Effect of refinement of skull surface measurement on Gamma knife radiosurgery

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Citation

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Abstract

Objective: The calculation of radiation dose and estimation of a skull collision in Gamma Knife radiosurgery (GKRS) are based on measurement of the surface of skull by a skull scaling instrument. This study was conducted to evaluate the measurement discrepancy between the Gamma Knife (GK) skull scaling instrument and actual surface as determined by MRI.Methods: 168 consecutive GKRS patients were included. Discrepancies between those values computed using the skull scaling instrument and the actual MRI were expressed as the difference between the two divided by that measured by MRI.Results: The dosage discrepancy over the deep, middle, and top targets was 3.15±0.31%, 3.51±0.37%, and 4.49±0.41%, respectively (p<.001). Mean difference in collision measurement by the caliper and predicted by the GK workstation was 4.75±0.07mm (p<.05).Conclusion: Significant differences exist in measurements between skull scaling instrument and those based on MRI. Refinement of skull measurements would make GKRS more precise.

INTRODUCTION

Gamma Knife has become an important tool in neurosurgery; it is commonly employed in the treatment of patient's with brain tumors, arteriovenous malformations, or functional disorders such as trigeminal neuralgia.[7,8,10,11] The clinical and imaging outcome are related to treated volume, radiation dose, and the disease pathology. Radiosurgery can occasionally lead to complications such as neurological deficits, radiation edema, and radiation necrosis.[4,8] The prescribed radiation dose is a function of collimator size, power of radiation source and depth of target. In Gamma Knife surgery, the calculation of depth to the target depends on the skull surface reconstructed from the 24 measurement points from the Gamma Knife (GK) skull scaling system. Interpolated contours from the skull scaling system are not always consistent with the known definition of the skull as depicted on a stereotactic MRI.[1] Such inconsistences of skull measurement from the skull scaling system may lead to inaccuracies in dose calculations and skull collisions with the collimator. Thus, the refinement of a skull surface could afford a better determination of radiation dose with fewer measurement errors and interpolated errors.

The Gamma Knife radiosurgical technique in targeting a lesion requires adjustment of the patient's head and frame position within the collimator. In very extreme location, skull and frame collisions with the collimator may arise. The Gamma Knife workstation used the same skull interpolation system to detect collisions. Due to discrepancies in skull surface estimation, collisions may also not be always accurately predicted. Investigating the actual skull surface by MRI could refine the skull surface and improve pretreatment collision prediction.

Refining the skull surface measurement could augment the accurate dosage calculation and better predict the collision at the moment of Gamma knife radiosurgery. In this study, we projected the skull surface reconstructed from the interpolated lines from the skull scaling system to the MRI imaging. The surface discrepancy in these two different measurements on the top, frontal, lateral, posterior fossa, and screw site were determined. Throughout understanding the skull surface measurement difference exiting in Gamma knife radiosurgery; it shed the light that the refinement of surface of skull could contribute accurate dosage delivery and enhance the prediction power of collision estimation in Gamma Knife radiosurgery.

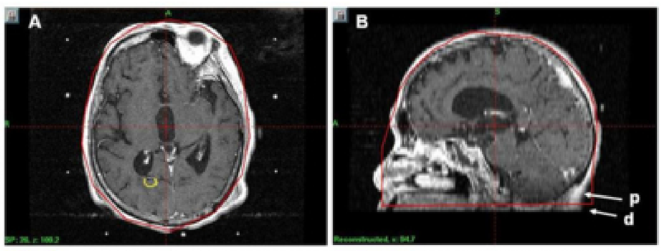
MATERIALS AND METHODS

168 consecutive patients who received Gamma Knife (GK) radiosurgery (model C, Elekta AB; Stockholm, Sweden) were entered into this study. In addition to the required MRI

(GE, EXCITE-HD, 1.5 Tesla, USA) sequence for Gamma Knife radiosurgery, all patients received a whole brain MRI using a T1 sequence with 3mm thickness from the top 1 cm above the scalp at the vertex to the skull base (C1-2 junction). The interpolated lines from the points measured by the GK skull scaling instrument (Elekta AB; Stockholm, Sweden) were projected into the MRI imaging (whole brain) (Figure 1A). The skull volumes were calculated by the product of surface area in each brain slices and thickness of MRI (3mm). In the lower part of brain without the interpolated line projection, the volume was calculated by the surface area of the last slice of MRI multiplied by the height (Figure 1B). The whole skull volume was the summation of the volume with and without interpolated line projection. Another method in skull volume measurement was based on the surface area in each MRI slices multiplied by the thickness of MRI (3mm).

