Reossification of the Orbital Wall following Ventral Translocation of the Fronto-orbital Bar and Cranial Vault Remodeling

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The purposes of this study were to determine the extent of ossification of the orbit following ventral translocation of the fronto-orbital bar and to find out whether age at the time of the procedure and presence of a concomitant syndrome adversely affect ossification. A retrospective review of 27 patients with craniosynostosis was conducted at the St. Louis Children's Hospital and the Children's Hospital of Oklahoma. Patients with preoperative, perioperative, and postoperative three-dimensional computed tomography scans were included. Eighty-eight percent of the lateral orbital wall defects and 92 percent of the defects within the roof of the orbit ossified completely in the postoperative period. When syndromic patients were compared with nonsyndromic patients (based on clinical findings only), three of the 19 syndromic defects and three of the 30 nonsyndromic defects demonstrated incomplete ossification in the lateral orbital wall ($p > 0.05$). Similarly, two of the 19 syndromic defects and two of the 30 nonsyndromic defects demonstrated incomplete ossification within the roof of the orbit ($p > 0.05$). With respect to age at the time of the procedure, four of the 37 defects and two of the 12 defects demonstrated incomplete ossification in the lateral orbital wall for age at the time of the procedure less than 12 months and greater than 12 months, respectively ($p > 0.05$). Similarly, two of the 37 defects and two of the 12 defects had incomplete ossification within the roof of the orbit for age at the time of the procedure less than 12 months versus more than 12 months, respectively ($p > 0.05$). Ossification of the orbital wall and roof is complete in the majority of cases within 1 year after the procedure, and neither age at the time of the procedure nor presence of a concomitant syndrome adversely affects ossification of the orbit after ventral translocation of the fronto-orbital bandeau. (*Plast. Reconstr. Surg.* 108: 1509, 2001.)

Craniosynostosis, or premature fusion of the calvarial sutures, is associated with deformation of the calvarium, which varies depending on the suture involved.[1] Fusion of the coronal and the metopic sutures leads to reduction in the volume of the anterior cranial fossa.[2] To enable an increase in the volume of the anterior cranial fossa, cranial vault remodeling is also combined with a ventral translocation of the fronto-orbital bandeau. The translocation results in intraoperative osseous defects at the lateral orbital wall and the roof of the orbit. The extent and the timing of ossification of these defects are unknown. Previous studies have documented that age at the time of the procedure and the presence of a concomitant syndrome (detected clinically) adversely affect the ossification for calvarial defects.[3] However, the effects of these factors on ossification of the orbital roof and wall are unknown. Early and complete ossification would result in a stable fixation, which is unlikely to relapse. The objective of this study was to determine the extent and timing of ossification of these defects and whether age at the time of the procedure or presence of a concomitant syndrome had any effect on the outcome of ossification.

Patients and Methods

The charts of all patients who were evaluated at the Cleft and Craniofacial Deformities Institute, St. Louis Children's Hospital, Washington University Medical Center, and Children's Hospital of Oklahoma, University of Oklahoma Health Sciences Center, between 1989 and 1999 and who had coronal or metopic craniosynostosis were reviewed. Criteria for inclusion

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within the study were as follows: (1) a surgical procedure of ventral translocation of the fronto-orbital bar and/or orbit, (2) a preoperative three-dimensional computed tomography scan, (3) a perioperative three-dimensional scan within 1 month after the procedure, and (4) a three-dimensional scan approximately a year after the procedure (mean interval, 13.9 months).

Twenty-seven patients met the above criteria and were the subjects of this study. This group included 12 male and 15 female patients. Nineteen patients had coronal synostosis (nine bicoronal and 10 unicoronal), and eight had metopic synostosis. Of these, nine patients had syndromic and 18 had nonsyndromic craniosynostosis. (The diagnosis of syndromic versus nonsyndromic was based on clinical findings only and not molecular diagnosis.)

