THE EFFECTS OF PRIMARY ALVEOLAR BONE GRAFTING ON MAXILLARY GROWTH AND DEVELOPMENT

by

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Submitted to the Graduate Faculty of the School of Dentistry in partial fulfillment of the requirements for the degree of Master of Science in Dentistry, Indiana University School of Dentistry, 1993.

Thesis accepted by the faculty of the Department of Pediatric Dentistry, Indiana University School of Dentistry, in partial fulfillment of the requirements for the degree of Master of Science in Dentistry.

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ACKNOWLEDGMENTS

I would like to express my appreciation to Dr. David R. Avery (Chairman), Dr. Ronald A. Branca, Dr. David K. Hennon, Dr. Charles L. Nelson and Dr. A. Michael Sadove for their participation on my Graduate Committee. Special thanks go to Dr. Brian J. Sanders and Dr. Richard B. Troyer for their encouragement and support. I would also like to thank Dr. David Bixler and Dr. B. Keith Moore for their assistance in data analysis, and Dr. Rosario H. Potter for performing the statistical analyses. A special thank you goes to Dr. Barry L. Eppley for his guidance and understanding. Lastly, I wish to thank my parents and brothers for their love and support.

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INTRODUCTION

Primary alveolar bone grafting refers to an alveolar cleft technique that is performed in infants less than 1 year of age. Based on the results of varying surgical techniques, opponents of primary bone grafting claim that early repair limits maxillary and midfacial growth. Some practitioners believe, however, that primary alveolar grafts effectively establish maxillary arch continuity, provide resistance to forces that cause the arch to collapse toward the midline and do not significantly attenuate craniofacial growth. This investigation served as a follow-up of the unilateral and bilateral cleft lip and palate patients who underwent primary alveolar bone grafting at James Whitcomb Riley Hospital of the Indiana University Medical Center from September 1983 to March 1985. Through the use of cephalometric data, arch symmetry measurements and palatal surface area values, this study examines the maxillofacial growth and development of those patients.

REVIEW OF LITERATURE

Bone grafting of the alveolar cleft has long been considered to be an important part of the surgical regimen for the cleft lip and palate patient. Considerable controversy exists, however, over the optimal timing of the procedure and its effect on facial growth.

Timing of alveolar grafting is most generally defined by the age of the patient and stage of dental development. Primary alveolar grafting refers to an alveolar cleft technique that is performed in infants less than 1 year of age or prior to complete eruption of the deciduous dentition. Bone grafting that takes place at 2 to 5 years of age or after the eruption of all the primary teeth refers to early secondary alveolar grafting. Procedures performed at 6 to 12 years of age and during the presence of the mixed dentition refer to secondary alveolar grafts. Late secondary or tertiary alveolar grafts refer to procedures performed after the eruption of the permanent dentition.[1,2]

Witsenburg and others [2-12] noted that in cases where the maxillary defect is not grafted and the frequently occurring oronasal fistula left open, the following sequelae, apart from possible psychosocial disturbances, may occur:

1. Malposition of one or more teeth in the anterior maxillary region
2. Insufficient periodontal bone support for the teeth adjacent to the bony cleft, with the consequent chance of early loss of these teeth
3. Less favorable hygienic conditions caused by the malposition of the teeth and the presence of an oronasal communication, and consequently, a higher risk of caries and periodontal inflammation exists

4. Insufficient retention for full or partial dentures and a higher risk for fractures of roots of abutment teeth of fixed prostheses
5. Adverse effects on speech because of irregular tooth position, a tapered dental arch and escape of air via the oronasal communication
6. Facial asymmetry due to a difference in form of the nasal alae and collumellar deviation, and lack of bony support for the alar base
7. Nasal crusting caused by the lack of separation of oral and nasal secretions

Other problems that arise when the cleft is not grafted include:

8. Retention of food particles in mucosal recesses and/or narrow fistulae
9. Deficiency of a firm bony base for support of a denture
10. Insufficient bone to enable orthodontic movement of teeth into the best position and occlusion
11. Relapse after orthodontic expansion of collapsed maxillary segments
12. Long artificial teeth or an excess of labial acrylic in situations where fixed or partial dentures are worn because of lack of sufficient alveolar processes at the site of the cleft with consequent retention of food particles, mucosal inflammation and development of calculus in relation to the denture
13. Poor esthetics of the lips because of lack of natural support from alveolus and teeth
14. Unfavorable conditions for surgical repair of the posterior palate.

