A Retrospective Analysis of Growth of the Constructed Condyle-Ramus in Children With Hemifacial Microsomia

JOHN B. MULLIKEN, M.D.
NALTON F. FERRARO, D.M.D., M.D.
A. RONALD VENTO, M.D.

A retrospective analysis of changes in costochondral rib grafts used to construct the condyle-ramus in children with hemifacial microsomia (HFM) was made. The mean age at surgical correction was 6.5 years, and the average follow-up was 4.5 years. Direct measurements were made on panoramic radiographs. The condyle-ramus length was expressed as a percentage change comparing the constructed with the normal side. During the first 2 postoperative years, there was either no change or a slight decrease in the length of the rib graft. After 2 years, however, the costochondral graft elongated at a slow, irregular rate. The mode change was 11 percent over the postoperative study period. In four patients who exhibited rapid growth of the normal condyle-ramus (greater than the mean change of 0.94 cm), the constructed side failed to keep pace. In another group of four patients who exhibited moderate elongation of the normal side, the grafted side grew commensurately or demonstrated greater than normal percentage change in length. There was no correlation between the initial size of the costochondral graft, age at time of operation, or presenting type of mandibular deformity. These findings are discussed in terms of the intrinsic growth and the functional matrix theories of mandibular development.

KEY WORDS: *hemifacial microsomia, costochondral rib graft, growth analysis, mandible*

Early operative elongation of the hypoplastic mandible in children with hemifacial microsomia was first advocated by Osborne (1964) and later by Converse et al (1973). This surgical strategy has been practiced by the Craniofacial Centre at Children's Hospital for the past decade (Murray et al, 1984). The working concepts have been (1) that the hypoplastic mandible interferes with normal downward growth of the maxilla and (2) that with asymmetrical skeletal growth the mandibular distortion becomes worse and produces secondary deformation of the midface. Thus, correction of the mandibular abnormality in childhood establishes a more normal "functional matrix" for symmetric midfacial growth.

The term hemifacial microsomia has become an accepted misnomer. Bilateral mandibular hypoplasia occurs in 16 percent of patients (Vento and Mulliken, 1988). Costochondral grafting is designed to lengthen the mandibular ramus on the more severely affected side, to advance the symphysis, and to rotate the mandible to the midline, thus creating a unilateral open bite. The open bite is regulated with an orthopedic appliance over a 2-year period, allowing downward growth of the maxilla on the affected side until the occlusal plane is level. Longitudinal study has confirmed our hypothesis that mandibular elongation permits more symmetric mandibular and midfacial growth (Kaban et al, 1988). Children who are treated in the early mixed dentition phase demonstrate vertical growth of the maxilla and its alveolar process.

Three basic dysmorphic types of skeletal anomaly have been described in HFM when using the mandible and temporomandibular joint (TMJ) as referents (Pruzansky, 1969; Swanson and Murray, 1978; Murray et al, 1984). Type I HFM presents as a morphologically normal, but small glenoid fossa, condyle, and ramus. Type II HFM presents as a hypoplastic and malformed temporomandibular joint, ramus, and glenoid fossa, which may also be malpositioned. Type III HFM indicates complete absence of the ramus, glenoid fossa, and TMJ. This classification has been further modified by subcategorizing Type II into Types IIA and IIB based on the location and functional position of the TMJ (Mulliken and Kaban, 1987; Kaban et al, 1988). In Type IIA HFM, the malformed joint is adequately positioned for symmetric mandibular opening. In Type IIB HFM, the joint is malpositioned anteriorly, inferiorly, and medially (Kaban

Dr. Mulliken is Associate Professor of Surgery, Harvard Medical School. Dr. Ferraro is Instructor of Oral and Maxillofacial Surgery, Harvard School of Dental Medicine. Dr. Vento is a Craniofacial Fellow in the Division of Plastic Surgery, Children's, Brigham, and Women's Hospitals, Boston, MA.

