PETITION

Petition for Gamma Knife in the Western Portion of the State (Health Service Areas I, II, and III)

PETITIONER

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STATEMENT OF THE PROPOSED CHANGE

The Charlotte-Mecklenburg Hospital Authority d/b/a Atrium Health (Atrium) respectfully petitions the State Health Coordinating Council (SHCC) to create a special allocation for one Gamma Knife to meet the stereotactic radiosurgery needs of citizens in the western portion of the state (Health Service Areas (HSAs) I, II, and III) in the 2020 State Medical Facilities Plan (SMFP).

BACKGROUND

Stereotactic radiosurgery (SRS) uses many precisely focused radiation beams to treat tumors and other problems in the brain, neck, lungs, liver, spine and other parts of the body. SRS is used instead of, or in conjunction with, traditional (i.e., open) surgery due to its extreme accuracy, efficiency and outstanding therapeutic response. GammaKnife surgery is a form of SRS, primarily used for treating brain disorders.

There are currently only two providers of Gamma Knife services in the state of North Carolina. Wake Forest Baptist Medical Center in Winston Salem acquired a Gamma Knife pursuant to Policy AC-3 and began operation in 1999. Vidant Medical Center in Greenville began operation in 2005. Gamma Knife procedure volumes for each provider over the last eight federal fiscal years (FFY) are shown in the table below, along with the compound annual growth rates. The information below shows that both providers have seen an increase in volume over the 8-year period from FFY 2011 to 2018. Additionally, the total number of Gamma Knife procedures grew 6.93 percent annually from FFY 2011 to 2018.

Facility	FFY 2011	FFY 2012	FFY 2013	FFY 2014	FFY 2015	FFY 2016	FFY 2017	FFY 2018	Compound Annual Growth Rate
Wake Forest Baptist Medical Center	354	364	335	375	439	460	457	496	4.94%
Vidant Medical Center	49	79	107	133	123	230	164	148	17.11%
Total	403	443	442	508	562	690	621	644	6.93%

Source: State Medical Facilities Plans and Hospital License Renewal Applications.

TECHNOLOGY OF GAMMA KNIFE

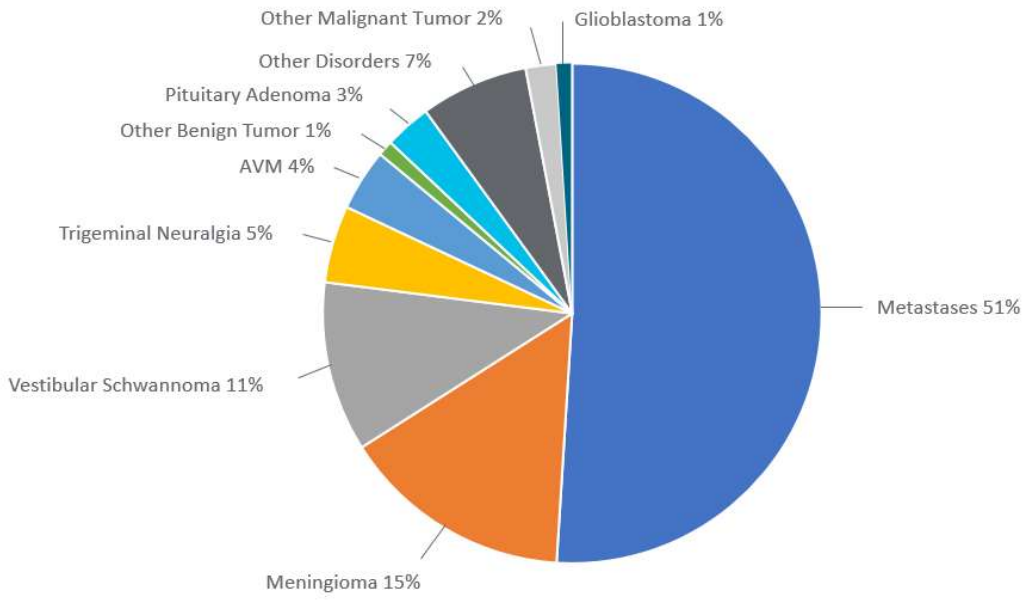
Stereotactic radiosurgery was developed in the 1950s and was originally employed with a single beam method to treat trigeminal neuralgia patients. Gamma Knife radiosurgery was subsequently developed as a dedicated tool to provide higher and more precise therapeutic doses of radiation to the brain while minimizing the impact on patients' normal brain tissues. The first Gamma Knife was developed in 1968 and utilized 179 cobalt sources in a hemispheric array. At the time of its introduction, imaging technology was limited to radiographs and angiography. As such, the initial indications for Gamma Knife surgery were primarily vascular abnormalities.

