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Computer Calculations of Target Parameters for a Stereotactic Apparatus

By

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With 5 Figures

Summary

Riechert and Mundinger's stereotactic apparatus (1956) has been modified and partly reconstructed so that the parameters of different target points, adopted during a single procedure, can be immediately calculated by a computer. The mathematical foundations and derivations are given.

The expansion of clinical information regarding stereotactic brain operations employing multiple target points during one operation provides an opportunity to include computer calculations in the operative procedure[5]. Moreover, Modell II. (developed in 1951) of the stereotactic apparatus of Riechert and Mundinger[6, 7, 8] has been so modified that a computer calculation of the focus parameters can be performed. The obvious advantages for clinical use are described elsewhere[1, 2, 3, 4].

Two points are fundamental: the target point, which will be reached by the probe, and the trepanation point where the probe will enter the skull.

If the calculations are to be performed with the coordination of these two points, it is then necessary to appreciate the principles of construction of our current stereotactic apparatus (Figs. 1 and 2): G is the basal ring which is fixed temporarily onto the patient's head. B is the target arc which, by pivoting the X-axis, produces a partial sphere with radius $R = g$. $\vec{z}$ and $\vec{t}$ are the target and the trepanation point; the angles α, β, φ, ψ, and the penetration depth T have to be determined.

The $\vec{g}$ point is next calculated, by an equation which relates the line of approach through $\vec{z}$ and $\vec{t}$ to the spherical shell:

$$\vec{z} + L \cdot \vec{e} = \vec{g}, \tag{1}$$

in which the unit vector in electrode direction, $\vec{e} = (\vec{t} - \vec{z})/|\vec{t} - \vec{z}|$ and L is a parameter which measures the distances on this line. Squaring the terms in equation (1), and letting $\vec{g}^2 = R^2$, gives the expression

$$L^2 + 2 \cdot L \cdot (\vec{z} \cdot \vec{e}) + \vec{z}^2 - \vec{R}^2 = 0 . \tag{2}$$

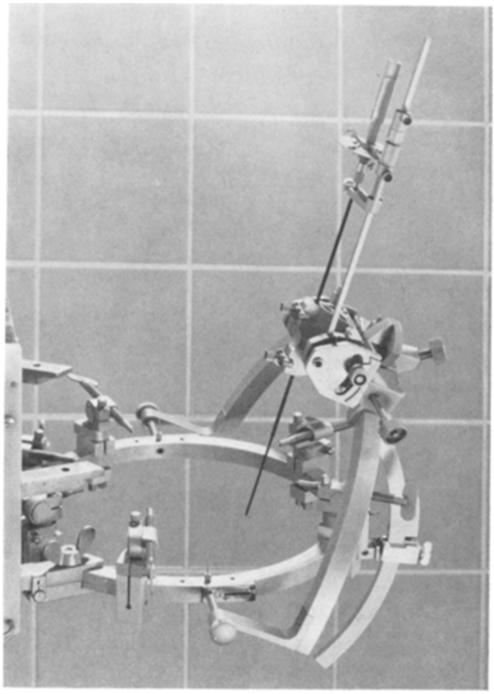

Fig. 1. Stereotactic apparatus—model by Riechert and Mundinger modified by Birg and Mundinger (1973) for the computer calculations of the angle parameters and needle depth. At the basal ring the locking pins for the fixation at the skull are attached. The target arc with a goniometer is fixed to the basal ring by two axle bearings and a graduated segmental arc. An electrode with another goniometer (Mundinger) is introduced down to the stroke of the depth adjustment and is held by the block for the probeholder

From this quadratic equation, two penetration points $\vec{g}_1$ and $\vec{g}_2$ are obtained of which only the "superior" interests us. Hence,

$$L = -(\vec{z} \cdot \vec{e}) + \sqrt{(\vec{z} \cdot \vec{e})^2 - z^2 + R^2} \tag{3}$$

$$\vec{g} = \vec{g}_1 = \vec{z} + \vec{e} \cdot \left(\sqrt{(\vec{z} \cdot \vec{e})^2 - z^2 + R^2} - (\vec{z} \cdot \vec{e})\right). \tag{4}$$