Figure 1

Figure 1: Illustration of interpolated line measured by skull scaling and volume measurement (A) Interpolated line measured by skull scaling was projected to MRI (T1 sequence) for volume calculation (B) The whole tumor volume was summation of the height of the reconstructive MRI without interpolated line projection multiplied by surface area of last slice MRI and volume measured in (A).



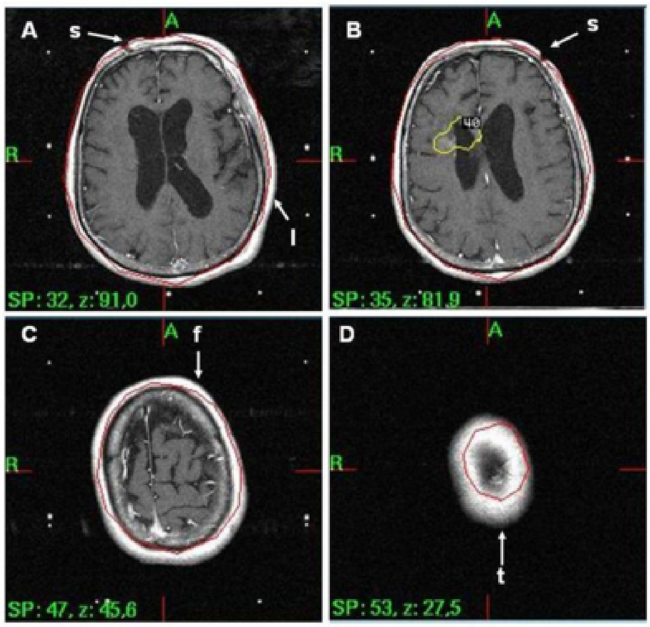
d: distance between interpolated line and surface of the MRI

h: height of the reconstructive MRI without interpolated line projection

The maximum distance between the lines projected from the skull scaling measurement and surface line from the MRI were recorded over the top, frontal, lateral, posterior fossa, and screw penetration area (Figure 2). These distance discrepancies were computed with regard to top, frontal, lateral, posterior fossa, and screw distance measurements. The ratio of volume discrepancy was defined as the volume difference between the two measurements divided by that measured by MR imaging.

Figure 2

Figure 2: Illustration of distance discrepancy (A) Illustration of right screw distance discrepancy and lateral screw discrepancy (B) Illustration of left screw distance discrepancy (C) Illustration of frontal screw discrepancy (D) Illustration of top distance discrepancy; s: screw distance discrepancy; l: lateral distance discrepancy; f: frontal distance discrepancy; t: top distance discrepancy



The dosage discrepancy was determined by the time interval to achieve the same peripheral dosage calculated from the Gamma Knife (GK) skull scaling instrument divided by that by the surface of MRI. The dosage calculation based on the MRI surface was achieved by the fine adjustment of depth of 24 points from GK skull scaling system to approach the MRI surface. The ratio of dosage discrepancy was presented by ratio of the time interval calculated from skull scaling system and MRI.

The radiation dosage delivered to the target depended on the depth of the target due to the radiation dosage reciprocally related to the distance from the skull surface. The ratio of dosage discrepancy related to different location of targets was computed. The locations of target at the pituitary fossa, brain stem, and cerebellum were defined as deep targets. The lesions located between the sellar and lateral ventricular body were defined as middle targets. Any lesions above the ventricular body were defined as top targets. The ratio of dosage discrepancy related to different locations was computed.

In collision evaluation, the distance between the skull/frame/screw and helmet was measured by a fine caliper and defined as the measured collision distance. The collision distance predicted by Gamma Knife work station was defined as the predicted collisions distance. The collisions discrepancy was defined as the distance difference between the predicted clearance by the Gamma Knife work station and the actual measured collision distance.