Today, Gamma Knife surgery is a leading treatment solution that is primarily focused on tumors in the brain. There are, however, continually expanding clinical capabilities and applications for this technology. Gamma Knife is a very precise radiosurgery procedure, limiting radiation dose to healthy tissue while focusing energy on pathological tissues. This allows for the treatment of virtually all disorders in the brain with a high degree of precision. Recent Gamma Knife innovations make it possible to treat patients without invasive fixation (i.e. stereotactic frames), thus enhancing patient comfort while assuring the same high level of dosing precision.

REASON FOR REQUEST

Demand for Gamma Knife Services

The pie chart below lists the distribution of conditions treated on Gamma Knives as reported by the leading Gamma Knife provider, Elekta, for 2017.



Source: Elekta, 2018

The predominant conditions treated with a Gamma Knife include: benign and malignant brain tumors (including vestibular schwannoma, also known as acoustic neuroma), trigeminal neuralgia, and arterio-venous malformations (AVM). In 2017, these conditions comprised over 85 percent of all cases treated on Gamma Knives.

To demonstrate the demand for Gamma Knife services in North Carolina, specifically the Western portion of the state, Atrium has prepared the following analysis using the incidence rates of the predominant conditions treated with Gamma Knife or other radiosurgery devices. The incidence rates for each condition were multiplied by the population of the state and the relevant Health Service Areas. The percentage of each condition appropriate for Gamma Knife SRS was then multiplied by the resulting number of cases in each condition.

The population figures used in the calculation are from the Office of State Budget and Management for 2018. The total population of North Carolina was estimated to be 10,401,960 in July 2018. The total population of the eastern and western regions of the state as defined by the HSA was calculated by summing the respective county populations. In July 2018, the population of the western part of the state (HSA I, II and III) was 5,401,490 and the population of the eastern part of the state (HSA IV, V and VI) was 5,000,470.

The formula used to calculate the number of potential Gamma Knife cases is described below using the factors for meningiomas (a common, benign brain tumor).

> Incidence rate per million [74.4] X (State population [10,401,960] / 1,000,000) X % Indicated for Gamma Knife [50%] = Potential radiosurgery cases [387]

Where the literature source provided a range of incidence rates, the calculations were performed for both the low and high values. As the table below indicates, using just the five most prevalent

conditions the number of potential radiosurgery cases in North Carolina could be between 2,042 and 3,484 (more contemporary population-based analyses support the higher projections).

Category	Condition	Annual Incidence (per million)		Prevalence (per million population)	% Indicated for Gamma Knife	Potential Gamma Knife Cases in NC	
		Low	High			Low	High
Benign Tumors	Meningioma		74.4	975	50%	387	387
	Vestibular Schwannoma		19	200	80%	158	158
Malignant Tumors	Metastases	83	143	NA	90%	777	1,339
Vascular Abnormalities	Ateriovenous Malformations	8.9	13.4	180	70%	65	98
Functional Disorders	Trigeminal Neuralgia	126	289	700	50%	655	1,503
					TOTAL	**2,042**	**3,484**

Sources: Gamma Knife Radiosurgery: A Review of Epidemiology and Practice, Hamilton, T.; Kano, H; Lunsford, L.; 2014 and Epidemiology of Metastatic Brain Tumors, Fox, B., Cheung, V., Patel, A., Suki, D., and Rao, G., Epidemiology of Metastatic Brain Tumors, Neurosurgery Clinics, January 2011, Vol 22, Issue 1, Pages 1-6.