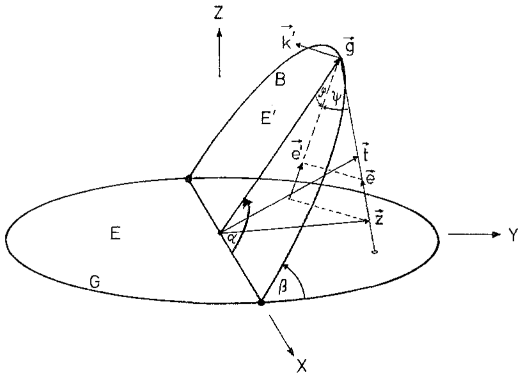

Fig. 2. Mathematical principle of the modified stereotactic apparatus

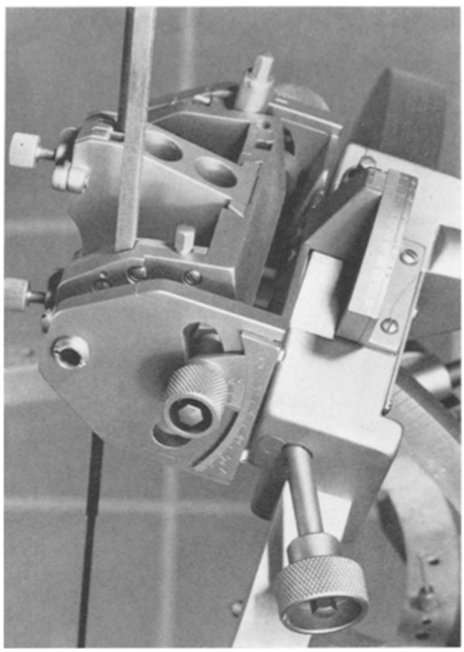

Fig. 3. A detailed picture of the block for the probe-holder. The block can be moved on the target arc. The vernier scales which measure the adjustment of the angle of traverse and the angle of gradient of the electrode can be seen

From Fig. 2, therefore, both the angles α and β are determined by as: $\cos\alpha = g_x/R$; $\tan\beta = g_z/g_y$. To calculate the two remaining angles, φ and ψ, a unit vector $\vec{k}'$ is constructed, which is perpendicular to the plane of the target arc (E'). The complementary angle of ψ is obtained by the formation of the scalar product $(\vec{k}'\vec{e})$, hence:

$$\sin\psi = (\vec{k}' \cdot \vec{e}) . \tag{5}$$

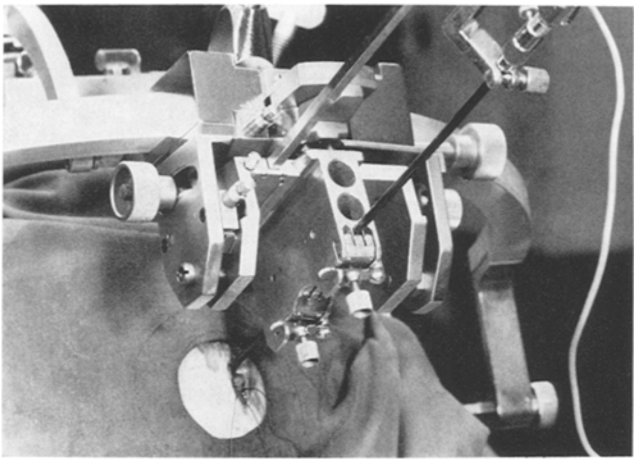

Fig. 4. Situation of an operation. The thermoprobe, which is fixed in the probe-holder, is advanced through the trepanation opening to the target point

$\vec{k}'$ itself is defined by angle β, (subtended by the planes E and E'), so that

$$\vec{k}' = \vec{k} \cdot \cos\beta - \vec{j} \cdot \sin\beta , \tag{6}$$

where $\vec{i}$, $\vec{j}$, $\vec{k}$, as usual, signify the unit vectors in x-, y- and z-direction. Relating equations (6) and (5) gives:

$$\sin\psi = e_z \cdot \cos\beta - e_y \cdot \sin\beta . \tag{7}$$

To calculate the electrode-angle of traverse, the target point $\vec{z}$ is projected in the plane E'. The projection becomes

$$\vec{e}\,' = \vec{e} - (\vec{e} \cdot \vec{k}') \cdot \vec{k}' . \tag{8}$$

If the angle between $\vec{e}\,'$ and $\vec{i}$ is denoted by δ, then

$$(\vec{e}\,'\vec{i}) = e' \cdot \cos\delta , \tag{9}$$

or, from (8),

$$\cos\delta = e_x/e' , \tag{10}$$

since $\vec{k}'$ is perpendicular to $\vec{i}$.