This paper was presented at the Forty-Fifth Meeting of the American Cleft Palate Association, Williamsburg, VA, April 1988.

Reprint requests: Dr. John B. Mulliken, The Craniofacial Centre, The Children's Hospital, 300 Longwood Ave., Boston, MA 02115.

et al, 1981). Classification of the type of dysmorphic mandible determines whether the correction is accomplished by ramus elongation or by costochondral construction. Thus, vertical or oblique osteotomy of the hypoplastic ramus is used for children with skeletal Type I and Type IIA HFM, whereas total construction of the condyle-ramus and, if necessary, the glenoid fossa is undertaken in skeletal Type IIB and Type III HFM. The condyle-ramus is constructed with costochondral rib graft (Munro, 1980; Murray et al, 1984). The temporomandibular joint is placed as anatomically correctly as possible.

An obvious question is whether the constructed condyle-ramus graft actually grows. A follow-up evaluation completed in 1987 demonstrated that the graft becomes incorporated into the functional facial skeleton (Kaban et al, 1988). The entire constructed complex grows, remodels, and supports dental function (Kaban et al, 1988). The purpose of our current study is to attempt to quantify the vertical growth of the rib graft segment used to build a condyle-ramus in children with skeletal Type IIB and Type III hemifacial microsomia. Furthermore, the operative and orthodontic management are reviewed because they may also affect the subsequent growth of the rib graft.

METHOD

Treatment Protocol

The records of 19 children with Type IIB or Type III HFM were analyzed. The documentation included photographs, posteroanterior and lateral cephalometric films, panoramic radiographs, preoperative submental vertex films, and dental models. Eleven patients had to be excluded from the study because of postoperative ankylosis ($N=2$), infection ($N=2$), bilateral ramus anomalies ($N=3$), or a follow-up period of 2 years or less ($N=4$). The remaining eight patients in the study group were categorized by the degree of mandibular hypoplasia and associated deformities (Murray et al, 1984; Kaban et al, 1988) (Table 1). The mean age at time of surgical correction was 6.5 years. The average period of follow-up examination was 4.5 years.

Construction of an Acrylic Splint

Patients were examined and a line drawn on the midpoint of the chin (i.e., the vertical axis of the symphysis), which is not perpendicular to a true horizontal plane because the chin is deviated to the hypoplastic side. The line was then transferred to the mandibular dental cast. The upper cast was placed in an articulator, and the lower case was positioned so that the symphyseal midline was a true vertical perpendicular to a true horizontal plane. A certain degree of overcorrection was made. An interocclusal acrylic splint was fashioned with clasps as needed, and a generous opening was made in the splint, for suctioning and feeding, on the side of the open-bite. Two appliances were often fabricated; one necessitated a more ambitious elongation and overcorrection of the mandible and a smaller splint was used in case complete intraoperative translocation of the mandible was not possible.

TABLE 1 Study Group: HFM Mandibular Anomaly and Associated Malformations

Patient	*Mandible (Type)*	*Microtia (Grade)*	*7th Nerve (Paresis)*	*Soft Tissue (Deficit)*
1	IIB	3	None	Moderate
2	III	3	Upper/lower	Severe
3	IIB	Normal	Normal	Severe
4	III	3	Upper	Moderate
5	III	3	Upper/lower	Moderate
6	III	3	Lower	Severe
7	III	Normal	Normal	Moderate
8	IIB	Normal	Normal	Moderate

Radiographic Analysis

A panoramic radiograph, posteroanterior and lateral cephalographs, submental vertex view, and dental models were obtained from all patients. In addition, computed tomography and, in some instances, three-dimensional reconstructed tomograms were used in planning the operation. The child was categorized preoperatively as having Type IIA or Type IIB HFM. In rare instances, the preoperative strategy to elongate the existing ramus was changed to rib graft construction after exploration of the TMJ and intraoperative observation of the condylar head and the position of the hypoplastic ramus.