The value was presented as the mean± SE (standard error of the mean). Student t test was used to determine the volume difference between groups. The linear regression was used to measure contributing factors related to volume discrepancy and collision discrepancy.

RESULTS

The mean skull volumes (+/- standard error of the mean) measured by the GK skull scaling instrument and MRI were 3258.99± 30.74 cc and 3520.67± 35.03 cc, respectively ($p<0.0001$). The ratio of volume discrepancy was 8.05±0.41 %. The measurement discrepancy over the top, frontal, lateral, and posterior fossa area was 9.1±0.3, 5.5±0.11, 3.4±0.11, and 5.61±0.14mm, respectively ($p<0.001$). The ratios of volume discrepancy were significant related to distance discrepancy of the top, frontal, lateral, and posterior fossa (Figure 3). However, the distance discrepancy over top, frontal, and lateral skull surfaces contributed to most of the measurement errors (Table I).

Figure 3

Figure 3: Dispersion graph showing the relation between the ratio of volume discrepancy (%) and dosage discrepancy (%) segregated by top, middle and deep target.

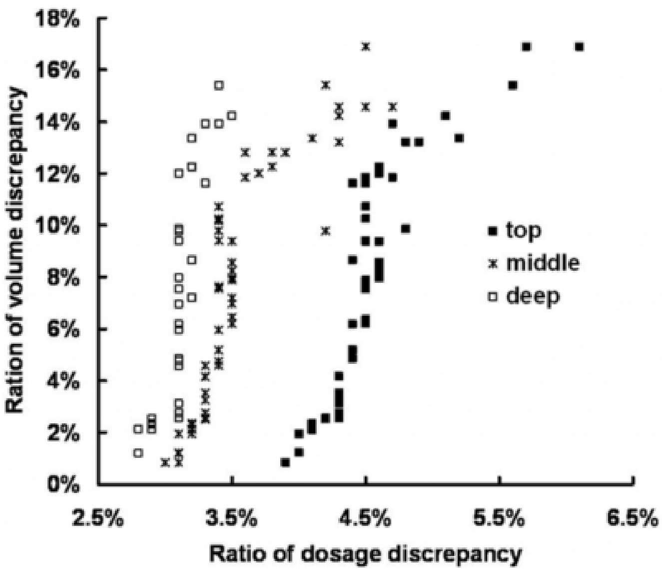


Figure 4

Table 1: Factors related to Skull volume data errors

Location	Ratio of volume discrepancy Pearson Correlation coefficient	p-value
Top	0.9393	<0.001
Frontal	0.786	<0.001
Lateral	0.769	<0.001
Posterior fossa	0.277	<0.001

The dosage discrepancy was 3.79±0.66% in the whole series. The dosage discrepancy over the deep, middle and top target was 3.15±0.31%, 3.51±0.37%, and 4.49±0.41%, respectively ($p<0.001$). The dosage discrepancy existed between top and middle target ($p<0.0001$), middle and deep target ($p<0.001$), and top and deep target ($p<0.001$), respectively.

The volume discrepancy was significantly correlated to the dosage discrepancy ($R^2=0.457$, $p<0.001$). The dispersion between the volume and dosage discrepancies segregated by different location of targets such as deep ($R^2=0.831$, $p<0.001$), middle ($R^2=0.906$, $p<0.001$), and top ($R^2=0.872$, $p<0.001$) was depicted in Figure 3.

One hundred and eleven shots were associated with collisions in Gamma Knife radiosurgery. The mean collision distance predicted by the Gamma knife workstation was 8.07±0.23mm. The collision distance measured by fine caliper at the moment of Gamma Knife radiosurgery was 3.32±0.21mm. The collision distance discrepancy between the prediction and measurement was 4.75±0.07mm. The difference in collision distance was related to the top, frontal, lateral, posterior fossa, and screw distance discrepancy illustrated in Figures 4 and 5. The statistical results of correlation coefficient and p value are depicted in Table II. The difference in collision distances was strongly related to the screw, frontal and top distance discrepancies. The screw distance discrepancy had the greatest power in estimating collision in Gamma Knife radiosurgery (Figure 6).

Figure 5

Figure 4: Dispersion graph showing the relation between the ratio of volume discrepancy (%) and distance discrepancy (mm). Dispersion graph showed the ratio of volume discrepancy and top distance discrepancy (A), frontal distance discrepancy (B) lateral distance discrepancy (C) , and posterior fossa discrepancy (D).