The surgical procedure for correction of coronal synostosis included a craniotomy followed by excision and shaping of the fronto-orbital bandeau and its ventral advancement. The extent of the ventral translocation was calculated from a longitudinal orbital projection view of the three-dimensional computed tomography scan on a graphic workstation using the Analyze software program (Mayo Clinic, Rochester, Minn.). Each side was calculated separately. The ventral translocation of the fronto-orbital bandeau was stabilized centrally with either a nonvascularized bone graft or a titanium or absorbable plate. Laterally, a tenon-and-mortise, nonvascularized calvarial bone graft was inserted at the pterion if absorbable polyglactin (Vicryl) sutures were used. No graft was used if rigid fixation was procured using an absorbable plate (Lactosorb, Lorenz, Jacksonville, Fla.). The ventral translocation resulted in an osseous defect in the lateral orbital wall and the roof of the orbit (i.e., the floor of the anterior cranial fossa). After stabilization of the fronto-orbital bandeau, the calvarium was trimmed, reshaped, and fixed to obtain optimal shape and symmetry.

The surgical procedure for correction of metopic synostosis was performed in a similar manner. Preoperative measurements were taken before the procedure to obtain an ideal correction of the shape of the fronto-orbital bar. Again, rigid fixation or a nonvascularized bone graft was used to stabilize the bar centrally. A tenon-and-mortise, nonvascularized bone graft was used laterally at the pterion if absorbable polyglactin (Vicryl) sutures were used. No graft was used if rigid fixation was procured using an absorbable plate (Lactosorb, Lorenz) (Fig. 1).

The surgical procedure for correction of hypertelorism was performed transcranially, and the extent of mesial and ventral translocation was calculated using the Analyze program to manipulate three-dimensional computed tomography scan images.

Patients who underwent the surgical procedure before age 12 months had fixation (including the tenon-and-mortise bone graft) using absorbable polyglactin sutures, except for

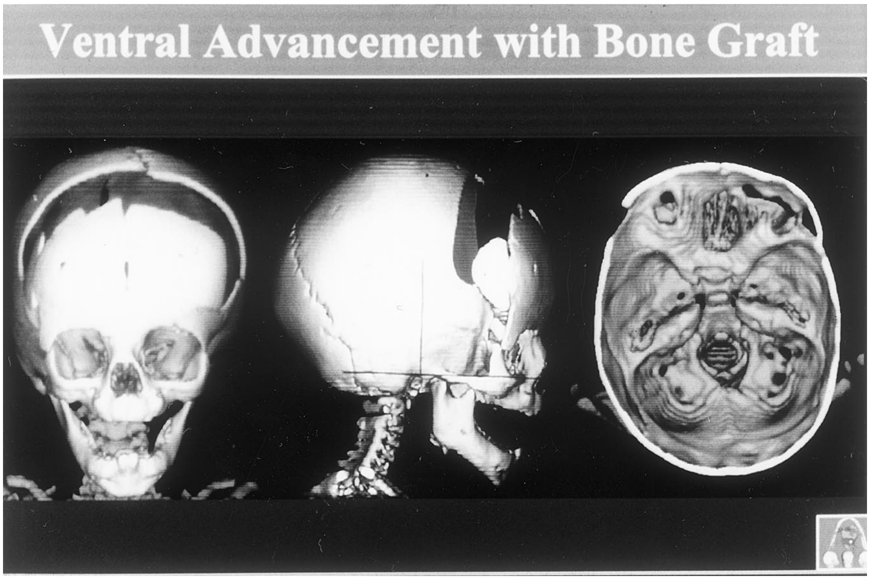

FIG. 1. Ventral advancement with bone graft at the pterion.

patients with coronal synostosis; these patients received a single stair-step titanium plate to stabilize the ventral advancement at the nasion. The last five patients who had the procedure underwent rigid fixation using absorbable (Lactosorb) plates at the nasion and the pterion. No tenon-and-mortise graft was used at the pterion for these patients. Patients who underwent the surgical procedure after they were 48 months old had rigid fixation using a titanium plate on the calvarium, at the pterion and at the nasion.