Surgical Procedure

Intubation can be difficult in children with mandibular Type IIB and Type III hemifacial microsomia. For children under 4 years of age, oral intubation is accomplished first, and then a nasal tube is passed using an anterior commissure laryngoscope. For children over 4 years of age, direct nasal intubation is usually possible with the aid of a flexible nasopharyngolaryngoscope. The effect of a muscle relaxant must be dissipated before the surgical dissection so there will be no interference with identification of the facial nerve.

A curvilinear preauricular skin incision was used to expose the temporomandibular joint and condyle. The incision was extended down to the deep temporal fascia, with care being taken to avoid damaging the superficial temporal vessels (a temporoparietal fascial flap may be needed for subsequent auricular construction). The fossa was entered via a posterior capsular approach, and the hypoplastic condylar stump was examined.

A second, low submandibular incision was then made. The dissection was carried bluntly to the mandibular angle, thereby avoiding possible injury to the marginal branch of the facial nerve. The pterygomasseteric sling was incised and the dissection carried extensively along the lateral and medial borders of the mandible. The hemimandibular dissection had to be extensive enough to allow jaw advancement, elongation, and rotation. If necessary, a coronoidotomy was done. Muscle relaxant was given at this stage to facilitate mandibular translocation.

Another set of instruments was used for the intraoral manipulation. In some instances, especially in older children, a coronoidotomy and compensatory subcondylar osteotomy was done on the normal side to allow complete mandibular rotation. Once the orthodontic splint was in place, it was secured with three circummandibular wires. Intermaxillary fixation was accomplished with two piriform wires and a circumzygomatic drop wire on the unaffected side. The piriform and suspension wires were attached to the circummandibular wires. Gloves and gowns were changed as the mouth was separated from the lateral incisions, and the sterile instruments were reintroduced into the field.

The gap between the glenoid fossa and relocated mandibular angle was measured to approximate the length of costochondral graft that was needed. If the glenoid fossa needed to be constructed in a more lateral position, another short segment of full thickness rib graft doweled on the undersurface was secured to the zygomatic process of the temporal bone and, if necessary, to the malar eminence. The cartilage top of the graft was modeled as a condylar head. A 0.25-inch Penrose drain was passed from the preauricular incision through the submandibular incision, which helped to guide the graft into the glenoid fossa. The lower end of the graft was secured to the lateral surface of the ramus with stainless steel wires or titanium screws.

After 2 to 3 weeks of intermaxillary fixation, the interoperative acrylic splint was removed, cleansed, and immediately replaced. Several weeks later, differential grinding of the maxillary surface of the splint began. The orthodontic appliance was removed only for cleaning. If left out of the mouth, buckling of the rib graft may occur. The splinting was continued for a 2-year period.

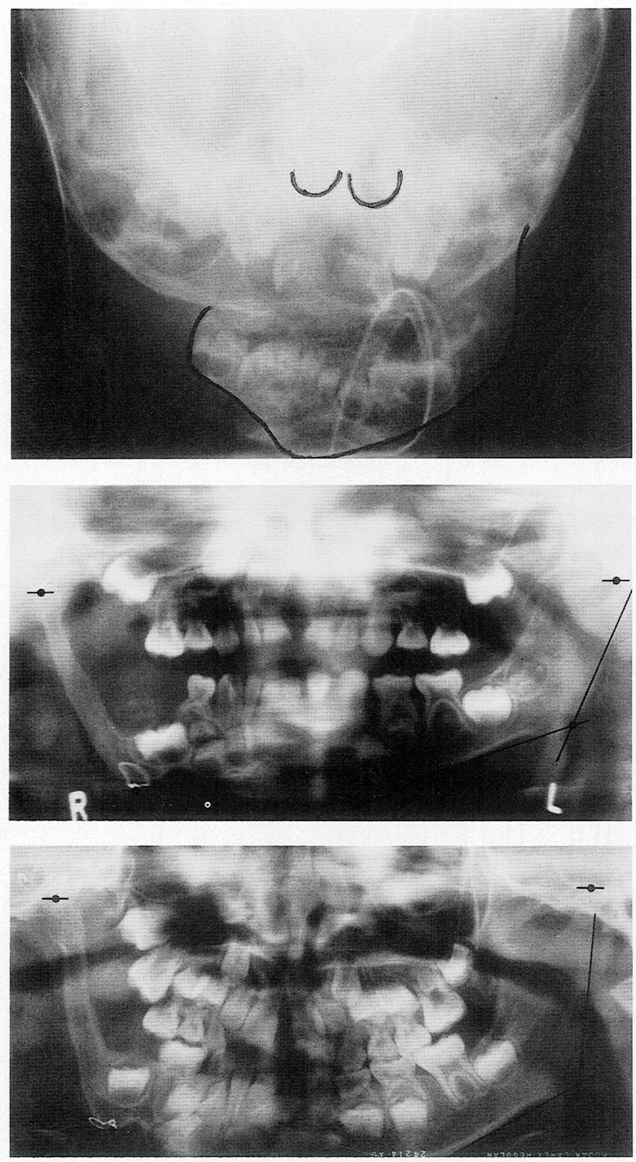
Postoperative Radiographic Analysis of Graft Length

