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Neurosurgical stereomorphometry *in vivo* — method description and error measurement

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Rules of geometry and stereomorphometry are often applied to narrow and deep neurosurgical approaches. Methods of research are based on the direct cadaver measurements, radiological analysis and intraoperative measurements. Newly developed devices allow direct morphometry to be performed in vivo, *during the operation.*
We describe the use of the neuronavigation system Stealth Station by Medtronic for such stereomorphometric measurements and evaluate the precision of the described method.

key words: neuronavigation, morphometry, skull base

INTRODUCTION

Skull base surgery is often a technically demanding and time-consuming procedure. Precise guidelines are often lacking. The application of stereomorphometric methods in neurosurgery allows us to compare such approaches and to optimise them. But any measurements of operative field and intraoperative landmarks are always difficult and erroneous. They could by substituted by cadaveric dissection [1, 5] or radiographic analysis [4].

A new technique named neuronavigation allows for direct measurements of coordinates in the three-dimensional space of the chosen points in real time. This sophisticated method, available commercially for six years, may be easily used for intraoperative stereomorphometry [3]. Its use has been described previously in the measurements of approaches dissected on the cadavers.

Neuronavigation systems, known also as frameless stereotactic systems, use tethered arms, ultrasound, infrared light emitting diodes or magnetic field to localise surgical instruments in three-dimensional space and to correlate their localisation with radiographic images [2]. Optical technology, which is the most widely used, has a reported accuracy of 2 to 4 mm [2].

We describe the way of measuring areas of approaches performed during real neurosurgical operations. We compare the accuracy of this method to the traditional way of measuring the surface with a ruler.

MATERIAL AND METHODS

Description of the intraoperative stereomorphometry method

We use the neuronavigation system named Stealth Station Mach 3, manufactured by Sofamor Danek Medtronic, USA. The image data file of a patient's head from the magnetic resonance imaging device or computed tomography device is usually transferred to the neuronavigation system with the help of magnetooptic discs. Once the data are copied, the operation starts in the usual way. The registration of the patient is performed and craniotomy is continued. After completing the registration procedure, which lasts about five minutes, the system reports the registration error.

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When the stage of the operation in which the stereomorphometry should be performed is reached, the location of five points, designing a pentagon, is registered. The operating surgeon has to mark the point, and an assistant stores the location of this point as a target or an entry point of a trajectory.

It was a point of question to us how to store the coordinates of a selected point during the operation in such a way that it could be measured and analysed after the procedure. The system in its standard configuration does not allow us to read the direct coordinates of the measured point in space. Measurements of surfaces or distances during the operation are possible but significantly prolong the operation and distract the surgeon's attention in a way that is not acceptable. Obviously it would not be ethical to prolong the operation of any patient solely for scientific measurements.

The Stealth Station allows us to store up to 10 trajectories, called "plans". Each plan is based on two points — the entry and the target point. These points can be stored in a fast and easy way during the operation, therefore, they are ideal for *in vivo* stereomorphometry.

The set of five points stored in a selected stage of the neurosurgical approach defines a pentagon (Fig. 1). Distances between the points selected and stored in memory can be measured after the operation. The surface of the pentagon may be measured in a couple of ways. We used to divide the pentagon into three triangles and measure their area. The area of the pentagon is simply the sum of the triangles' areas.

Error measurement method

The traditional method of surface measurements and the neuronavigation measurements were compared. A pentagon was drawn on the resin phantom of the human head. The area of the pentagon was measured with a compass and a ruler based on the rule of triangles. The ruler had a 1-millimetre scale. The area of the pentagon was the sum of the areas of the three triangles. Their areas were calculated from the lengths of their sides.

Then the computed tomography of the phantom was performed and the data were sent to the neuronavigation system. The area of the pentagon was measured in the same way, as described above, during the real operation. The measurement was repeated 10 times. The reported internal system error during the experiment was 1.3 mm.

One-way analysis of variance was performed with the data sets. The statistical significance of the differences between measurements with a ruler and measurements with navigation was tested.

RESULTS

The results of the direct measurements of the pentagon's area with the ruler are described in Table 1.

The results of the measurements of the pentagon's area with the neuronavigation system are shown in Table 2.

There is no statistically significant difference between the results of measurements with a ruler and with neuronavigation (one-way analysis of variance, $p < 0.05$).