Of the 27 patients who underwent ventral translocation of the orbit, three patients also underwent ventral translocation of the fronto-orbital bar later to correct hypertelorism. This resulted in a total of 30 surgical procedures.

The age at operation varied between 3 months and 95 months, with a mean age of 13.1 months. Twenty-two surgical procedures were performed when the patients were less than 12 months of age, and the remaining eight were performed when the patients were ≥ 12 months of age. The mean ventral advancement of the fronto-orbital bandeau was 7.36 mm on the right and 6.64 mm on the left.

The osseous defects were assessed using the postoperative hard copies of the three-dimensional computed tomography scans. Ossification was graded "complete" if it demonstrated complete integration with the adjacent bone (Fig. 2), "incomplete" if this integration continued to demonstrate an osseous defect (Fig. 3), or "absent" if the size of the defect was identical to the intraoperative osseous defect. Each side (right and left) and each defect (lateral orbital wall and roof of the orbit) were graded separately. Thus, in all, 98 defects (25 right orbital wall defects, 24 left orbital wall defects, 25 right roof of orbit defects, and 24 left roof of orbit defects) were assessed.

Statistical analyses were performed using Fisher's exact test to assess whether the age at operation or a diagnosis of syndromic or nonsyndromic craniosynostosis had any effect on the ossification of the defect of the lateral orbital wall or the roof of the orbit (statistically significant at $p < 0.05$). Notably, there were only 27 patients but 98 defects. Although the unit of analysis was "defects," the "defects" within the given subject may not have been independent. However, they were treated as independent observations when the tests were performed.

RESULTS

Lateral Orbital Wall

Of the 49 defects of the lateral orbital wall, 43 (87.75 percent) demonstrated complete ossification of the bony defect and six (12.25 percent) demonstrated incomplete ossification. None of the defects demonstrated absent ossification.

Syndromic versus nonsyndromic craniosynostosis. Three of the 19 defects in syndromic craniosynostosis patients and three of the 30 nonsyndromic defects in craniosynostosis pa-

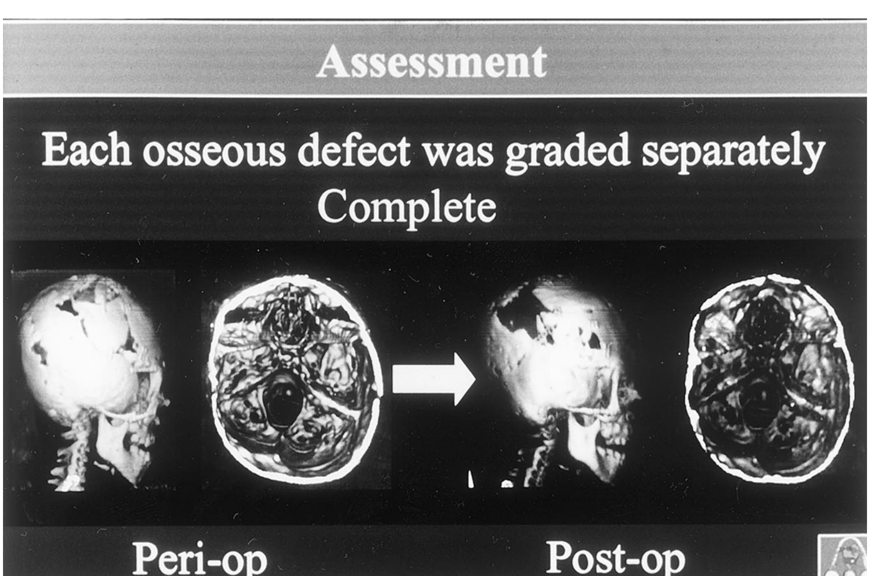

FIG. 2. Complete ossification of the lateral orbital wall and the roof of the orbit.