Panoramic films were taken in the immediate postoperative period and repeated at yearly intervals. Direct measurements were made on the radiographs by a single observer. The outlines of the normal and constructed condyle-ramus were drawn by another investigator. On the normal side, the ramus height was measured from the top of the condyle to an intersection point of two tangents drawn to the posterior and inferior border of the mandible (Kaban et al, 1981). Measurements on the constructed condyle-ramus were made from the top of the condylar head to one of the two following fixed points inferiorly: either (1) at the fixation wire (or screw) or (2) at the intersection point of tangents drawn to the posterior border of the graft and inferior border of the mandible (Fig. 1).

Not all follow-up radiographs were taken on the same machine, so direct measurements could not be compared. To minimize the magnification factors, angulation, and other procedural differences, the condyle-ramus length was expressed as a percentage change by comparing the constructed with the normal side.

Data Reduction

The changes in the length of the constructed and "unaffected" side of the mandible were analyzed using the last observation during the first 2 postoperative years ("initial length") and the last available measurement ("follow-up length"). The percentage change on the constructed side of the mandible was compared with the percentage change observed on the normal side of the mandible.



A

B

C

FIGURE 1 Patient #7, panoramic radiographic measurements. *A*, Preoperative anteroposterior radiograph (age 10 months), taken under general anesthetic during excision of preauricular skin tags and middle ear examination. Note absence of right condyle-ramus (Type III), cant of piriform apertures, and deviation of chin and dental midlines. *B*, One year postoperative construction with costochondral rib graft. The open bite, maintained with a dental appliance, permits vertical midfacial growth. Intersecting tangents were drawn on the normal side, interosseous wires superimposed on the constructed side, and then measurements were made to the top of each condyle. *C*, Five years postoperative film with points used to document percentage change of condyle-ramus length.

Results

The results for the eight patients in the study group are shown in Table 2. The mode change was 11 percent on the constructed side over the study period. In four patients (numbered 1 to 4), large changes in normal condyle-ramus length were not matched by a similar elongation on the constructed side of the mandible. In other words, the growth on the constructed side did not keep pace when changes on the "unaffected" side were larger than the average "normal" growth (mean change = 0.94 cm).

TABLE 2. Changes in Mandibular Length Following Surgery

		Normal Side			Constructed Side			
	Age at Operation	Length (cm)		Percentage	Length (cm)		Percentage	Years of Follow-Up
Patient	(Years)	Initial	Latest	Change	Initial	Latest	Change	(At Last Visit)
1	7.5	4.2	6.2	48	7.0	7.7	11	3.5
2	2.0	3.6	4.7	31	6.1	6.8	11	6.5
3	2.5	5.0	6.2	24	4.4	4.7	7	5.0
4	12.0	6.1	7.1	16	7.2	8.0	11	6.5
5	10	4.5	5.1	13	6.3	7.0	11	5.0
6	8.0	5.3	5.5	4	7.0	7.3	4	3.5
7	1.5	4.8	5.7	19	5.7	7.1	23	4.0
8	8.0	4.5	5.0	11	4.0	4.9	22	2.5

In another group of four patients (numbered 5 to 8), the constructed side of the mandible grew in the expected range (see Table 2). The observed change was commensurate with the normal side (Fig. 2).