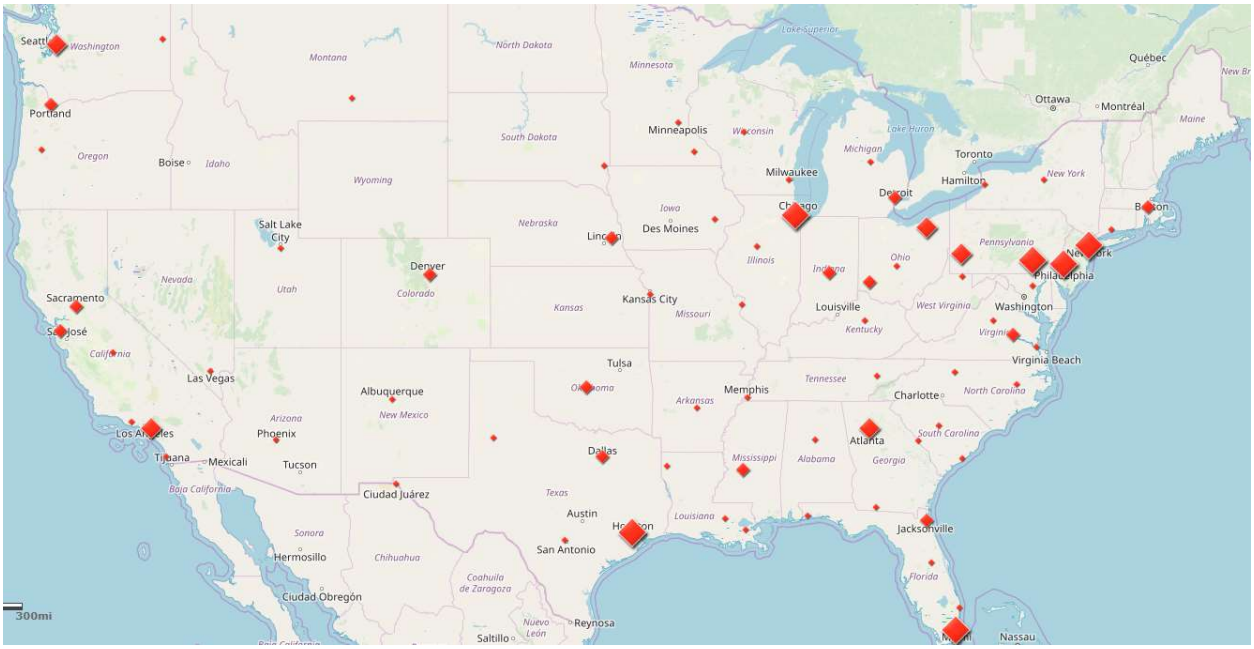
Using the same approach to apply the incidence rates to the HSA population results in the following table:

Category	Condition	HSA I, II, III Potential Gamma Knife		HSA IV, V, VI Potential Gamma Knife	
		Low	High	Low	High
Benign Tumors	Meningioma	201	201	186	186
	Vestibular Schwannoma	82	82	76	76
Malignant Tumors	Metastases	403	695	374	644
Vascular Abnormalities	Ateriovenous Malformations	34	51	31	47
Functional Disorders	Trigeminal Neuralgia	340	781	315	723
	TOTAL	**1,060**	**1,809**	**982**	**1,675**

Limited Access to Gamma Knife Services

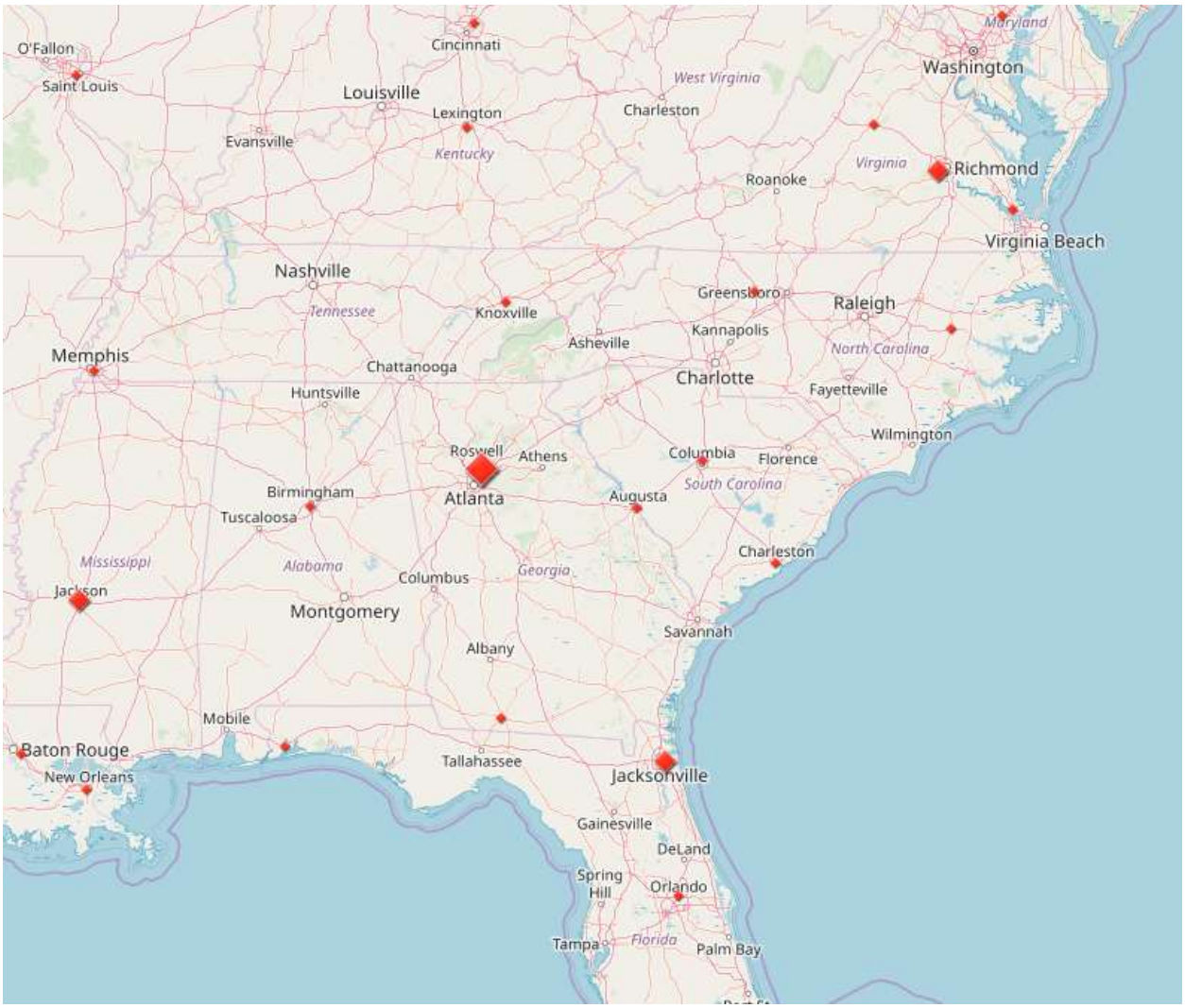
Currently, there are currently only two providers of Gamma Knife services in North Carolina. Wake Forest Baptist Medical Center in Winston Salem began operation in 1999. Vidant Medical Center in Greenville began operation in 2005. Approximately 126 hospitals and clinics nationwide have a Gamma Knife. The maps below show the locations of Gamma Knives in the US, the mid-Atlantic region and finally in North Carolina.

