Motion of bones and volume changes in the neurocranium after craniectomy in Crouzon's disease

A roentgen stereometric study

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Craniectomy was performed on a boy with Crouzon's disease at 22 months of age. Metallic implants (tantalum balls, 0.5 mm in diameter) were inserted in the calvaria during surgery, and the child was examined postoperatively by roentgen stereometry at intervals of about 100 days (total observation time, 309 days). The thyroid radiation dose was 250 μGy for one examination. The effect of craniectomy was recorded with a high degree of accuracy in terms of motion of bones and volume changes in the calvaria. Expansion occurred almost entirely through motion of free bone flaps in the frontal region, while a linear craniectomy in the region of the sagittal suture caused small changes. The rate of expansion decreased rapidly and stabilization was recorded about 250 days after surgery.

Key Words • Crouzon's disease • craniectomy • x-ray stereophotogrammetry • metallic implant • craniosenosis

Crouzon's disease is characterized by premature synostosis of craniofacial sutures, and early craniectomies are often carried out to relieve or prevent increased intracranial pressure and its neurological consequences. However, it is not always possible to distinguish patent from fused sutures, as interpretation of x-ray films may prove incorrect, and exact methods are not yet available to diagnose the onset of synostosis or the fusion of craniectomy sites.

A roentgen stereometric method has recently been developed by which motion between bones in all three dimensions and volume changes can be recorded with a high degree of accuracy, provided metallic implants can be inserted and remain stable in the bone. Complicated motion between facial bones was recorded with this method in infants with a cleft lip and palate. We decided to use the method in a child with Crouzon's disease to record the effect of craniectomy in terms of motion of the bones and volume changes.

Clinical Material and Methods

This study deals with a boy with Crouzon's disease who at the age of 8 months had an abnormal head shape and some exophthalmos. The anteroposterior diameter of the calvaria was short and the height was increased with a prominence in the region of the anterior fontanel (Fig. 1). Conventional radiographs revealed premature synostosis of the coronal and the sagittal sutures. When the boy was 22 months old, craniectomy was performed in the region of the fused sagittal suture with extension to the lambdoidal suture, and free bone flaps were created in the frontal region (Fig. 2). All bone edges were covered with polyethylene film.

Insertion of Implants

Tantalum balls, 0.5 mm in diameter, were implanted as follows: three in the frontal bone just above the supraorbital ridge, three in each of the free bone...
Cranial volume changes after craniectomy flaps, and three in each parietal bone segment (Fig. 2). With the insertion instrument, the implant is held in the tip of a needle which is introduced through the skin or pressed directly against the bone during surgery. While the tip is held firmly in place, the implant is driven 0.5 to 1.0 mm into the bone by means of a spring-loaded piston released by a trigger mechanism. An adjustable stop block is mounted on the needle to eliminate the risk of uncontrolled penetration. The anatomical conditions for insertion in the chosen areas were studied in autopsy material (two stillborn infants and a 6-month-old child), and in no instance did implants penetrate to the inner surface of the bone. Tantalum pins, 1.5 × 0.5 mm in size, were inserted in both jaws of the patient in preparation for stereometric recording of facial growth.

The child was examined by roentgen stereometry at intervals of 105, 99, and 105 days, with the initial examination 35 days after surgery. The thyroid radiation dose is 200 to 250 μGy for one pair of stereo films.

**Stereometric Calculations**

The stability of implants is checked at each examination by calculation of angles and distances between the three implants in each segment and comparison of actual to initial values. The resultant mean error in this test of rigid-body fitting is given in millimeters, and a mean error of 0.2 mm is regarded as the limit for rigid-body behavior. The implant triangle or rigid-body model (R-B M) represents the bone segment in the calculations of motion, computed according to the kinematics of rigid bodies and expressed in terms of rotations about and translations along the cardinal axes of the head (Fig. 3). Motion is calculated relative to a reference R-B M which is regarded as fixed, and skeletal structures are not analyzed. At each examination, the reference R-B M is reoriented in the calculations to its initial position in the laboratory coordinate system and identical orientation is not required at exposure. In this study the R-B M in the frontal bone was used as reference (Fig. 2, segment 1). Calculation of volume of the polyhedron defined by the implants is carried out using a method described by Claesson, et al. The projection of the implants, and the connecting lines defining the polyhedron, on the sagittal and transverse planes as drawn by computer are shown in Fig. 4.

**Precision**

Comparing two repeated evaluations of stereo pairs, no rotation angle differed more than 0.4°, no
FIG. 3. Directions of the three cardinal axes about and along which rotations and translations are calculated for the skeletal segments. The positive directions for the rotations are indicated.