DISCUSSION

Experimental studies in animals indicate that costochondral grafts have intrinsic growth potential. Roy and Sarnat (1956) demonstrated that the rib in a growing rabbit elongates at the costochondral junction and suggested that this site would be an ideal source for a "growth center." Shatten et al (1958) documented that costochondral junction grafts, placed heterotopically in rats, grow 70 percent of that measured for in situ cartilage. Ware and Taylor (1966) showed there was growth of rib cartilage used to replace the condyle in rhesus monkeys, but they cautioned that growth of the transplant was unpredictable.

In 1920, Gillies may have been the first to use a costochondral graft to replace the mandibular condyle (MacIntosh and Henny, 1977). Costochondral grafts are currently used for the correction of TMJ ankylosis in adults (Lindqvist et al, 1986) and in children with ankylosis or following condylar excision (Ware and Brown, 1981). Ware and Brown (1981) noted the lack of uniformity of growth of costochondral transplants, from minimal change to overgrowth, causing unilateral prognathism. Figueroa et al (1984) reported symmetric facial growth almost 7 years post costochondral graft for unilateral mandibular condylar dysplasia in an 8-year-old boy.

Probably the first case of a child with HFM corrected with a costochondral rib graft was reported by Osborne (1964) and documented further by Knowles (1966). Knowles found a 10-mm increase in mandibular height on the grafted side versus a 3-mm increase on the normal side 2 years postoperatively. The occlusal plane remained tilted, and there was diminished height of the ipsilateral maxilla. Costochondral rib grafts are now commonly used to build the condyle-ramus in HFM patients, both adults (Obwegeser, 1974; Swanson and Murray, 1978) and children (Munro, 1980; Murray et al, 1984). Longitudinal study has shown that costochondral grafts placed in childhood facilitate more symmetric mandibular and midfacial growth (Kaban et al, 1988). However, Kaban et al (1988) did not answer the question of whether the rib graft itself actually grows.

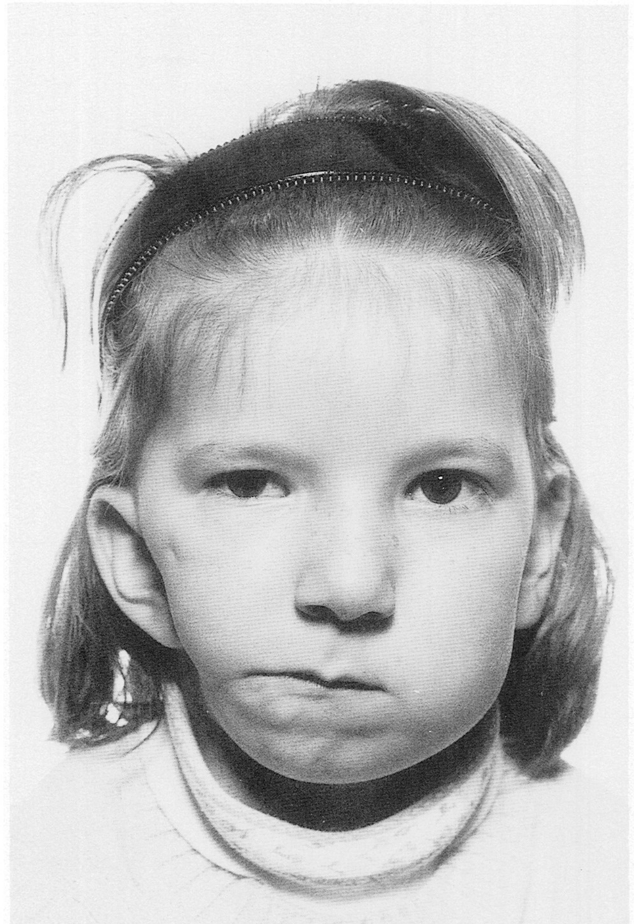
The experimental data reported in our current study suggest that the costochondral rib graft begins to elongate after 2 years postoperatively. The constructed condyle-ramus did not grow in a spurt, as in a normal condyle-ramus, but rather at a slow, irregular rate. In patients who exhibited rapid growth in the normal condyle-ramus, the grafted side failed to grow at the same pace. However, in another group of patients, with moderate elongation on the normal side, the constructed side changed proportionately.

