A New Methodology for Laboratory Evaluation of Neurosurgical Approaches Based on the Volume and Shape of the Surgical Space with a Mathematical Model to Quantify the Surgical Maneuverability in Laboratory Settings*

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Abstract

We conducted this study to validate the volume/shape of the surgical exposure and to introduce a mathematical model to quantify the maneuverability in a surgical space. We executed the pterional and lateral supraorbital approach four times in fresh cadavers in skull base laboratory. The surgical volumes were filled with a computed tomography (CT)-imageable mixture; CT scans were obtained to evaluate the volume and shape of the surgical space. The volume of the surgical space was 23.60 and 32.90 mL for the lateral supraorbital and pterional approach, respectively, ($p < 0.05$). The three-dimensional shape of the lateral supraorbital approach was cylindrical and that of the pterional approach pyramidal. The volume of the surgical approach can be used to define, together with other variables, the maneuverability (maneuvering in a surgical volume) by using the following formula $M \approx \frac{AV}{L}$ where M , A , V , and L represent the maneuverability, the degree of the surgical freedom, the volume of the surgical exposure, and the surgical depth, respectively. Volume and shape of the surgical exposure are two objective parameters that can be used to define and contrast different microsurgical approaches in a laboratory setting. The volume of the surgical exposure may be integrated into a mathematical formula defining maneuverability.

Keywords

- anatomical study
- cadaveric study
- neurosurgical approach
- surgical operability

Different neurosurgical approaches should be compared and contrasted based on the ability to safely perform neurosurgical maneuvers in the surgical volume exposed (operability) and on the approach morbidity. While an approach may only be validated by clinical practice, a significant amount of information may be gathered by anatomical investigations. Therefore, it is helpful to characterize and contrast different approaches in a laboratory setting. To that effect developing new methodologies and refining those already available is

critical to increase the objectivity and usefulness of the data gathered in anatomical investigations.

In this article, we propose the volume of the surgical exposure and the shape of the surgical corridor as important parameters that can be obtained in laboratory settings to define neurosurgical approaches. We investigated a laboratory model that provides the ability to evaluate these two parameters. Then, we showed how the volumetric information provided can be integrated into a theoretical mathematical model of the surgical maneuverability associated with a given neurosurgical approach in a laboratory setting.

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Figure 1 Microscopic view showing the insertion of the computed tomography–imageable mixture into the surgical space (left and right).

This mathematical model combines the value of the volume of the surgical exposure, with the degree of the surgical freedom and with the depth of the surgical approach.

The overall aim of this article is to enhance the research methodologies in anatomical neurosurgical laboratories.

Materials and Methods

Specimens

We used four fresh noninjected human cadaver heads. Uninjected cadavers were used to avoid any interference with the planned computed tomography (CT) scanning of the specimens.

Filling Material

The filling material consisted of pieces of fat harvested from the cervical area of the specimens. The fat pieces were first cut into small pieces, then soaked in iohexol (Omnipaque 300) for

~30 minutes and finally mixed with ~50 mL of silicone rubber (3110 RTV silicone rubber; Dow Corning, Midland, MI). The silicone rubber rendered the fat pieces sticky so that they would not move from the original location at which they were placed.

Imaging Protocol

High-resolution CT scans were obtained for every specimen: slice thickness, 1 mm, contiguous nonoverlapping slices; gantry setting, 0 degrees; scan window diameter, 225 mm; pixel size, $>0.44 \times 0.44$.

Neuronavigation System

The planning software (iNtellect Cranial) of the Stryker Navigation System (Stryker Instruments, Kalamazoo, MI) was used to segment the fat–silicone mixture inserted into the surgical cavity.

Figure 2 Microscopic view showing the dry piece of cotton interposed between the mixture filling the surgical cavity and the dura (left). On the right the dural closure is shown.

Figure 3 The volume of the exposed surgical space. Notice that the volume associated with the pterional approach is significantly greater than that of the lateral supraorbital approach ($p < 0.05$).

Surgical Procedure

A total of eight neurosurgical procedures were performed using a surgical microscope (OPMI-CS; Carl Zeiss, Oberkochen, Germany) and standard microsurgical instruments.

The surgical approaches used were the pterional approach as described by Yasargil,^{1,2} and the lateral supraorbital approach as described by Hernesniemi.^{3,4}

Every approach was executed four times, twice on the left side and twice on the right side.

The head was kept in the surgical position by using a Spetzler headrest (V Mueller, McGaw Park, IL). The surgical cavity was filled with the fat-silicone mixture (►Fig. 1) under minimal brain tissue retraction. We surrounded the mixture material with a thin layer of dry cotton so as to make the CT-imageable mixture match as much as possible the surgically exposed space and hence minimize the mixture leak into surrounding topographical areas. Even though this measure

may have prevented major leaks, the mixture still might have run over into neurovascular structures (►Fig. 2).