Location of Gamma Knives



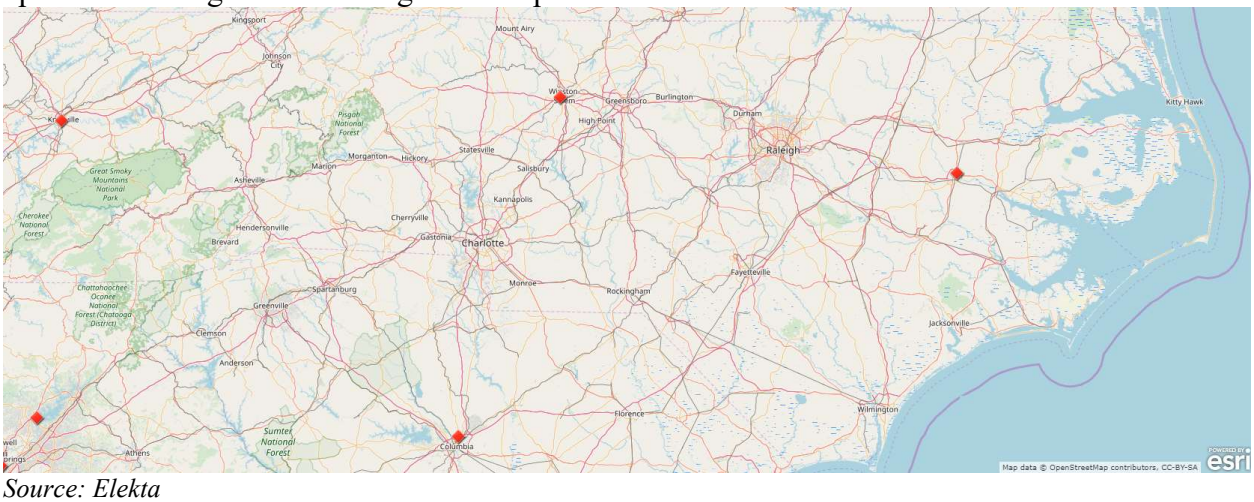
Source: Elekta

The larger icons above reflect the clustering of multiple Gamma Knives in a metropolitan area. The size of the icon is representative of the relative number of Gamma Knives in the area.



Source: Elekta

The map above provides a clear indication of the much higher number of Gamma Knives in operation in Virginia and Georgia as compared to North Carolina.



Source: Elekta

The table below shows the number of Gamma Knives currently in operation in each state (including Washington, D.C.) and the population per Gamma Knife. There are eight states that do not currently have a Gamma Knife. As the table indicates, North Carolina has less accessibility to Gamma Knife therapy on a per population basis than 39 other states, including all of North Carolina's neighboring states. In fact, North Carolina has the same number of Gamma Knives as South Carolina, even though North Carolina's population is more than double the size of South Carolina's.