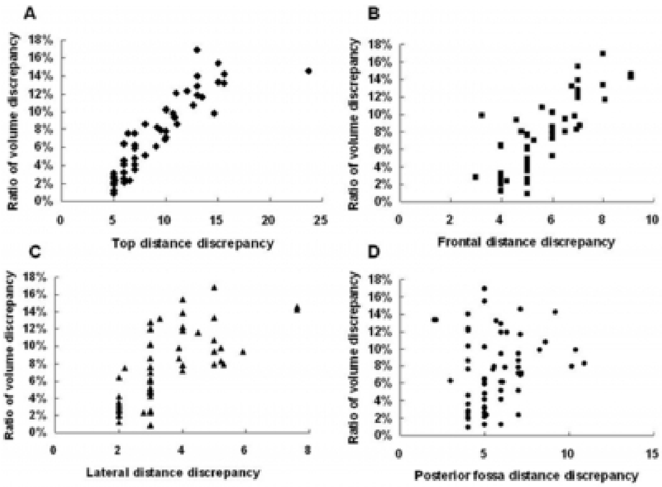


Figure 6

Figure 5: Dispersion graph showed the collision discrepancy (mm) and distance discrepancy (mm). Dispersion graph showed the collision discrepancy and top distance discrepancy (A), frontal distance discrepancy (B), lateral distance discrepancy (C), and posterior fossa discrepancy (D)

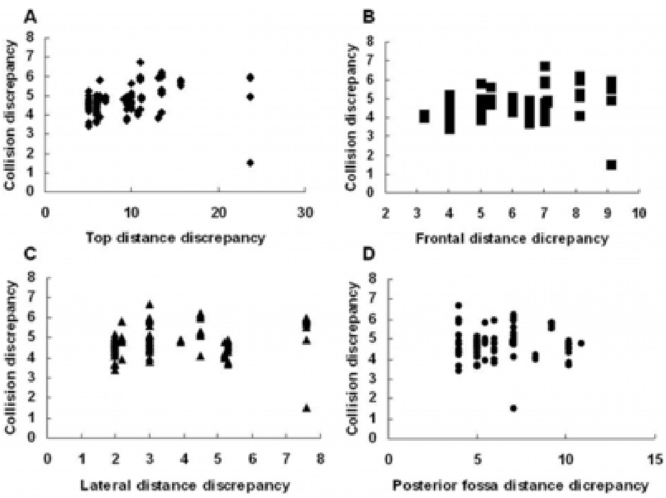


Figure 9

Figure 6: Dispersion graph showing the relationship between the collision discrepancy (mm) and screw distance discrepancy (mm). The straight line represents the algebraic expression: y=1.029+0.86x (r=0.611; R=0.3; p

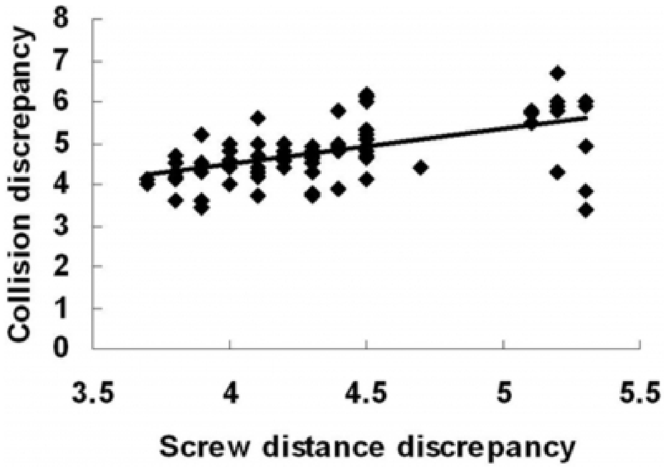


Figure 8

Table 2: Factors related to distance discrepancy between predicted and actual fine caliper measurement

Location	Distance discrepancy in collision Pearson Correlation coefficient	p-value
Top	0.521	<0.001
Frontal	0.596	<0.001
Lateral	0.307	0.001
Posterior fossa	0.198	0.037
Screw	0.611	<0.001