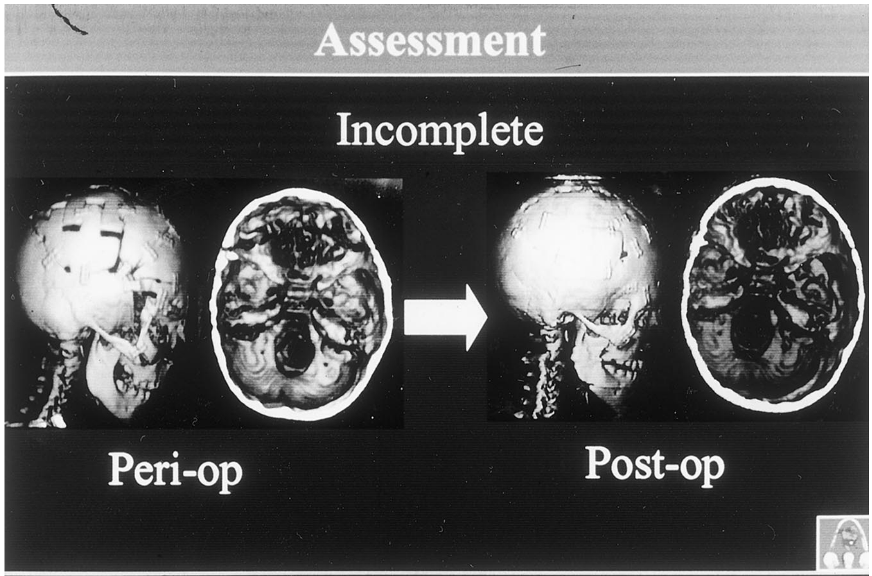

FIG. 3. Incomplete ossification of the lateral orbital wall and the roof of the orbit.

tients demonstrated incomplete ossification. This result was statistically nonsignificant (p = 0.55).

Age at operation ≤ 12 months versus > 12 months. Four of the 37 defects in patients whose age at operation was ≤ 12 months demonstrated incomplete ossification, compared with two of the 12 defects in patients whose age at operation was greater than 12 months. This result was statistically nonsignificant (p = 0.59).

Roof of Orbit

Of the 49 defects of the roof of the orbit, 45 (91.83 percent) demonstrated complete ossification of the bony defect and four (8.17 percent) demonstrated incomplete ossification. None of the defects demonstrated absent ossification.

Syndromic versus nonsyndromic craniosynostosis. Two of the 19 defects in syndromic craniosynostosis patients and two of the 30 defects in craniosynostosis patients demonstrated incomplete ossification. This result was statistically nonsignificant (p = 0.63).

Age at operation ≤ 12 months versus > 12 months. Two of the 37 defects in patients whose age at operation was ≤ 12 months demonstrated incomplete ossification, compared with two of the 12 defects in patients whose age at operation was greater than 12 months. This result was statistically nonsignificant (p = 0.22).

The extent of ventral movement of the orbits, which did not ossify, was 5, 5, 8, 7, 7, and 10 mm. This was not very different from the mean (7.6 mm) or the range (4 to 15 mm). Age at operation of these patients was 95, 10, 3, and 4 months. Five of six patients had fixation using absorbable sutures, and the sixth patient received titanium plates.

DISCUSSION

Unlike the long bones of the extremities, the bones of the calvarium develop through a process of mesenchymal condensation, followed by ossification starting around the eighth fetal week.[4] Through a process known as intramembranous ossification, centers of ossification develop from which radiating bony trabeculae emerge and, in a centrifugal-type pattern, grow to eventually fuse with other nearby centers.[5] Under normal circumstances, fusion across sutural lines does not occur until later.

