Stereotactic noninvasive volume measurement compared with geometric measurement for indications and evaluation of gamma knife treatment

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Object. Volume estimation is one of the most important criteria in the evaluation and follow up of radiosurgical treatments and outcomes; however, several limitations are involved in the calculation estimation of target volumes.

Methods. Retrospective and prospective studies were conducted to evaluate the efficacy of a new noninvasive stereotactic method when it is compared with geometric volume calculation of intracranial tumors for planning stereotactic radiosurgery treatment as well as for follow up and outcome evaluation. Two equations were created that permit comparison of the calculated and measured volumes. These equations took linear and quadratic forms, respectively. Volume estimation using the stereotactic approach compared with traditional volume calculation gave more accurate results regardless of the shape and size of the lesion.

Conclusions. The use of stereotactic volume calculation is highly recommended in planning, follow up, and determination of the outcome in patients participating in radiosurgical treatment and should lead to more uniform reports of the response to treatment.

Key Words • intracranial tumor • volume measurement • stereotaxy • gamma knife surgery

Volume measurement in radiosurgery is a crucial function both for deciding whom to treat and for assessing the effectiveness of treatment at follow-up intervals. Thus, it is important to have a reliable and reproducible method to measure volumes. All currently used methods have their problems.

One of the most common methods used to estimate the volume of intracranial lesions is to take the largest diameters seen on CT and/or MR imaging from which a geometric volume assessment is then made.\(^7\)

The product of the diameters is multiplied by a factor 0.52, which results from the quotient of the equation of the volume of the sphere and the equation for the calculation of the volume of the cube:\((4/3 \pi r^3)/(2r)^3 = 3.1416 / 6 = 0.52\).

This approximation of volume measurement has been generally accepted by professionals in imaging departments because all imaging units are equipped with the tools for diameter measurements.\(^6,7\)

This method has limitations because most tumors are not spherical and indeed tend to be more irregular after surgery.\(^2\)

The objective of this current study was to compare stereotactic volume measurement when using GammaPlan (Elekta Instrument AB, Stockholm, Sweden) with geometric volume measurement by using retrospective and prospective analyses. The aim was to determine the level of accuracy and the impact of the two methods on the decision to treat a given patient; we also sought to determine which method is more reliable for the evaluation of the treatment response.

Materials and Methods

The medical records of 100 patients who were treated with GKS and whose treatment volumes were calculated with stereotactic planning software on multiplanar MR and CT images were analyzed.

The GammaPlan system (version 5.34; Elekta Instrument AB) was used to measure the longest diameters of \(x, y,\) and \(z\) lesions previously treated with GKS and they were named \(x', y',\) and \(z'\) in the same way that they are measured in the imaging devices when volumes are being determined.

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To calculate the tumor volumes in 50 follow-up patients, a noninvasive stereotactic method was designed so that the cranial pin fixation method was not used and the patient was positioned on the MR table in the stereotactic frame (Fig. 1), allowing transference of images to the GammaPlan workstation. The targets were outlined on these images in a stereotactic environment derived from the fiducial markers in the Leksell MR indicator box (Elekta Instrument AB).

The spatial distortion in all MR machines was considered and the degree of maximum distortion in the periphery of the magnetic work field was verified with the specific phantom provided by the manufacturer. The value of the x, y, and z coordinates for each fiducial marker in the MR indicator box was checked. The average distortion was 300 μm in the axial plane (range 200–400 μm) in image acquisition with no cranial pin fixation.

The volumes of cases involved in the study were distributed between 0.08 and 24.7 cm³.

The accuracy of image measuring based on the use of maximum diameters and the factor of 0.52 as previously stated was checked against the true volumes measured on GammaPlan both for the day of treatment and on follow-up examinations. A diameter based on calculated volume not more than 2% different from the stereotactically measured volume was accepted. Best approximations between measured and calculated volumes were made using the minimal square method (OriginPro, version 6.1).

Results

The following expressions of the best approximation were obtained to relate the measured and calculated volumes: a linear and a quadratic linear expression were obtained and their relationships are illustrated in Fig. 2. Linear expression: \( V_{gp} = 0.6531 + 0.07160 V_g \), with a 0.9413 correlation coefficient, where \( V_{gp} \) is the GammaPlan volume and \( V_g \) is the geometric volume.

Quadratic expression: \( V_{gp} = -0.1540 + 0.9677 V_g - 0.0091V_g^2 \), with a 0.9060 correlation coefficient.

The high correlation coefficients reflect the extent of scattering of data. The percentage of difference between the geometric calculated volumes (\( V_g \)) corrected from the previous equations and the volume measured with the planning system (\( V_{gp} \)) resulted in wide differences in individual cases. In the case of linear approximation, the percentage of differences were between −802.2 and 35.6%, whereas in the linear quadratic approximation they are in the −160.0 to 187.5% error.

Such differences are inaccuracies in the calculated method arising from the irregularity of the shapes observed while using a calculation tool based on regular shapes. This means more accurate tools for volume calculation are needed. In our sample the stereotactic method was acceptable while other calculated methods are not.

Discussion

This study shows that great care must be taken in interpreting changes in volume based on calculations of maximum diameters in an imaging series. The gold standard for these measurements must be remeasurement within the same MR unit and performing the measurements within a stereotactically definable space.

The review of images obtained in 100 patients treated with GKS demonstrates that volume measurements based on currently accepted calculation methods are not sufficiently accurate for the precision available using GKS. There is a need for volume measurements to be performed within a stereotactically defined space as outlined in this
paper. This could be achieved by one of two methods. Either the patients return to the institution at which they received their treatment or, alternatively, an increased availability of equipment in referring hospitals could enable trained staff to perform the imaging studies within stereotactically defined space. These images could then be sent to the institution where GKS was performed and accurate calculations of the volumes could be made using the original treatment planning software.

Results of treatment today are reported in terms of changes in tumor volume; yet our study suggests that to date no adequate and universal method exists for the calculation of such volumes. A second significant consequence of these findings is that patients may be offered or denied GKS treatment because pretreatment assessment of the volume of the target to be treated may be significantly inaccurate. Our findings suggest that the stereotactic noninvasive volume calculation could be an acceptable method to perform volume calculations at any stage in the management of GKS patients and there is a need for the wider availability and simplicity in use of such equipment.

References


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