Our data also show that it was impossible to compare growth between patients. In any particular child, the constructed side of the mandible seemed to grow independently of the normal side. Furthermore, this small sample showed no evidence of linearity. In other words, the percentage change in length was not the same over the various intervals. For example, patient #8 demonstrated a 22-percent elongation on the constructed side, and this patient was followed for the shortest period.

The rate of change in the normal side of the mandible appeared to be related to individual growth patterns, and the rate was not predictable from the data. For example, the subjects with the largest changes in normal mandible length (#1) and the smallest change (#6) were about the same age at operation (8 and 7.5 years, respectively), had an equal interval to last follow-up examination (3.5 years), had similar normal mandible lengths (4.2 and 5.3 cm), and had constructed mandibles of the same length (7.0 cm). We found no correlation among the initial size of the costochondral graft, age at time of surgical correction, or presenting type of mandibular deformity.

Normal mandibular development, from birth to maturity, does not necessarily follow an average growth curve. Significant variations exist, including differences from one growth phase to the next in the same individual (Van der Linden, 1986). The most notable adolescent growth spurt in the face is seen in the ramus and less so in the mandibular body (Van der Linden, 1986). Mandibular growth is not linear, accelerated growth is variable, and the final position of the jaw depends on lengthening of the condylar process and complex appositional-resorptive processes in the ramus (Enlow, 1982). The older theory that mandibular growth is intrinsic is supported by cephalometric implant studies (Björk and Skieller, 1983). On the other hand, Moss emphasizes the functional matrix theory that mandibular growth occurs secondarily in response to demands of related organs, tissues, and functioning spaces (Moss and Rankow, A