If this petition is granted and another Gamma Knife is ultimately developed in North Carolina, the state would have 3.4 million people per Gamma Knife which would only elevate its population per Gamma Knife ranking to 36, just below Tennessee. Atrium realizes that a population to Gamma Knife ratio, taken alone, may not be sufficient to show a need for another Gamma Knife in North Carolina; however, it is helpful to show that the population of the state could easily support an additional Gamma Knife compared to national standards.

State	Gamma Knives	2018 Population	Population per Gamma Knife	Rank
DC	1	702,455	702,455	1
AK	1	737,438	737,438	2
SD	1	882,235	882,235	3
NE	2	1,929,268	964,634	4
RI	1	1,057,315	1,057,315	5
MT	1	1,062,305	1,062,305	6
PA	11	12,807,060	1,164,278	7
OR	3	4,190,713	1,396,904	8
HI	1	1,420,491	1,420,491	9
NJ	6	8,908,520	1,484,753	10
MS	2	2,986,530	1,493,265	11
LA	3	4,659,978	1,553,326	12
WV	1	1,805,832	1,805,832	13
WA	4	7,535,591	1,883,898	14
OH	6	11,689,442	1,948,240	15
OK	2	3,943,079	1,971,540	16
NM	1	2,095,428	2,095,428	17
GA	5	10,519,475	2,103,895	18
VA	4	8,517,685	2,129,421	19
IN	3	6,691,878	2,230,626	20
FL	9	21,299,325	2,366,592	21
SC	2	5,084,127	2,542,064	22
NY	7	19,542,209	2,791,744	23
MN	2	5,611,179	2,805,590	24
CO	2	5,695,564	2,847,782	25
TX	10	28,701,845	2,870,185	26
WI	2	5,813,568	2,906,784	27
AR	1	3,013,825	3,013,825	28
NV	1	3,034,392	3,034,392	29
MO	2	6,126,452	3,063,226	30
IA	1	3,156,145	3,156,145	31
UT	1	3,161,105	3,161,105	32
IL	4	12,741,080	3,185,270	33
MI	3	9,995,915	3,331,972	34
TN	2	6,770,010	3,385,005	35
CT	1	3,572,665	3,572,665	36
CA	10	39,557,045	3,955,705	37
KY	1	4,468,402	4,468,402	38
AL	1	4,887,871	4,887,871	39
NC	2	10,383,620	5,191,810	40
MD	1	6,042,718	6,042,718	41
MA	1	6,902,149	6,902,149	42
AZ	1	7,171,646	7,171,646	43
DE	0	967,171	N/A	44
ID	0	1,754,208	N/A	45
KS	0	2,911,505	N/A	46
ME	0	1,338,404	N/A	47
ND	0	760,077	N/A	48
NH	0	1,356,458	N/A	49
VT	0	626,299	N/A	50
WY	0	577,737	N/A	51

Source: US Census Bureau, Elekta.

Growth in Atrium Cancer Cases

The western part of the state, and more specifically the Charlotte metropolitan region, has experienced a population explosion. According to county population data from North Carolina Office of State Budget and Management, Mecklenburg County was the fastest growing county in the state from 2010 to 2019. In fact, the Charlotte metro area includes five of the top 15 fastest growing counties: Union (9), Gaston (10), Cabarrus (11) and Iredell (14). The population growth also contributed to an associated increase in the pathologies relevant to Gamma Knife therapy, particularly brain tumors. Atrium's cancer program, the Levine Cancer Institute (LCI), has expanded dramatically over the last several years. In 2018, 18,000 new patients were seen at LCI. We have experienced 80 percent volume growth over the last five years.

In 2018 LCI treated 2,576 patients with the conditions cited earlier as key conditions typically treated with a Gamma Knife. Applying the same assumptions on the percentage of cases indicated for Gamma Knife, LCI treated enough patients to potentially need 1,618 Gamma Knife procedures as shown in the table below. While there may be medical reasons due to complications and comorbidities to reduce the number of actual Gamma Knife procedures, even if the number of procedures is reduced by half the number of procedures is well above the projected capacity of a single Gamma Knife device.

Category	Condition	2018 Atrium Health Patients	% Indicated for Gamma Knife	Potential Gamma Knife Cases from AH Patients
Benign Tumors	Meningioma	1,278	50%	639
Malignant Tumors	Metastases	744	90%	670
Vascular Abnormalities	Arteriovenous Malformations	160	70%	112
Functional Disorders	Trigeminal Neuralgia	394	50%	197
			TOTAL	**1,618**

At LCI, the physicians and health professionals from Atrium, Carolina Neurosurgery & Spine Associates, and Southeast Radiation Oncology Group, P.A. collaborate to provide SRS for our patients and cooperatively engage in cutting-edge radiosurgery research. This team, comprised of providers with international reputations, has been at the forefront of the major advancements in the last decade for the management of brain metastasis.