FIG. 4. Computer drawings of the polyhedron defined by the implants projected on the sagittal (ZY) and the transverse (XZ) plane. The connecting lines between the edges of the polyhedron that are hidden in the lateral and axial views are indicated by broken lines. The figures show all 15 implants at Day 309, and the volume is 235.2 cu cm. The implant triangles, numbered according to Fig. 2, are shaded.

Results

The error in rigid-body fitting was less than 0.2 mm in the bone flaps and the parietal bone segments while the R-B M in the frontal bone showed a small deviation from rigid-body behavior (Table 1). Motion of the bone segments in the calvaria was considerable during the first observation period compared to that of the second and third periods (Table 2), and motion of the free bone flaps dominated over that of the parietal bone segments. The calculated motion during 309 days is shown in Fig. 5 for representative segments. Due to faulty examination, segment 4 (Fig. 2) was obscured in the initial and second examinations, and motion of this segment was calculated only for the last observation period.

The volume of the polyhedron defined by the 12 implants common for all examinations was calculated to 115.9, 141.9, 149.3, and 150.8 cu cm for the initial, second, third, and fourth examinations, respectively.
Cranial volume changes after craniectomy

The increase in percentage of volume was 22.4, 5.2, and 1.0 for consecutive intervals of about 100 days.

Discussion

Previous studies of the effect of craniectomy on the neurocranium have reported subjective evaluation of skull shape, measurements of head circumference, radiographic evaluation of changes in the width of the craniectomy, and anthropometric measurements. Two-dimensional evaluations of cranial growth postoperatively by means of conventional roentgen stereophotometry were presented by several authors, and in one instance with metallic implants inserted in the neurocranium.

The purpose of this study is to apply a roentgen stereometric method to study motion of bones and changes of brain case volume after craniectomy. As the implant stability proved satisfactory to the requirements of the method, with a minor deviation in the reference segment, complicated motion of the bone segments could be recorded and visualized threedimensionally with a high degree of accuracy. With nearly identical observation intervals, an increase in volume could also be compared from one period to another and the rate of expansion evaluated. It is, therefore, our opinion that roentgen stereometry represents an important supplement to the conventional clinical and radiological follow-up methods.

Our observations showed a continuously decreasing rate of expansion with stabilization at about 250 days after surgery, a finding which is in agreement with other reports. As expected, the free bone flaps exhibited greater movements than the parietal bone segments. The limited success of the linear craniectomies may be explained by the presence of premature synostosis of sutures in the cranial base, and this has to be considered in treating Crouzon’s disease.

TABLE 1

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<tr>
<th>Days after 1st Examination</th>
<th>Segment</th>
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<tr>
<td>105</td>
<td>0.189 0.025 0.036 — 0.045</td>
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<tr>
<td>204</td>
<td>0.271 0.097 0.100 — 0.034</td>
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<tr>
<td>309</td>
<td>0.367 0.039 0.163 0.161 0.081</td>
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*The mean error given for Segment 4 refers to the observation interval of 204 to 309 days after the initial examination. The segments are numbered as shown in Fig. 2.

TABLE 2

<table>
<thead>
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<th>Motion of segments in the calvaria relative to the frontal bone*</th>
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<td>Segment</td>
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*Data are given as rotations about and translations along the body-fixed cardinal axes. The segments are numbered as shown in Fig. 2.
†Motion given for Segment 4 refers to the observation interval of 204 to 309 days after the initial examination.

FIG. 5. Computed motion of implant triangles (R-B M’s) in the calvaria. The triangles are projected on the three cardinal planes, the frontal (XY), the sagittal (ZY), and the transverse (XZ). The changes (broken lines) are given in relation to the positions in the coordinate system of the initial examination. Observation time was 309 days. Segment numbers are given as in Fig. 2. The movement of Segment 5 is not visible in the sagittal projection. Skeletal outlines are drawn schematically.

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Brenner and Kraus⁵ suggested that the radiological abnormalities characteristic of premature craniosynostosis represent late or final stages of the disorder, that surgery should be undertaken before synostosis is visualized on radiograms, and that the disturbance should be recognized earlier. By means of metallic implants and roentgen stereometry, sutural growth can be recorded with a high degree of accuracy, and small changes can be observed within short observation intervals.⁶ We suggest that the roentgen stereometric method may be used for early diagnosis of premature growth disturbance in the cranial sutures, and, thus, contribute to improved treatment in patients with premature craniosynostosis.

References


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