The first attempts to graft autogenous bone to the cleft maxilla, as reviewed by Koberg[1] and Witsenburg,[2] were by von Eiselsberg [13] in 1901 and Lexer [14] in 1908. Von Eiselsberg[13] occasionally used a part of the bone and soft tissues of the little finger as a pedicled graft. Lexer,[14] probably the first to do so, recommended the use of a free bone graft for the maxilla in cleft patients. Drachter[5] considered the use of bone of the little finger too great of a mutilation and in 1914 reported closure of a cleft with tibial bone and periosteum. Beck and Jesser [15] in 1921 grafted the upper jaw using the pedicled posterior part of the inferior turbinate.

The concept of early bone grafting to repair the bony clefts of the alveolus and hard palate was first introduced in the literature in 1955 by Schmid[16] and Nordin and Johanson.[17] They suggested that the early placement of autogenous iliac bone between the maxillary processes would improve growth and occlusion and prevent future collapse of the arch.

During the ensuing '50s and early '60s, primary alveolar grafting became very popular, and accordingly, a routine procedure in many craniofacial centers throughout the world.[1,2,9,18] Indications for the procedure ranged from the repair of the bony deficiency and stabilization of the premaxilla, to the creation of a new bone matrix for the eruption of teeth in the cleft area. It was speculated that early elimination and correction of the bony defect would normalize, or even stimulate, maxillary growth.

In 1950 the use of maxillary orthopedic appliances in early cleft lip and palate treatment was introduced by McNeil.[19] He claimed that the appliance exerted a continuous gentle force on the palatal tissues, which in turn, acted as a stimulus for the deposition of new bone. Pressure from the appliance was thought to reposition the cleft segments into a more favorable arch configuration, thereby, reducing the cleft area in the maxilla. Proponents reasoned that alveolar grafting, in conjunction with maxillary orthopedics, would maintain arch stability and improve growth and dental occlusion.[8,10,19-26]

By the 1970s many who had earlier advocated primary alveolar grafting had abandoned the procedure.[18] Based on the results of varying surgical techniques, opponents of primary bone grafting claim that early repair limits maxillary and midfacial growth.

Johanson and Ohlsson[8] advocated early orthopedic correction through the use of a screw-plate appliance prior to placement of the bone graft. Serial radiographic examinations indicated bony continuity of the alveolar process and improved conditions for teeth erupting adjacent to the cleft. Normalized growth of the jaw and occlusal stability were also noted.

Brauer and Cronin [20] presented a sequence for the treatment of complete clefts during the patient's first two years. Movements of the maxillary segments are controlled through maxillary orthopedics. Grafting is performed at an average of 8-12 months of age and when the maxillary and mandibular arches are in a proper relationship. The fifth, sixth, or seventh rib is harvested and inserted as a wedge or onlay graft, or as a combination of the two. Brauer and Cronin believe the purposes of the graft are: (1) to fix the cleft maxillary segment to the normal side, (2) to provide support for the teeth in the region of the bony cleft, and (3) to build out the flat contour often seen on the cleft side of the maxilla.

Pruzansky[27] described pre-surgical orthopedics and bone grafting in infants to be excessive and unnecessary. In response to early treatment in which proponents claim that the maxillary shelves should be brought under the growth-stimulating influence of the cartilaginous septum, he argued that the arch form is dictated primarily by muscle and connective tissue continuity. Based on the preliminary results from his review of crossbites in unilateral cleft cases, Pruzansky found no justification for early orthopedics and surgery since 37 percent of the cases showed no crossbite. He observed that a great number would require no orthodontic treatment or a minimal amount for the correction of arch collapse or tooth rotation. He noted that early grafting, especially in cases where expansion preceded grafting, produced and maintained excessively wide clefts in the posterior region. This widening could inhibit speech development and retard velopharyngeal valving at an early age.

Georgiade et al.[9] reviewed over 2200 cleft lip and palate patients and concluded that many of the results, particularly in the bilateral cleft and complete alveolar cleft group, were short of their desired goals from both functional and esthetic standpoints. The authors believed that no one surgical procedure would work well for every surgeon and that the severity and type of cleft must be considered individually. Recommendations were made that bone grafting should be performed prior to any collapse of the arches.

Skoog[25] reported on the use of autogenous grafts in 79 cases of bilateral and unilateral clefts. Through radiographs taken at various intervals, he observed that tooth buds moved into the grafted bone and that permanent teeth could erupt in a more normal position. Skoog claimed that the primary function of the grafting procedure is to provide a framework along which periosteal continuity between the maxillary segments is recreated. By restoring the continuity and normal shape of the maxillary framework, the characteristic depression of the lip and alar base was corrected, and the floor of the nose was elevated. Following bilateral grafting, the freely movable premaxilla was incorporated into the arch, which was functionally advantageous.