LCI's primary radiosurgery device, a non-dedicated linear accelerator that is used for many purposes aside from SRS, has reached its functional limit in terms of the number of patients that can be treated on an annual basis. A recent chart review of Atrium brain metastasis patients who also needed surgical resection indicated that patients experienced a delay in SRS treatment approximately 50 percent of the time. Absent a more efficient and dedicated device, we will be unable to adequately serve the many patients in our large catchment area who rely on our comprehensive cancer services. The addition of a Gamma Knife to the western region of North

Carolina will offer an opportunity to advance both the research and patient care abilities in the region.

Superiority of Gamma Knife SRS to Other SRS Alternatives

Gamma Knife offers advantages to the other SRS alternatives currently in use in the state. These advantages include precision in treating target tissue (tumors) with less damage to healthy tissue. While it is not an easy task to determine a single parameter that both sums up the overall accuracy of a stereotactic system and can be used to draw conclusions about any clinical advantage of such a system, it has been observed that, when looking at a specific dosimetric parameter in a study, the optimal modality for stereotactic radiosurgery has been shown to depend on target size, shape, and location[1]. Most published studies, when trying to assess accuracy tend to focus on an aspect within the chain of uncertainty for use of a system. What is known is that reducing uncertainty within the radiosurgery process is key and that any advantage that positions the clinician closer to that goal must be weighed seriously versus all other considerations. The case can be made that tests of end-to-end accuracy provide a reasonable standard by which modalities and delivery systems can be compared.

- When comparing Gamma Knife to linear accelerator systems, published data suggests that mechanical accuracy data gives a slight edge to Gamma Knife versus a CyberKnife especially earlier CyberKnife models where the robot guiding the treatment can be a contributor to error (0.48 mm +- 0.23 mm vs. 0.6mm, respectively).[2,3]
- For a Varian "standard" linear accelerator (CLINAC model), the vendor specification is <1 mm for mechanical and radiation isocenter accuracy. Isocenter verification on a CLINAC utilizing end-to-end testing shows accuracy to within 0.6mm. The more modern standard linear accelerator model, the Truebeam (including the Truebeam STx dedicated SRS linear accelerator model), has an isocenter couch/gantry/collimator isocenter axis with a max published measured radius of 0.675 mm vs a specification of <0.75mm. This compares with an accuracy of 0.48 mm for Gamma Knife.
- When comparing the Gamma Knife to a dedicated SRS linear accelerator, end-to-end testing results are similar – 0.48 mm vs 0.4-0.85 mm[4], respectively – but with a caveat that the linear accelerator data can be interpreted as mostly inherent error that, based on the quality assurance test method, cannot be easily corrected through mechanical means.
- Data from early Gamma Knife and linear accelerator comparison studies focusing on treatment planning techniques indicate an advantage for Gamma Knife in conformality to irregular shapes and less heterogeneity in dose distribution.[1]
- Rotational accuracy in linear accelerator or CyberKnife treatments is more critical based on the use of techniques that sometime center the treatment isocenter outside of the tumor target versus Gamma Knife techniques which almost always place the isocenter within the target.[3]
- The question of low-dose spillage resulting from treatment planning and delivery techniques is relevant for linear accelerator treatments when compared with Gamma Knife since that low-dose spillage associated with the Volumetric Modulated Arc Therapy (VMAT) technique used in linear accelerator delivery has been shown to be statistically greater than Gamma Knife planning techniques when planning greater than 7

brain metastases. It is hypothesized that the cumulative effect of low-dose spillage may be statistically significant for patients requiring multiple courses of SRS.[5]

Delivery Platform	Mechanical Accuracy	Comment	Reference
CyberKnife	0.6 mm	Includes robot pointing, collimator, robot/imaging coincidence, imaging algorithm	Dieterich (2014). SRT II: Uncertainties in SRT [PowerPoint Slides], Retrieved from https://www.aapm.org/education/VL/vl.asp?id=3902
Standard linear accelerator	0.675 mm (max)	Isocenter couch/gantry/collimator isocenter axis	C Glide-Hurst & M Bellon et al., Med Phys 40:3 (2013)
Dedicated linear accelerator	0.4-0.85 mm E2E	E2E on linear accelerator; no correction method available	Wang et al., Physics in Medicine and Biology 57:3 (2012)
Gamma Knife	0.48 mm+-0.23 mm	E2E; Gamma Knife (Uncertain previous model)	Mack et al, Med Phys 29:4 (2002)
Gamma Knife	0.5±0.6 mm	E2E; Gamma Knife Icon	HT Chung et al., JACMP, 19(4): p. 148-154 (2018)