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DISCUSSION

The surface of the skull in Gamma Knife radiosurgery is typically reconstructed from a 24 points measurement by GK skull scaling system. The volume of the skull measured by the GK skull scaling was underestimated as compared to those measured from the surface of MRI. As such, the prescribed dosage to the region of interest in Gamma Knife radiosurgery may be overestimated. Based on the recognition of this discrepancy between the interpolated line from GK skull scaling and the actual data from MRI, the estimation of a collision could be refined. From our study, better delineation of the skull surface could more precisely define the radiosurgical dose calculations as well as provide a more accurate estimation of a collision in Gamma Knife radiosurgery. Overestimation of collisions from incorrect skull contours may lead to suboptimal placement of isocenters in an attempt to avoid collisions. In reality, a more accurate skull contour can allow for optimal isocenter placement and maximal reach in the model C, 4C, and Perfexion Gamma Knife units.

The application of intracranial volume measurement by MRI in prediction of severity of Parkinson and multiple sclerosis has been established.[5] The reconstructive skull surface from a CT scan is commonly utilized method for X-Knife radiosurgery, Cyberknife, or Tomotherapy.[239] In Gamma knife radiosurgery, the skull surface measurement remains rendered by an interpolated line algorithm based upon a 24 points measurement from the GK skull scaling system. This may result in different radiation dosage calculations because of inaccurate skull surface renderings.

In this study, we found that there were significant skull surface discrepancies between the GK skull measurement system and that computed on the basis of the actual MR imaging. The discrepancy of radiation dosage delivered to the target depended on the depth of the target due to the radiation dosage reciprocally related to the distance from the skull surface. For example, a pituitary tumor was located at the center of head and the distance from the skull to pituitary tumor was assumed to be 14 cm. A skull measurement discrepancy of 5 mm over the scalp contributes a dosage error of approximately 3.6% in single hole of collimator. However, some tumors such as parasagittal mengiomas or brain metastases may be located within 1 cm of the skull surface. In this case, a skull measurement discrepancy of 5 mm would contribute to nearly 100% dosage error in single hole of collimator. The dosage discrepancy calculated at different depth of targets showed the same trend. The more superficial target showed the more dosage discrepancy, which could reach as high as 4.49±0.41%. In deep lesion, the dosage discrepancy was at least 3.15±0.31%. From this point of view, the refinement of skull measurement could improve the accuracy of dosage calculation in Gamma Knife radiosurgery.

The Gamma knife radiosurgical technique in targeting a lesion involves adjusting the target towards the center of the collimator. In very extreme location such as very lateral or posterior fossa, there are possible collisions of the patient or frame with the collimator. Even for new Perfexion Gamma Knife radiosurgery, the possibility of a collision remains.[6] Based on the Gamma knife workstation algorithm for estimation of collision which is derived of the skull and frame measurements, there should be at least a 12 mm clearance to consider an isocenter “safe” and reachable for Gamma Knife radiosurgery. In isocenters with collision distance less than 12mm, the possibility of real physical collision may be recognized at the moment of treatment. If the collision was met at the treatment, the radiosurgical treatment would have to be altered by angle change, movement of the isocenter, or adjustment of the stereotactic frame. In this study, we found that there was discrepancy in collision predicted by Gamma Knife work station and the actual clearance distance measured at the Gamma Knife treatment. The actual collision distance at the moment of Gamma Knife radiosurgery was around 3.32±0.22mm. The mean discrepancy between the measurement and prediction was 4.75±0.07mm which were highly related to screw distance discrepancy of 4.34±0.4 mm. This indicated that safe collision discrepancy could be reduced to as short as 3.32 mm. Furthermore, the screw distance discrepancy measured from the MRI could also be an indicator to evaluate the possibility of shot collision in Gamma Knife radiosurgery. By having a more accurate MRI based rendering of the skull and frame, Gamma Knife radiosurgical collisions can be more accurately predicted.

CONCLUSION

There existed significant differences between the skull surface rendering derived from the interpolated line algorithm based on GK skull scaling system and that derived from the actual MR imaging. Refinement of the skull surface measurement by MRI could permit more accurate dosage calculations and enhance the power to predict isocenter collisions in all models of the Gamma Knife.

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