Influence of Head Model in Biomagnetic Source Localization

Sadamu Tomita^, Shigeki Kajihara^, Yasushi Kondo^, Yoshikazu Yoshida^, Kenji Shibata*, and Hisashi Kado**

Summary: We evaluated the influence of the head model on biomagnetic source localization by utilizing a computer simulation. We localized the source of a magnetic field that was calculated using a realistic head model, and then evaluated the localization errors. It was seen that the sphere model adequately localized the dipole in cases near the sensor, but not in cases where the dipole was deeply situated.

Keywords: MEG; Biomagnetism; Nonlinear least squares method; Boundary element method.

Introduction

The homogeneous sphere model is commonly used in biomagnetic source localization (Barth et al. 1986). However, considering the complex shape and the varying electric conductivity of the human head, the homogeneous sphere model is only an approximation. A more realistic model that adequately explains the head shape and electrical conductivity has also been studied in order to improve the accuracy of source localization (Kajihara et al. 1992). Localization with a more realistic model requires an excessive amount of computation time. For this reason, we have used a sphere model with extra care taken in model fitting. In this study, we estimated the difference between localization with a sphere model and localization with a more realistic model, by using a computer simulation. We evaluated the error in biomagnetic source localization with a sphere model by considering the magnetic field calculated using the Boundary Element Method (BEM) with a realistic model, as a measured magnetic field.

Biomagnetic Source Localization

Localization method

We assumed that the head was a homogeneous sphere, and that the magnetic fields produced from a single current dipole inside f the head could be calculated by using an analytical formulation (Sarvas 1987) which considers the effects of the volume current. Using the modified Newton method, we applied the nonlinear least squares method to the localization algorithm. The cost function is

$$f = \frac{\sum_{i=1}^{N} (Bex_i - Bth_i)^2}{\sum_{i=1}^{N} Bex_i^2}$$

where Bex is an experimental magnetic field and Bth is the theoretical one from the above formulation. Measuring points were arranged concentrically on the surface of the sphere with a radius of 117 mm, and they were spaced at 25 mm intervals.

Localization errors

To confirm the performance of our localization method, we evaluated the localization errors derived from the computer simulation. The localization errors were determined as follows.

$$\Delta r = |r' - r|$$
$$\Delta\alpha = \cos^{-1} \frac{P \cdot P'}{|P||P'|}$$
$$\Delta P = \frac{\left||P| - |P'|\right|}{|P|}$$

where r and P are the true dipole position and moment,

^Keihanna Research Laboratory, Shimadzu Corporation, Japan.
*Health Care & Therapy Systems Dept., Shimadzu Corp., Japan.
**Superconducting Sensor Laboratory/Electrotechnical Laboratory, Japan.
Accepted for publication: November 6, 1995.
Correspondence and reprint requests should be addressed to Sadamu Tomita, Keihanna Research Laboratory, Shimadzu Corporation, 3-9 Hikaridai Seikacho Sorakugun, Kyoto 619-02, Japan.

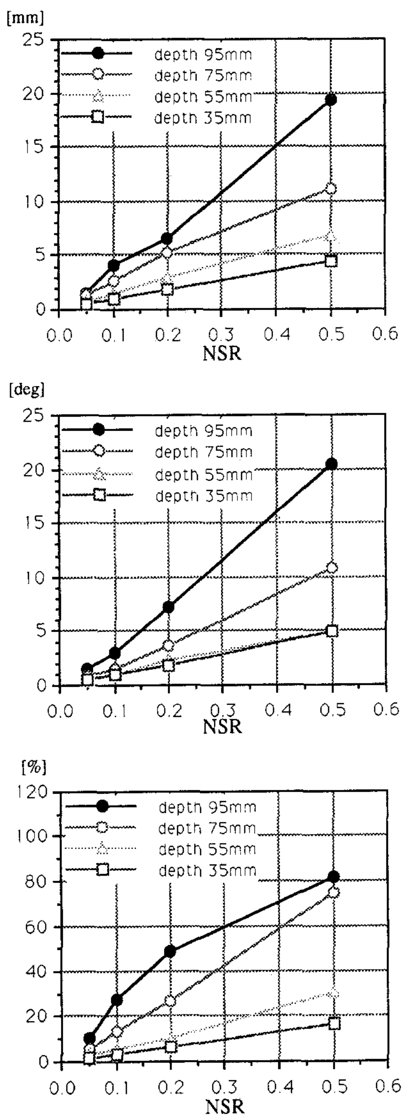

Figure 1. Localization errors derived from noise.

and the dashed variables represent the estimated values for these parameters. Δr, $\Delta\alpha$, and ΔP stand for the error about the dipole position, the dipole direction and the dipole magnitude.