Atrium radiotherapy centers are largely equipped with standard linear accelerators and currently do not have a dedicated stereotactic device in operation. Technical innovations in linear accelerator technology has made them versatile and efficient tools in the battle against cancer, advancing the quality of care by bringing once highly specialized treatments like Stereotactic Body Radiotherapy (SBRT) to more centers and patients across a distributed radiotherapy market. Atrium does own a CyberKnife radiotherapy device that is currently located at Atrium's facility in Cabarrus. At the time when the CyberKnife was installed 12 years ago, it was an ideal choice for a variety of stereotactic therapies. In recent years the CyberKnife has been viewed less favorably by our specialists than linear accelerators which were more versatile and suitable for some types of stereotactic treatment. The CyberKnife has not been upgraded since early in its useful life and is now technologically and functionally less capable than newer linear accelerators because it lacks advanced treatment planning algorithms or precise and efficient beam-shaping added devices.

ALTERNATIVES CONSIDERED

Under the North Carolina Certificate of Need (CON) statute, Atrium identified three potential avenues by which it could pursue developing the needed Gamma Knife. After careful consideration, only one option, through a special allocation in the 2020 SMFP, was identified as a reasonable alternative. As discussed above, maintaining the status quo is not a reasonable alternative given the need for a Gamma Knife in the western half of the state. The other alternatives that were considered are as follows:

1. **File a petition for an additional linear accelerator configured to perform SRS.**
   Gamma Knife is a simpler, and therefore more reliable, technology than linear accelerator SRS. It is subject to less "down time" due to technological issues. Treatment planning tends to be simplified leading to increased throughput, particularly for oligimetastases (1-4 brain lesions) which make up the vast majority of metastatic brain tumors. In addition, approximately 20 percent of patients with brain metastases have between 5 and 10 lesions at diagnosis. These patients are not currently eligible for SRS on most linear accelerators but could be treated on a Gamma Knife. Linear accelerator-based SRS typically uses a machine not dedicated for SRS, hence each treatment takes a longer period of time and there is less time dedicated to SRS treatments as these devices serve as "general use" radiation machines as well (i.e., treating other patients who require more conventional forms of radiotherapy). A dedicated SRS treatment machine would allow for increased volume of patient treatments and expand treatment indications (e.g., more than 4 brain metastases, trigeminal neuralgia, movement disorders).

   The Gamma Knife is acknowledged as the gold standard for cranial SRS by referring physicians and is sought out by patients for its unparalleled precision in treating brain tumors. Atrium rejected this alternative because linear accelerators configured to perform SRS are not capable of providing the same level of precision and efficiency as Gamma Knife for patients with intracranial pathologies.

2. **File a CON to develop a Gamma Knife in response to a need determination in the SMFP.**
   This option is unreasonable as a need determination for a Gamma Knife has not been published in the SMFP since 2005. There is not a written methodology to determine when a Gamma Knife is needed in North Carolina. The SHCC has the authority to decide whether a Gamma Knife is needed, so it is impossible to determine when such a decision could be reached. As such, Atrium rejected this alternative.

3. **Special Allocation.**
   The currently proposed petition seeks a special allocation for one Gamma Knife unit in the western portion of the state, which includes HSAs I, II and III. Given the shortcomings of the previous alternatives with regard to meeting the need for Gamma Knife services, Atrium believes this approach is the only reasonable pathway to developing greater access to this important service

The final alternative, a special allocation in the 2020 SMFP as proposed in this petition, is the only alternative that will ensure the development of Gamma Knife services in the western portion of the state, where access is clearly needed. As such, Atrium believes the current petition is the most effective alternative for developing needed access to Gamma Knife services for the residents of HSAs I, II and III. As discussed above, Gamma Knife technology offers a significant number of benefits when it comes to patient care. North Carolina, particularly the western portion of the state, does not yet have adequate access to this important technology. As demonstrated above, Atrium estimates that there is adequate patient volume in the western part of the state to support the need for a special allocation of a Gamma Knife unit as requested in this petition. Atrium believes that a

special allocation in the 2020 SMFP is the only reasonable alternative to develop this service, given the deficiencies of other potential approaches.

ADVERSE EFFECTS IF PETITION IS NOT APPROVED

The proposed special allocation will increase accessibility to Gamma Knife services for those who live in the western part of the state. Increased access is needed for this population as Gamma Knife technology offers significant benefits to patients and payors, as detailed above.

Without the approval of this petition, patients residing in HSAs I, II and III will not have adequate access to Gamma Knife services. As a result, accessibility to treatment options that are considered to be the "gold-standard" will be limited, and the likelihood that patients may experience delays in the treatment and healing process will be increased.