When $e' = \cos\psi$ [according to Eq. (5)], $\cos\delta = e_x/\cos\psi$ is obtained. φ is given by

$$\varphi = \delta - \alpha. \qquad (11)$$

The electrode-depth results in $T = A - L$, where A is a constant, dependent only on the measurements of the stereotactic apparatus. With our apparatus

$$T = 312{,}5 - L. \qquad (12)$$

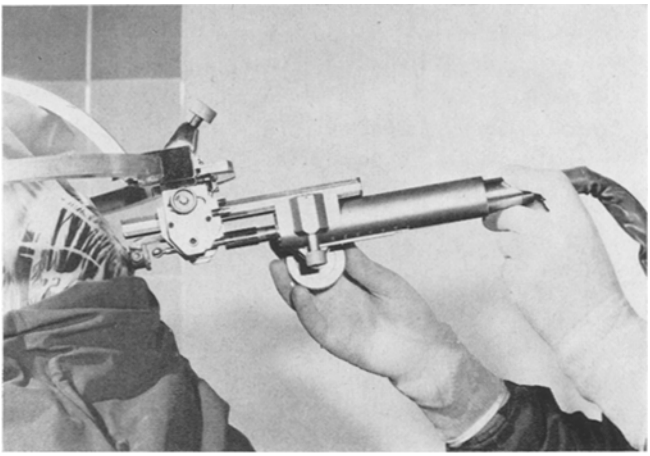

Fig. 5. Picture of an operation in progress. In the block for the probe-holder is embedded a fishtail to which a newly developed drill-aggregate is attached. The spherical trepan (6 mm in diameter) can be seen in front of the expanding ring which keeps the incision open. The high-speed drill turbine is operated—according to the VDE-instructions—by compressed air. The advancing movement of the drill is effected via a spindle sleeve which can be placed and fixed in all the required positions

To perform the calculation with a small computer, the angular function sin, cos is replaced by the corresponding tangent function so that the inverse tangent must be performed as the only sub-programme. The final result is, in brevity,

$$w_1 = e_y \cdot g_z - e_z \cdot g_y$$

$$w_2 = g_y^2 + g_z^2$$

$$L = \sqrt{(\vec{z} \cdot \vec{e}) - z^2 + R^2} - (\vec{z} \cdot \vec{e}).$$

Lateral angle $\qquad \alpha = \arctan\left(\sqrt{w_2}/g_x\right) \qquad (13)$

Angle of elevation $\qquad \beta = \arctan\,(g_z/g_y) \qquad (14)$

Electrode angle of gradient $\psi = \arctan\left(w_1/\sqrt{w_2 - w_1^2}\right)$ (15)

Electrode angle of traverse $\varphi = \arctan\left(\sqrt{1 - w_1^2/w_2 - e_x^2/e_x}\right) - \alpha$ (16)

Needle depth $T = 312{,}5 - L\,.$ (17)

Because the inverse tangent is meaningless, the signs must always be examined. The calculation of all target parameters is thereby performed.

The values obtained can be checked with a similar programme, which performs the calculation of the target point when focus parameters are given. If the latter target point agrees with the former, an electronic phantom examination is carried out. In changing the position of the electrode, the latter programme is also an advantage. After introducing the new focus parameter into the computer, the new target point will be determined immediately.

The programmes are written in Basic and Fortran and can be processed by a small computer with at least 8K core store. In about 150 stereotactical brain operations the reliability of the programmes and the precision of the now modified stereotactical apparatus have been proved. In addition to the computer calculations of the target parameters, the further possibility of focusing the target point on the phantom is given by this model.

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