The noisy magnetic field data was calculated by adding a theoretical value to the random one that followed in the Gaussian distribution. The standard deviation is given by

$$\sigma_n = \frac{NSR}{\sigma_s}$$

where σ_s is the standard deviation of Bth. NSR was set up to 0.05, 0.1, 0.2, 0.5.

The sensor array was positioned with it's center on the Z axis. The current dipole was positioned at a point

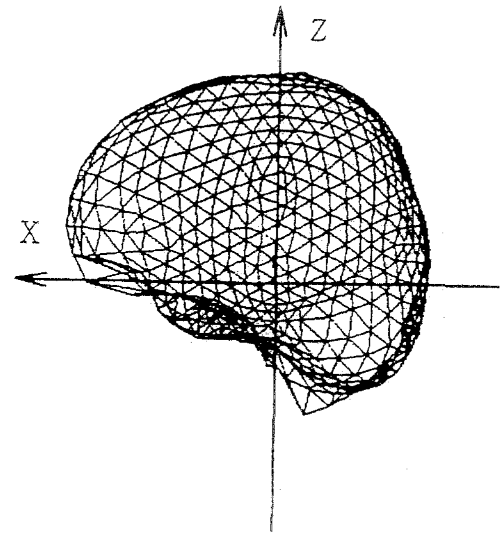

Figure 2. Triangular representation of the boundaries of the skull.

with a depth of 35 mm, 55 mm, 75 mm or 95 mm from the sensor array, and its direction was defined as being parallel to the X axis on the point which depth was. The simulation was performed 50 times in each condition and Δr, $\Delta\alpha$, and ΔP were averaged respectively. The results are shown in figure 1. There is a tendency for Δr, $\Delta\alpha$, and ΔP to be accurate when the dipole is positioned near to the sensor array.

Difference of Accuracy between Head Models

Magnetic field calculation with a realistic model

As shown in figure 2, the head shape was modeled via a triangular segmentation of the skull's boundaries that were determined from MRI images. The conductivity inside the head was estimated at 0.33 Ω^{-1}/m and outside the head it was 0 Ω^{-1}/m. We calculated the magnetic fields at each measuring position by using BEM. The number of elements was between 5,000 and 10,000 in order to ensure reasonable calculation accuracy at each measuring position (Kajihara et al. 1992).

Simulation of the biomagnetic source localization

Several measuring positions were used, including the left superior and the left superior frontal regions, as well as the left, superior, and posterior aspects of the head. The sensor array was placed at these positions, with due consideration given to the thickness of the scalp the. Dipoles were simulated at depths of 35 mm, 55 mm and 75 mm from the sensor array, and their directions are shown in figure 3. The sphere model is approximated to the skull's boundaries by using a least squares method at each measuring point. The dipole positions and mo-

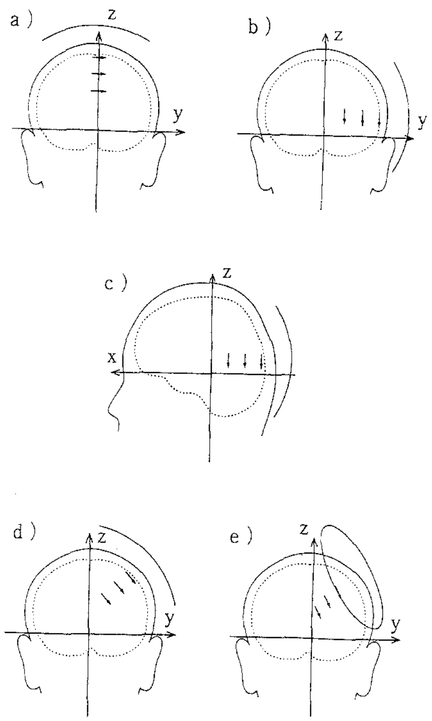

Figure 3. The dipole and sensor array locations. Sensor arrays located above: (a) the top (vertex) of the head; (b) the left (temporal) region; (c) the occipital region; (d) the upper left (temporal) region, and (e) the upper left (frontal) region.

Table I. Localization errors derived from the use of different head models. At each position, a dipole was situated at a depth of 35 mm, 55 mm and 75 mm.