Skoog[28] subsequently introduced a primary repair approach that utilized the osteogenic potential of the periosteum. The technique involved the use of periosteal flaps for the purpose of creating bony continuity, preventing collapse of the maxilla and contributing to the restoration of symmetry of the arch. The three- and six-month postoperative evaluations yielded promising results, with conclusions to be made after long-term follow-up studies.

A five-year follow-up study by Hellquist and Skoog[29] evaluated the influence of primary periosteoplasty in 66 cases of complete unilateral cleft lip and palate. Using radiographs, photographs and study models, the investigators compared maxillary growth and the deciduous occlusion in 36 patients who had undergone periosteoplasty in conjunction with cleft lip and/or palate repair with 30 patients who were operated without periosteoplasty. In all patients who had been treated by periosteoplasty, new bone formed within the alveolar cleft. Comparisons of the intercanine and intermolar dimensions between the periosteoplasty and control cases indicated that the new bone did not withstand scar contracture that followed palatoplasty. No increased frequency of anterior crossbite was found, nor was the maxillary arch length adversely affected. The authors concluded that primary periosteoplasty effectively restores the bony framework and does not retard or impair maxillary growth.

Longacre et al.[30] claimed that placement of a split-rib-graft prior to palatoplasty would correct the flattening of the alar carilage and improve the level of the nostril floor as well as the nostril tip contour. Laminated bone was found to have filled the alveolar and maxillary defect, and decreases in the incidence of crossbite and retrusion were also noted.

Lynch et al.[21,31] compared 32 patients who were grafted prior to 18 months of age, with 32 similar patients in whom bone grafting had been deferred beyond the age of 6 years. Management of these patients included lip repair at approximately 1 month of age, followed by the delivery of an acrylic splint to align the maxillary segments. Bone grafting was performed for stabilization of the alveolar arch and for correction of the bony deficiency at an average age of 6-9 months. Cephalometric analyses indicated that at 6 years of age there was no significant difference between the two groups in the rate of maxillary growth.

Nylen et al.[22,32] reported on 39 unilateral and 14 bilateral cleft lip and palate patients who ranged from 5 1/2 to 13 years of age. The appearance of the lip, nose and face was assessed, speech capability was analyzed, hearing and otological pathology were investigated and the skeletal profile and dental occlusion were evaluated. In the 39 unilateral patients, 80 percent had an acceptable appearance, while 20 percent required secondary surgery of the lip and nose. In the 14 cases, 50 percent needed secondary operation of the lip and nose. The results of the cephalometric analysis suggested no tendency toward maldevelopment of the facial skeleton. The authors also reported that primary bone grafting offers the advantages of premaxilla stabilization, support for the alar base, restored continuity of the dental arch with the possibility of tooth eruption through the graft, and improved speech patterns due to the facilitation of palate closure.

Pickrell et al.[12] reported on 25 infants with complete unilateral clefts of the lip, alveolus and palate, and stated: (1) primary rib grafts in the maxilla do not increase in size concomitantly with facial growth and development, (2) teeth do not migrate and erupt spontaneously through a rib-bone graft, (3) rib-bone grafts do not form a true alveolar process (a permanent alveolar notch remains), and (4) the orthopedic effect of the bone graft decreases proportionately as its incorporation progresses.

Rehrmann et al.[33] concluded after a 10-year follow-up that primary bone grafting retarded the development of the maxillary arch and arrested local growth of the maxillary bone. Based on these negative findings, they abandoned alveolar grafting until the complete eruption of the permanent dentition.

Robinson and Wood[23] found from their evaluation of pre and post-operative dental casts and occlusal radiographs that primary alveolar grafts prevent the collapse of the lesser segment. They found that the lesser segment was brought under the growth stimulus of the nasal septal cartilage and that the maxillary arch consequently grew as one unit. Teeth formed at the periphery of the graft migrated into the grafted area, which improved the position of teeth within the arch and enhanced the possibilities of a better dental occlusion.

Rosenstein et al.[24,34-36] continued to use primary bone grafts and were satisfied with the maxillary growth that resulted. They advocated the use of a maxillary prosthesis prior to lip closure. Through cheiloplasty and use of the obturator, the alveolar segments were orthopedically molded into approximation. Since the autogenous split-rib bone graft is inserted only when the segments are in end-to-end approximation, there was a minimal gap to bridge. The maxillary prosthesis is then worn continuously until the the time of palatoplasty. The four steps of palatal obturator fabrication, cheiloplasty, alveolar grafting and palatoplasty are completed by the age of 2.