Atrium believes that a special allocation in the SMFP is the only reasonable alternative to develop this service, given the deficiencies of other potential approaches.

NO UNNECESSARY DUPLICATION

As noted above, there are only two operational Gamma Knife units in North Carolina. Based on a review of data, Atrium believes that there is a demand for more than one unit in the western portion of the state and residents of this region do not have adequate access to this service. As a result, the proposed petition for a special allocation of one unit of Gamma Knife equipment in the western portion of the state will not result in the unnecessary duplication of health resources in the area.

CONFORMITY WITH THE BASIC PRINCIPLES

The proposed petition is consistent with the basic principles of the SMFP: safety and quality, access, and value.

Safety and Quality

Gamma Knife procedures are very safe and the level of precision of the radiation beams allow for less damage to normal tissues than other SRS methods. The result is better patient outcomes and fewer complications/negative outcomes.

Access

As noted above, there are only two existing Gamma Knife units in North Carolina and as a result the state, particularly the western portion, has inadequate access to this technology. Nearby states such as Georgia, Virginia, Florida, South Carolina and Tennessee have greater access to Gamma Knife services than North Carolina on a per population basis.

Accessibility of Gamma Knife in Neighboring States

State	Gamma Knives	2018 Population	Population per Gamma Knife
Georgia	5	10,519,475	2,103,895
Virginia	4	8,517,685	2,129,421
Florida	9	21,299,325	2,366,592
South Carolina	2	5,084,127	2,542,064
Tennessee	2	6,770,010	3,385,005
North Carolina	2	10,383,620	5,191,810

Source: Elekta; U.S. Census Bureau

If this petition is granted and ultimately another Gamma Knife unit was developed in North Carolina, the state would have 3,461,207 people per Gamma Knife, slightly ahead of Tennessee, but still far behind many other states.

Value

The expansion of Gamma Knife access will reduce treatment delays associated with alternative SRS configured linear accelerators operating at a high utilization level. Earlier treatment can often lead to lower costs and complications. Atrium estimates that there is adequate patient volume in the western portion of the state to support a Gamma Knife unit. This broad geography will allow a future Gamma Knife provider to draw sufficient volume to efficiently utilize this technology.

SUMMARY

In summary, North Carolina, and specifically the western part of the state, needs an additional Gamma Knife radiosurgical device in order to serve the many patients who would benefit from this important technology. Our citizens are specifically lacking adequate access to the accepted gold standard for cranial radiosurgical therapy. Atrium is uniquely positioned to provide Gamma Knife therapy, due to our large patient volumes, our comprehensive, multi-disciplinary expertise, and our demonstrated, and nationally recognized commitment to advancing the science of radiosurgical care and we respectfully request the SHCC to approve this petition.

REFERENCES

[1]Verhey et al., Comparison of radiosurgery treatment modalities based on physics dose distributions, *IJROBP*, 40(2), p 497-505 (1998)

[2] Mack et al, Quality Assurance in stereotactic space: A system test for verifying the accuracy of aim in radiosurgery, *Med Phys* 29:4 (2002)

[3]Dieterich (2014). SRT II: Uncertainties in SRT [PowerPoint Slides], Retrieved from https://www.aapm.org/education/VL/vl.asp?id=3902

[4]Wang et al., An end-to-end examination of geometric accuracy of IGRT using a new digital accelerator equipped with an onboard imaging system, *Physics in Medicine and Biology*, 57:3 (2012)

[5]Potrebko PS, Keller A, All S, et al. Gamma Knife versus VMAT radiosurgery plan quality for many brain metastases. *J Appl Clin Med Phys*. ;19(6):159–165

[6] HT Chung et al.,Assessment of the accuracy and stability of frameless Gamma Knife radiosurgery, *JACMP*, 2018, 19(4): p. 148-154

[7] C Glide-Hurst & M Bellon et al., Commissioning of the Varian TrueBeam linear accelerator: A multi-institutional study, *Med Phys*, 40:3 (2013)

[8]Gao et al, Evaluation of IsoCal geometric calibration system for Varian linacs equipped with on-board imager and electronic portal imaging device imaging systems, *JACMP,* 15(3) 2014

[9]CLINAC iX Specifications - https://varian.force.com/servlet/servlet.FileDownload?retURL=%2Fapex%2FCpEventPresList%3Fid%3Da0OE000000pZaMdMAK&file=00PE000000VdYOPMA3

[10]Truebeam STx Specifications - https://varian.force.com/servlet/servlet.FileDownload?retURL=%2Fapex%2FCpEventPresList%3Fid%3Da0OE000000pZaMdMAK&file=00PE000000VdZ5OMAV