Segmentation

The image dataset was imported to the neuronavigation working station. We then proceeded to manually segment the fat-silicone mixture that had been used to fill the surgical cavity. The volume of the fat-silicone mixture was then automatically calculated. This volume was equated with the surgical volume exposed. We also extracted a three-dimensional (3-D) image of this volume.

Statistical Analysis

Results were compared using a paired *t*-test by using the commercially available MedCalc software for Windows, version 9.6.3.0 (MedCalc Software, Mariakerke, Belgium).

Results

- The fat-silicone mixture was visible in all the specimens examined, and the segmentation process was successful in all specimens.
- The model was able to pick up differences in the volume exposed by the two surgical approaches examined. In fact the mean volume of the surgical space was 23.60 cc (SD 3.4; range 20.37 to 28.22) for the lateral supraorbital approach, and 32.90 cc (SD 4.11; range 28.53 to 37.78) for the pterional approach ($p < 0.05$) (►Fig. 3).
- The model highlighted the relationships between the surgical exposure and the radiological counterparts (►Figs. 4 and 5).
- The model showed differences in the 3-D shape of the different surgical corridors. ►Figures 6 and 7 show the 3-D

Figure 4 Axial, coronal, and sagittal computed tomography images showing the surgical space exposed by the lateral supraorbital approach as demonstrated by the mixture filling the space.

Figure 5 Axial, coronal, and sagittal computed tomography images showing the surgical space exposed by the pterional approach as demonstrated by the mixture filling the space.

objects representing the surgical space provided by each approach. These virtual objects show the 3-D shape of the surgical space afforded by the two approaches examined, and the relationships between this space and the coronal and the axial planes of the brain. The shape of the surgical exposure space provided by the lateral supra-orbital approach approximated that of a cylinder while that of the pterional approach approximated that of a pyramid.

- The volume of the surgical exposure (V) was integrated with the depth of the surgical target (L) and with the surgical freedom (A) into a mathematical formula attempting to correlate factors related to maneuverability (M) in a laboratory setting, giving the following equation:

$$M \approx \frac{AV}{L}$$

Figure 6 Three-dimensional object depicting the shape of the surgical exposure provided by the lateral supraorbital approach and its relationships with the coronal and axial planes of the brain. This object is cylinder shaped.

Figure 7 Three-dimensional object depicting the shape of the surgical exposure provided by the pterional approach and its relationships with the coronal and axial planes of the brain. This object is pyramid shaped.

Discussion

Evaluation of Neurosurgical Approaches in a Laboratory Setting

Laboratory evaluation of different neurosurgical approaches may be looked upon as a phase one study demonstrating feasibility. The most important approach features that can be evaluated in such models are surgical maneuverability and approach anatomical morbidity.^{5,6} Surgical maneuverability may be defined in a laboratory setting as the ability to maneuver in a surgical volumetric space and has so been defined by others.⁷ Several parameters are related to maneuverability in a laboratory setting. These parameters include the ability to reach the target from different angles, the depth of the target, and the volume of the surgical corridor.⁸ The built-in anatomical morbidity of each approach should be clearly spelled out; however, it is a descriptive variable and can be easily derived from the approach description.

The Importance of the Surgical Space Volume in Evaluating Neurosurgical Approaches

It is obvious from observations during real surgical practice that the hands of the neurosurgeon and the surgical instruments move in 3-D space. Consequently, surgical space volume is more closely linked to surgical maneuverability than surgical surface area.

However, calculation of surgical space volume is challenging and this is probably why surgical surface area has been often reported as a relevant feature of different surgical approaches.

The Significance of Our Model

A large number of neurosurgical approaches to extra- and intracranial regions have been described and continue to be described on a regular basis. For example, if one looks at the March through June 2010 issues of the two major North American neurosurgical journals one finds at least 14 articles dealing with refinements, comparisons, or evalu-

ation of different neurosurgical approaches. (Please see *Journal of Neurosurgery* and *Neurosurgery*, March through June 2010.) These approaches have different degrees of complexity and overlap. Having objective tools to evaluate and contrast these different approaches could be helpful to sift through them.

Operability defined as the ability to safely and efficiently operate on the surgical target is the ultimate goal of any neurosurgical approach and can only be evaluated clinically. It is the final output of tangible and intangible factors. The most important intangible factor is represented by the technical skill of the surgeon that is clearly difficult to quantify. The target pathology is another important intangible factor that contributes to operability. Nevertheless, in laboratory setting only the tangible factors can be evaluated, so in this article we used the term maneuverability to define the aggregate contribution of the tangible factors examined.