Table 1. The results of the measurements of the pentagon area with a ruler; A, F, G — lengths of the triangles' sides; h_1, h_2, h_3 — triangles' heights; S_1, S_2, S_3 — areas of the triangles. The sum of the triangles' areas is the area of the pentagon $S_1 = ½ Ah_1$, $S_2 = ½ Gh_2$, $S_3 = ½ Fh_3$

Arithmetic mean of triangle's side [mm]	Arithmetic mean of triangle's height [mm]	Measurement accuracy [mm]	Triangle's area [mm^2]	Maximal error of the area measurement
A = 45.10	h_1 = 28.365	1.0	S_1 = 639.642	S_1 = 36.459
F = 33.35	h_2 = 10.521	1.0	S_2 = 175.447	S_2 = 21.054
G = 39.55	h_3 = 14.202	1.0	S_3 = 280.854	S_3 = 26.681

Table 2. The results of the measurements of the pentagon area with a neuronavigation system; A, F, G — lengths of the triangles' sides; h_1, h_2, h_3 — triangles' heights; S_1, S_2, S_3 — areas of the triangles. The sum of their areas is the area of the pentagon

Arithmetic mean of triangle's side [mm]	Arithmetic mean of triangle's height [mm]	Mean error	Triangle's area [mm^2]	Reported registration error [mm]	Maximal error of the area measurement
A = 45.26	h_1 = 28.885	0.1	S_1 = 653.679	1.3	ΔS_1 = 51.64
F = 33.85	h_2 = 10.596	0.1	S_2 = 179.341	1.3	ΔS_2 = 31.02
G = 39.96	h_3 = 14.401	0.1	S_3 = 287.738	1.3	ΔS_3 = 37.98

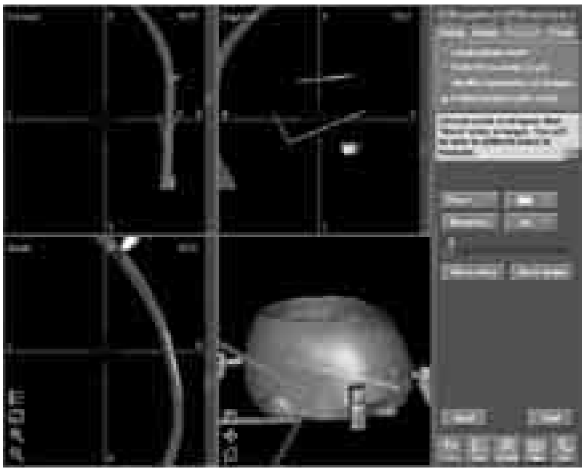

Figure 1. A screenshot of a navigation system during the measurements of a phantom approach. On the right upper view the measured pentagon is visible. On the right lower view the three-dimensional reconstruction of the resin phantom is visualised.

DISCUSSION

Numerous factors affect the precision of measurements performed with a ruler and with one of the most sophisticated devices — neuronavigation. The errors are systematic as well as random.

In order to minimise the random errors the same observer measured the same set of elements 10 times. The systematic error depends mainly on the scale of the instruments used. One cannot eliminate this error due to the limited accuracy of the human visual system. In our experiment the maximal systematic error of the ruler was 1 mm.

The systematic error Δa can be also calculated as $A - An = \Delta an$, where A is the most probable length of the measured distance (the arithmetic mean), n is from 1 to 10, and

$$\Delta a = \frac{|\Delta a_1| + |\Delta a_2| + |\Delta an|}{n}$$

We have calculated the area of the pentagon as the sum of the areas of the three triangles. Each triangle's area was calculated from the length of the side and its height.

$$S_1 = ½\, Ah_1$$

One can measure the circumference on the triangle.

The triangle's area is the function of two variables — the length of the side and the height.

$$S_1 = f\,\{A, h\}$$

The function is mononomial. Therefore, the calculation of the maximal error can be simplified by logarithmisation of the function

$$S_1 = ½\, A_{sr}\, h_{sr1}$$

$$\ln S_1 = \ln (½) + \ln A + \ln h_1$$

and then by calculating a differential function:

$$\Delta S_1/S_1 = \Delta A/A + \Delta h_1/h_1$$

Replacing the differentials with the error values we can calculate the maximal error.

$$\Delta S_1/S_1 = |\Delta A/A| + |\Delta h/h|$$

And the sum of these three areas gives us the area of the measured pentagon:

$$S_1 + S_2 + S_3 = S_{cal} = 1095.943\ [mm^2]$$

The maximal error is the sum of the maximal triangle's areas error:

$$\Delta S_1 + \Delta S_2 + \Delta S_3 = \Delta S_{cal} = 84.194$$

The measurements with neuronavigation are influenced by the registration error — in our case 1.3 mm, calculated by the system after completing the registration procedure. The total error of the pentagon's area is:

$$S = 1120.079\ [mm^2]$$

$$\Delta S = 120.646$$

The described method allows the surgeon to perform morphometry of the intraoperative anatomical structures without any additional modifications of the commercially available system. The precision of the measurement is satisfactory and the results are not significantly different from the results obtained with the traditional method.

The techniques of the skull base approaches are more and more complex, therefore, the methodology of intraoperative morphometry should be used to find precise guidelines, which are still needed for many of these approaches. First of all the analysis should take into consideration most of the petrosal approaches as well as approaches in the region of foramen magnum and paraclinoid.

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