In response to the increasing brain volume, bone growth at the sutural bone interface continues through a process of deposition and resorption.[6] Enlow[7] has demonstrated that the growing craniofacial skeleton is divided into depository and resorptive growth fields. Zins et al.[8] have studied the effects of bone graft survival according to whether the recipient bed represents a resorptive defect or a depository defect. This pattern of bone behavior may affect the ability of osteotomy defects involving the craniofacial skeleton to undergo spontaneous osteogenesis. Currently, we think of critical size defects as those that are incapable of spontaneous repair, irrespective of their location. Both cranial vault remodeling and fronto-orbital bar advancement result in osseous defects intraoperatively. The mechanism and timing of closure of these defects have been studied extensively in the animal model. Both the dura and the overlying periosteum play an integral role in ossification of these defects.[9] Reid et al.[10] demonstrated that reossification is hampered in the absence of dura and periosteum and that the dura plays a more critical role than the periosteum. In one infant, the osteogenic potential of the dura was demonstrated when complete regeneration of the calvarium occurred 3 months after a procedure during which the calvarium was removed for cranial vault remodeling. The patient had an intraoperative bradycardia and cardiac arrest which prevented the surgeon from replacing the calvarium intraoperatively.[11] The dura is responsible for initiation of the cascade of events, including an increase in transforming growth factor-β and messenger ribonucleic acid. These chemical inducers convert the osteoprogenitor cells, which results in an increase in the osteogenic potential of the dura.[12] After a fronto-orbital advancement, the bandeau is not in contact with the dura, except at the roof of the orbit. Although the dead space is obliterated over the subsequent months, early revascularization of the fronto-orbital bone graft is accomplished by the overlying periosteum vascularized by the scalp blood vessels.

The extent of reossification is dependent on the size of the defect. The minimum size of a defect that fails to reossify is defined as the critical size defect. The sizes of critical defects for most animal models have been identified and documented. The size of critical defects in humans has not been specifically defined and varies from infancy to senility. The osteogenic potential of the dura in an infant is significantly higher than that of an adult. This has been documented both in an animal model and in humans.[3,13] The human study[3] did not show a significant difference in the extent of ossification in infants as compared with older children. It is possible that the defect size at the lateral orbital wall and the roof of the orbit did not exceed critical defect size, thereby allowing rapid ossification in both infants and older children without great difficulty.

The extent of ossification of the calvarium following cranial vault remodeling was analyzed in a single study.[3] The study assessed the extent of ossification of the calvarium in 592 patients and used radiographs taken 1 year after the procedure to document the change. The authors reported that the calvarium failed to ossify in 5 percent of the patients. The presence of infection was the single most important factor, which adversely affected the extent of ossification. Presence of a syndrome or age did not achieve statistical significance.[3] The authors did not document the size of the defect intraoperatively or postoperatively, thereby precluding the accuracy of the extent of ossification.

The extent of ossification of the orbital roof and lateral wall following fronto-orbital bar advancement has never been documented. Early ossification of these areas is critical to prevent a relapse. Rigid fixation is essential to allow unhindered and rapid vascularization and ossification of the roof and lateral wall of the orbit. Both absorbable sutures with a bone graft at the pterion and absorbable plates without a bone graft at the pterion allowed adequate ossification. The small number of patients who underwent fixation with absorbable plates (five out of 27 patients) made it difficult to compare the extent of ossification using absorbable plates versus absorbable sutures.

Conclusions

This report quantifies the degree of ossification that occurs in the periorbital region following fronto-orbital bar advancement. In the current study, we demonstrated that, following cranial vault remodeling, complete bony reconstitution of the periorbital osteotomy defects occurs in the majority of patients. Age at the time of the procedure and presence of a syndrome did not adversely affect the extent of ossification. We further showed that reossification occurs at some point within 1 year after fronto-orbital bar advancement, as determined by three-dimensional computed tomography scans. The presence of two highly osteogenic tissues, namely, the dura and periorbital region, provides the osteoprogenitor cell line needed for the reparative process to proceed successfully.

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