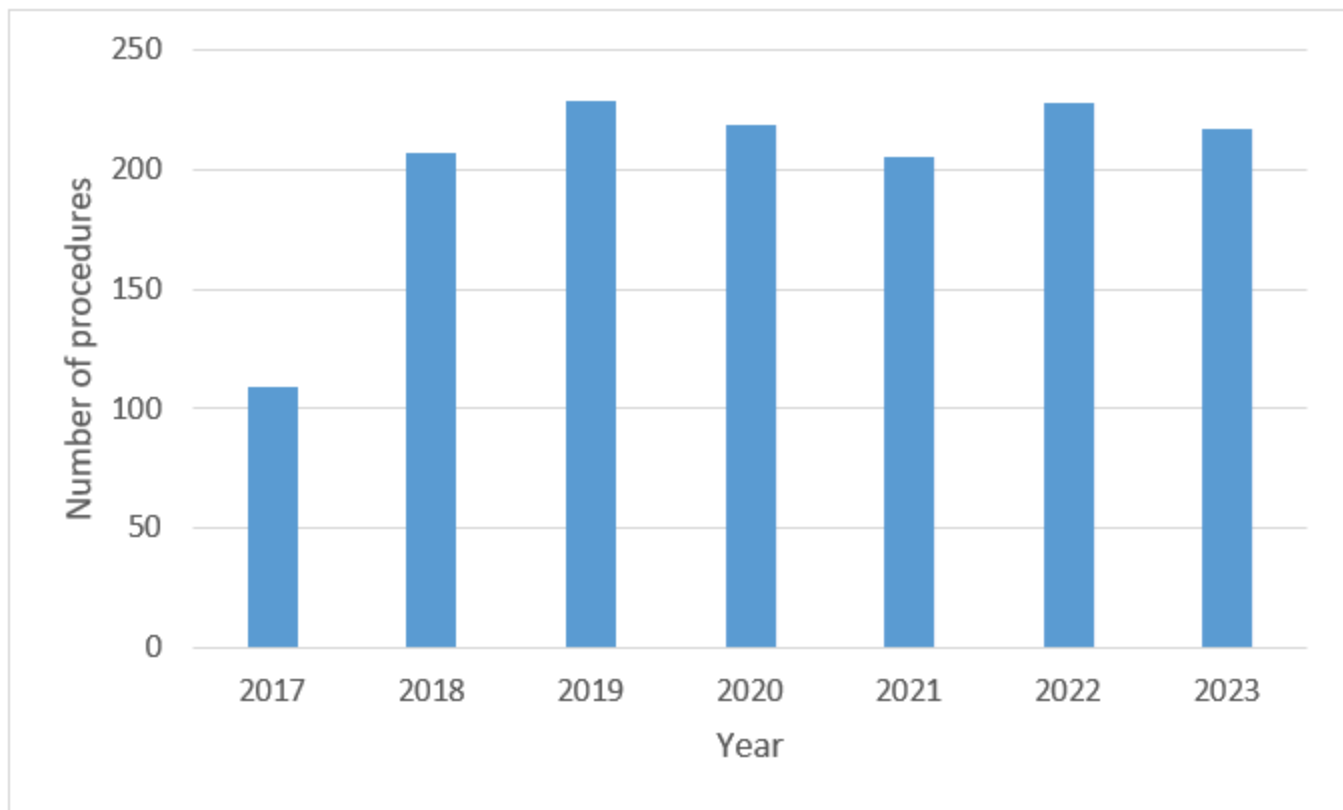


Figure 3

Number of procedures performed at the Gamma Knife Unit, in a private hospital in Johannesburg