The tangible factors are represented by the capability of exposing the target from multiple angles, by the depth of the target, and by the surgical volume of the exposure. We and others described in previous publications how to calculate the degrees of the surgical freedom and the surgical depth.⁸⁻¹² For angle measurements (surgical freedom), the angle can be defined as the angle of freedom of the movement of the instrument that can be measured in both the vertical and horizontal planes. This has been measured with image guidance systems by placing the tip of a preregistered instrument firmly at the selected target, while the handle moves in both the vertical and horizontal planes until further motion is restricted: the corresponding angles are then measured.¹² The angle can also be measured directly after the apex of the angle is placed at clearly defined targets.¹³ The surgical depth can be measured by calculating the distance between two selected points and this can be done by direct measurement or by using a neuronavigation system preregistered instrument tip to get the system's coordinates for each point.^{9,10,12} Then, the distance from one point to the other is calculated in millimeters using the following formula:

$$\sqrt{((x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2)}$$

While multiangled exposure and depth of the target have been described in the past and are generally accepted parameters to describe a surgical approach,^{4,8-14} the surgical volume of the exposure has not been utilized to describe surgical approaches in a laboratory model. Instead the area of the exposure has been used as its two-dimensional (2-D) surrogate.^{9,10,12} Clearly, as neurosurgical operations take place in 3-D space, the volume and the 3-D shape of the surgical space exposed are important variables in describing a surgical approach. The volume of the surgical space seems to be a better metric in describing a surgical approach than 2-D metrics such as areas. Furthermore, it is intuitive that operability, which is a clinical quantity and is therefore outside the scope and not evaluated by this article, is enhanced when the surgical space centered on the target is larger. Hence there is value in describing, in a laboratory model, the volume of the surgical space exposed. Describing the shape of a surgical approach makes understanding of the 3-D volume of the approach easier to communicate and may point to approach differences.

Hence the surgical space volume and its shape are important attributes of surgical approaches and both may be easily and objectively obtained by using our model. Therefore objective comparisons between different approaches to the same area may be based on the surgical volume exposed by each different approach as well as on the shape of the surgical corridor.

Our results show that our laboratory model is reliable, as it is able to reveal significant differences in the surgical exposure volume between the two approaches examined ($p < 0.05$) (►Fig. 3). It also shows differences in the 3-D shape of the surgical corridor linked to these two approaches (►Figs. 6 and 7).

In addition our model gives a good radiological correlation between the approach examined and the exposed anatomical area; this correlation may be useful clinically to match the area exposed by a particular approach to the topographical location of the clinical pathology at hand.⁶

Combination of the above information provides a reliable and objective way to characterize and contrast different surgical approaches.

Using The Volume of The Surgical Exposure to Assess Operability: A Proposal for A Mathematical Model of Operability

The volume of the surgical exposure, the depth of the target, and the ability to reach the target from different angles (or the surgical freedom which in this model should be looked at as the best surgical freedom that could be achieved when all the other variables, including the surgeon's skills, are constant) are all factors that are linked, by everyday surgical experience, to operability. These factors and their relationships may be incorporated into a mathematical model.

As our investigation was a laboratory one, we substituted the term maneuverability for operability. Hence the mathe-

matical value of theoretical operability (that we call maneuverability because this is a laboratory and not a clinical investigation) for a given neurosurgical approach can be calculated by using the following formula:

$$\text{where } M \approx \frac{AV}{L}$$

- M represents the maneuverability
- A represents the degree of the surgical freedom
- V represents the volume of the surgical exposure
- L represents the surgical depth

The above equation has been derived from the following principles: keeping everything else equal, the maneuverability associated with a given neurosurgical approach increases as the volume of the surgical approach increases. In the same way it increases as the degree of the surgical freedom increases. But, it decreases as the surgical depth increases. Mathematically, we can represent the relationships between the operability and every single variable alone as follows:

$$M \propto V \quad M \propto A \quad M \propto \frac{1}{L}$$

So, the relationship between maneuverability and the all the above variables can be represented in one mathematical relationship:

$$M \propto \frac{AV}{L}$$

Now, we can convert the above relationship to a mathematical model by virtue of the following equation:

$$M = C \frac{AV}{L}$$

where C is a constant representing intangible clinical factors (neurosurgeon's skills, pathology type, technology, patient general health, etc.) that contribute to operability.