B



C

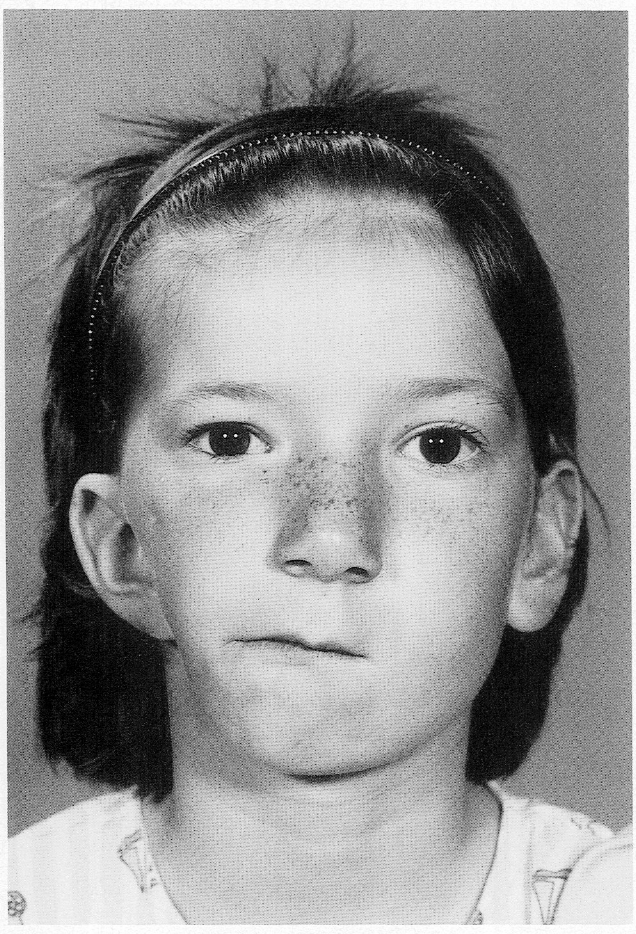


FIGURE 2 Patient #7 with skeletal Type III right hemifacial microsomia. *A,* Preoperative, at 2 years of age. *B,* One year postoperative, at 3 years of age. *C,* Five years postoperative, at 7 years of age. Her occlusal plane is slightly canted, and she may require secondary ramus elongation. Measurements demonstrate nearly equal percentage change in both condyle-ramus segments.

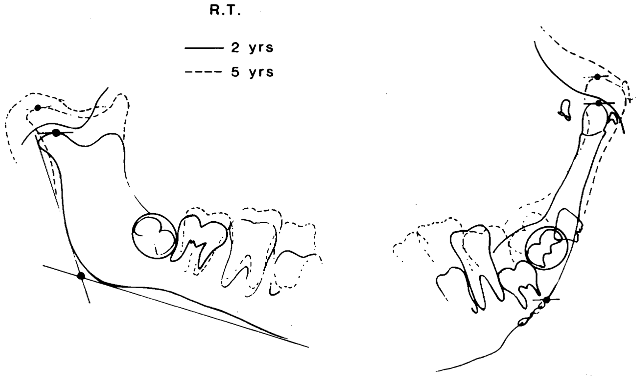


FIGURE 3 Tracings of panoramic radiographs of patient #5 with a Type III left hemifacial microsomia. Solid line is 2 years postoperative and interrupted line is 5 years postoperative. Registration is on the wires on left and third molar bud on right. Compare appositional bone growth along the posterior border of the ramus and condylar elongation on the normal to the constructed side.

1968). The two theories are not mutually exclusive. Both may have value when considering facial development in HFM.

The growing child with HFM presents an even more complex problem in terms of predicting adult morphology. There is hypoplasia of bony structures that may be responsible for intrinsic growth (e.g, the mandibular condyle, ramus, coronoid process, and the temporomandibular joint apparatus). Also, the "normal" side in HFM may not be entirely normal. There may be hypoplasia or compensatory elongation of the ramus on the less affected side. In HFM, the functional matrix is abnormal because of absence or hypoplasia of the muscles of mastication, abnormal occlusion, and often a facial nerve weakness (Poswillo, 1974). Mandibular deviation on opening also affects the functional matrix. The importance of this abnormal functional matrix (i.e., dysfunctional matrix) is supported by roentgen stereophotogrammetric studies with metallic implants in children with uncorrected HFM by Rune et al (1981). They found there was no correlation between the extent of the mandibular deformity and the displacement of the mandible with growth. The elongation of the costochondral rib grafts, documented in this study, suggests intrinsic growth, but certainly these grafts are also influenced by the dysfunctional matrix. Furthermore, the matrices differ on the two sides of the jaw in HFM, such as the muscle attachments, enveloping skin-subcutaneous tissues, and forces during movement.

As in normal mandibular development, growth on both the constructed and contralateral sides of the mandible seemed to proceed in a nonlinear fashion with individual variability. The two condylar-rami appeared to grow independently, perhaps related to intrinsic growth potential and functional matrix forces. It could not be determined from this study whether growth in the graft occurred at the costochondral junction, as evidenced by the experimental studies. Serial tracings of the panoramic radiographs suggested that the entire graft is growing and remodeling as a condyle-ramus, amalgamated within the mandible (Fig. 3).

Acknowledgment. The authors are indebted to Richard A. LaBrie, Ed.D., for statistical evaluation of our data.