Position	Depth [mm]	Δr [mm]	Δα [deg]	ΔP [%]	G [%]
Top	35	1.09	1.02	16	99.6
	55	2.23	1.76	5	99.2
	75	6.53	3.27	19	97.9
Left	35	1.21	1.68	5	99.2
	55	2.98	3.25	7	98.2
	75	12.85	7.66	155	96.6
Back	35	0.67	9.98	33	99.6
	55	2.91	5.03	4	99.9
	75	11.92	14.61	45	96.7
Up. Left	35	2.76	9.45	2	99.4
	55	3.35	14.07	1	97.8
	75	21.37	63.32	258	97.6
Front of Up. Left	35	3.62	3.57	33	99.7
	55	6.47	1.02	49	98.8
	75	18.88	1.05	6	94.2

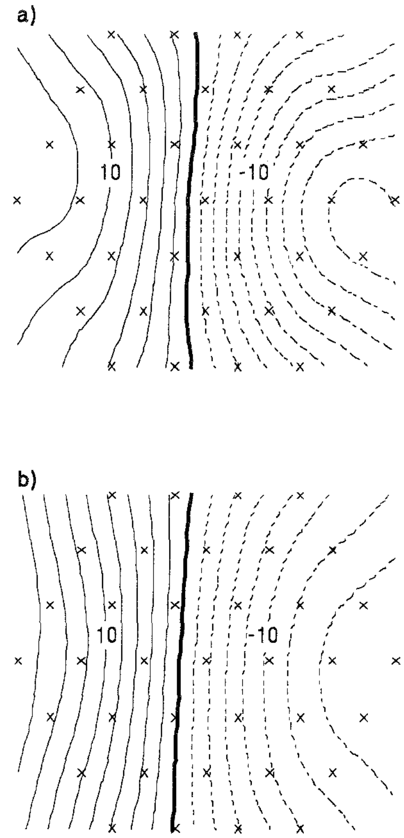

Figure 4. Magnetic field contour maps: (a) theoretical contour map; (b) contour map based on a localized dipole.

ments were then estimated and the associated errors were evaluated at each measuring position.

Results

Results are shown in table I. The goodness of the localization was $(G = 1 - f) \times 100$.

The localization accuracy for the superior, posterior, left, and left superior regions was less than 4 mm for the case where the true dipole was deep, but localization accuracy was more than 6 mm for the left superior frontal region. It appears to be difficult to approximate the skull's boundaries as a sphere in the vicinity of the left superior frontal region. In the cases where NSR was 0.2 and the depths were 55 mm and 75 mm, the localization accuracy was 3 mm and 5 mm, respectively. The localization error depended on the head model, and was 3 mm for the case of a dipole at a depth of 55 mm, but it was 10 mm for a dipole at a depth of 75 mm. For the case of a dipole close to the sensor array, localization using the sphere model results in reasonably good accuracy, but for the case where the dipole is deep, accurate localization requires a more realistic model. In figure 4, contour maps of the magnetic fields are shown. Map (a) was calculated by using BEM for the case of a dipole depth of 75 mm from the upper left side, and map (b) was estimated from (a).

Discussion and Conclusion

We evaluated differences in localization accuracy depending on the model that was used. For the case where the dipole was close to the sensor array, the difference head models had only a small influence on the localization accuracy, but at greater depths, the localization error was seen to be more than 10 mm. Therefore, we conclude that accurate localization requires a more realistic head model, just in case the dipole is deeply situated. Hämäläinen and Sarvas (1989) indicated that the sphere model was not accurate enough for computing the resultant magnetic fields of deep sources, or sources near the base of the skull in the frontal and fronto-temporal areas. We have indicated that these errors associated with the computation of magnetic fields causes errors in source localization, and we also report that the findings regarding the sphere model are similar to those reported by Hämäläinen et al (1989).

References

Barth, D.S., Sutherling, W., Broffman, J. and Beatty, J. Magnetic localization of a dipolar current source implanted in a sphere and a human cranium. Electroenceph. Clin. Neurophysiol., 1986, 63: 260-273.

Hämäläinen, M.S. and Sarvas, J. Realistic conductivity geometry model of the human head for interpretation of neuromagnetic data. IEEE Trans. on Biomedical Engineering, 1989, 36: 165-172.

Kajihara, S., Shibata, K. and Okuyama, Y. Precision of calculation by boundary element method for neuromagnetic data analysis. The 7th Congress of Japan Biomagnetism and Bioelectromagnetics Society, Fukuoka, June 1992.

Sarvas, J. Basic mathematical and electromagnetic concepts of the biomagnetic inverse problem. Phys. Med. Biol., 1987, 32: 11-22.