For simplification we can ignore the constant from the above equation thus deriving the final maneuverability equation:

$$M \approx \frac{AV}{L}$$

From the previous formula, estimating the surgical maneuverability for a given neurosurgical approach requires knowledge of the degree of the surgical freedom, of the volume of the surgical exposure, and of the surgical depth.

Limitation of The Present Study

Our model was developed and tested in cadavers, and has all the limitations of a cadaver study. In this particular study lack of cerebrospinal fluid and presence of cadaveric brain stiffness are relevant specific limitations. Of course the lack of circulation is a limitation of all cadaveric studies.

Our study was performed in normal brains devoid of pathology. Clearly large brain tumors significantly deform the surrounding anatomy thereby limiting the applicability of this model to patients with larger mass lesions.

Conclusion

In this article we provide, in an easy and reliable way, objective measurements of the surgical space and of the surgical shape associated with different surgical approaches, making objective comparison among different approaches possible in a cadaver model. In addition we provide a mathematical model based on degrees of freedom, depth, and volume of the exposure that is useful to objectively evaluate different surgical approaches.

This article should be looked at as an adjunct to other neurosurgical research methods that have been used in neurosurgical anatomical studies and should be looked upon as a tool to foster understanding of the differences among neurosurgical approaches. Clearly the proposed tool may be further refined and expanded.

References

- 1 Yasargil MG, Antic J, Laciga R, Jain KK, Hodosh RM, Smith RD. Microsurgical pterional approach to aneurysms of the basilar bifurcation. *Surg Neurol* 1976;6(2):83–91
- 2 Yasargil MG. *Microneurosurgery*. Stuttgart-New York: Georg Thieme Verlag; 1984:215–233
- 3 Hernesniemi J, Ishii K, Niemelä M, et al. Lateral supraorbital approach as an alternative to the classical pterional approach. *Acta Neurochir Suppl (Wien)* 2005;94:17–21
- 4 Romani R, Lehecka M, Gaal E, et al. Lateral supraorbital approach applied to olfactory groove meningiomas: experience with 66 consecutive patients. *Neurosurgery* 2009;65(1):39–52, discussion 52–53
- 5 Ammirati M, Bernardo A. Analytical evaluation of complex anterior approaches to the cranial base: an anatomic study. *Neurosurgery* 1998;43(6):1398–1407, discussion 1407–1408
- 6 Ammirati M, Kim HK, Cho YD. Anatomic-radiological evaluation of lateral approaches to the skull base. *Skull Base Surg* 1998;8(3):105–117
- 7 Di Rocco F, Oi S, Samii A, et al. Neuronavigational endoscopic endonasal sellar and parasellar surgery using a 2-mm-diameter lens rigid-rod endoscope: a cadaver study. *Neurosurgery* 2007;60(4, Suppl 02):394–400, discussion 400
- 8 Clatterbuck RE, Bernardo A, Spetzler RF. Discovering the novel surgical approach. *Clin Neurosurg* 2003;50:36–44
- 9 Figueiredo EG, Deshmukh P, Nakaji P, et al. The minipterional craniotomy: technical description and anatomic assessment. *Neurosurgery* 2007;61(5, Suppl 02):256–264, discussion 264–265
- 10 Figueiredo EG, Deshmukh P, Zabramski JM, Preul MC, Crawford NR, Spetzler RF. The pterional-transsylvian approach: an analytical study. *Neurosurgery* 2008;62(6, Suppl 03):1361–1367
- 11 Jittapiromsak P, Little AS, Deshmukh P, Nakaji P, Spetzler RF, Preul MC. Comparative analysis of the retrosigmoid and lateral supracerebellar infratentorial approaches along the lateral surface of the pontomesencephalic junction: a different perspective. *Neurosurgery* 2008;62(5, Suppl 02):ONS279–ONS287, discussion ONS287–ONS288
- 12 Pillai P, Baig MN, Karas CS, Ammirati M. Endoscopic image-guided transoral approach to the craniovertebral junction: an anatomic study comparing surgical exposure and surgical freedom obtained with the endoscope and the operating microscope. *Neurosurgery* 2009;64(5, Suppl 02):437–442, discussion 442–444
- 13 Tanriover N, Ulm AJ, Rhoton AL Jr, Yasuda A. Comparison of the transvermian and telovelar approaches to the fourth ventricle. *J Neurosurg* 2004;101(3):484–498
- 14 Ulm AJ, Tanriover N, Kawashima M, Campero A, Bova FJ, Rhoton A Jr. Microsurgical approaches to the perimesencephalic cisterns and related segments of the posterior cerebral artery: comparison using a novel application of image guidance. *Neurosurgery* 2004;54(6):1313–1327, discussion 1327–1328