References

Björk A, Skieller V. (1983). Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalometric implant studies over a period of 25 years. Eur J Orthod 5:1–46.

Converse JM, Horowitz SL, Coccaro PJ, Wood-Smith D. (1973). The corrective treatment of the skeletal asymmetry in hemifacial microsomia. Plast Reconstr Surg 52:221–231.

Enlow DH. (1982). Handbook of facial growth. 2nd ed. Philadelphia: WB Saunders, 1982.

Figueroa AA, Gans BJ, Pruzansky S. (1984). Long-term follow-up of a mandibular costochondral graft. Oral Surg Oral Med Oral Pathol 58:257–268.

Kaban LB, Moses MH, Mulliken JB. (1988). Surgical correction of hemifacial microsomia in the growing child. Plast Reconstr Surg 82:9–19.

Kaban LB, Mulliken JB, Murray JE. (1981). Three-dimensional approach to analysis and treatment of hemifacial microsomia. Cleft Palate J 18:90–99.

Knowles CC. (1966). Cephalometric treatment planning and analysis of maxillary growth following bone grafting to the ramus in hemifacial microsomia. Dent Prac 17:28–38.

Lindqvist C, Pihakar A, Tasanen A, Hempf G. (1986). Autogenous costochondral grafts in temporomandibular joint arthroplasty. J Maxillofac Surg 14:143–149.

MacIntosh RB, Henny FA. (1977). A spectrum of application of autogenous costochondral grafts. J Maxofac Surg 5:257–267.

Moss ML, Rankow RM. (1968). The role of the functional matrix in mandibular growth. Angle Orthod 38:93–103.

Mulliken JB, Kaban LB. (1987). Analysis and treatment of hemifacial microsomia in childhood. Clin Plast Surg 14:91–100.

Munro I. (1980). One-stage reconstruction of the temporomandibular joint in hemifacial microsomia. Plast Reconstr Surg 74:186–199.

Murray JE, Kaban LB, Mulliken JB. (1984). Analysis and treatment of hemifacial microsomia. Plast Reconstr Surg 66:699–710.

Obwegeser HL. (1974). Correction of the skeletal anomalies of otomandibular dysostosis. J Maxillofac Surg 2:73–92.

Osborne R. (1964). The treatment of the underdeveloped ascending ramus. Br J Plast Surg 17:376–388.

Poswillo D. (1974). Otomandibular deformity: pathogenesis as a guide to reconstruction. J Maxillofac Surg 2:64–72.

Pruzansky S. (1969). Not all dwarfed mandibles are alike. Birth Defects Original Article Series 5(2):120–129.

Roy EW, Sarnat BG. (1956). Growth in length of rabbit ribs at the costochondral junction. Surg Obstet Gynecol 103:481–486.

Rune B, Sarnas KV, Selvik G, Jacobsson S. (1981) Growth in hemifacial microsomia studied with the aid of roentgen sterophotogrammetry and metallic implants. Cleft Palate J 17:128–146.

Shatten WE, Bergenstal DM, Kramer WM, Swarm RL, Siegel S. (1958). Biological survival and growth of cartilage grafts. Plast Reconstr Surg 22:11–28.

Swanson LT, Murray JE. (1978). Asymmetries of the lower part of the face. In: Whitaker LA, Randall P, eds. Symposium on reconstruction of jaw deformities. St. Louis: CV Mosby, 171–195.

Van der Linden FPGM. (1986). Facial growth and facial orthopedics. Chicago: Quintessence, 93–102.

Vento R, Mulliken JB. (1989). The O.M.E.N.S. classification of hemifacial microsomia. Paper presented at the annual meeting of the American Cleft Palate–Craniofacial Association, Williamsburg, VA.

Ware WH, Brown SL. (1981). Growth centre transplantation to replace mandibular condyles. J Maxillofac Surg 9:50–58.

Ware WH, Taylor RC. (1966). Cartilaginous growth centers transplanted to replace mandibular condyles in monkeys. J Oral Surg 24:33–43.