Many of the early primary alveolar graft techniques used vomerine flaps, involving considerable dissection in the area of the prevomerine suture, to cover the bone grafts, most of which were carried out at the time of cheiloplasty. This area is generally considered to be an important growth center and should therefore be avoided. Rosenstein et al. found that by limiting the soft tissue dissection and bone grafting to the alveolar level only, the area of the vomeropremaxillary suture was avoided. Surgery involving the vomeropremaxillary suture may contribute to midfacial retrusion that is sometimes seen in unilateral and bilateral cleft lip and palate patients.[38,39]

Cephalometric evaluation of their 16 oldest unilateral cleft lip and palate cases enabled Rosenstein et al.[40,41] to conclude that primary alveolar grafting does not adversely influence facial growth. In fact, a more favorable maxillary segment alignment and a better dental occlusion were found.

Rosenstein et al.[42] used cephalometrics in a 25-year postoperative analysis of their oldest 36 patients whose skeletal growth for all practical purposes was complete. Twenty-five unilateral and 11 bilateral patients with average ages of 17 years 5 months and 16 years 5 months, respectively, were followed to determine the need for and type of orthognathic surgery. Eight of the 36 patients (22.2 percent) required orthognathic surgery to advance the maxilla. In one of these patients, the vertical height of the maxilla was also altered. Two patients required maxillary augmentation only in the form of an onlay graft. The authors concluded that their treatment protocol does not lead to a significant degree of maxillary hypoplasia.

Ross[43] examined the cranial base morphology of 342 children with clefts of the lip and palate and 200 noncleft children. Through cephalometric analysis he found that the cranial base was smaller in children with clefts. He theorized that this was due to the smaller size of the children and was not a reflection of an abnormality in the cranial base. The component structures of the cranial base in the cleft children were found to be equally propotional to those of the noncleft children. In addition, the spatial relationships between the cranial base components were similar for the cleft and noncleft children.

Ross[44] evaluated the effects of early surgery on facial growth and concluded that the major resulting problem was maxillary retrusion. This growth attenuation is a progressive process as evidenced by the frequency of orthodontic relapse after the completion of the pubertal growth "spurt." He believed that alveolar grafting should have no effect on long-term maxillary growth since the graft is placed in an area where growth usually does not take place. Early bone grafting could prevent collapse of the maxillary segments but would have no effect on the secondary dento-alveolar distortion related to palatoplasty. Ross claimed that the conflicting results from primary alveolar graft studies may actually be due to the surgical procedure used in palatoplasty and not to the placement of the bone graft.

Ross[45] later investigated the maxilofacial development of 439 males with unilateral cleft lip and palate, 243 of whom had received some form of alveolus repair. The results indicated that repair of the alveolus by any means was primarily responsible for the vertical deficiency of the anterior maxilla and that the deficiency was only slightly worsened by placement of the bone graft. Infant bone grafting was found to cause growth attenuation of the maxilla in length and height. Compensatory mandibular changes increased lower facial height and adversely affected vertical proportions of the face. Alveolar grafting performed at 4-10 years of age resulted in growth patterns similar to those of the infant bone graft group. Ross concluded that the vertical growth effects would be avoided only if bone grafting is postponed until age 15 or later.

Wood[26,45] reported on 20 cases that had been treated with presurgical maxillary orthopedics and primary bone grafting. Using serialized models, occlusal films and lateral cephalometric radiographs, the author compared the maxillo-mandibular development of his sample with 24 non-grafted cases. Wood concluded from this interim study that the primary bone graft (1) prevents collapse of the maxillary arch and does not resorb, (2) brings the segments under the growth mechanism of the nasal septal cartilage and, therefore, encourages the mid-third of the face to grow as one unit, and (3) improves occlusion by the reduction of pseudo-prognathia and by the tendency of the teeth that have formed at the cleft margins to migrate into the grafted area.

He found intraoral retaining appliances to be unnecessary when the presurgically corrected arch was bone grafted.

From a review of 33 cases, Epstein et al.[46] claimed that it is impossible to determine in infancy which patients will require maxillary orthopedics and subsequent grafting for arch stabilization. In no instances was the migration of teeth into the graft site observed. Furthermore, since proliferation of the alveolar process is not complete until eruption of the secondary dentition, early grafting leaves a permanent notch in the maxilla. The authors concluded that bone grafting should be delayed until the late secondary dentition has erupted for optimal satisfaction of functional and esthetic needs.

Matthews et al.[10] examined the results of early bone grafting in 94 children; of these, 75 were unilateral and 19 bilateral. In all cases the graft had been placed at approximately 3 months of age. Radiographs indicated that the graft did not resorb, and that in 31.5 percent of the cases, teeth erupted into the graft area. Forty-seven percent of the cases required only minor orthodontics and in 14 percent of cases, maxillary collapse occurred despite radiographic evidence of bone in the grafted area. One limitation of the study is that it covers a period of only seven years, with the oldest patients approaching 9 years of age. Moreover, since all cases during the period were grafted, there was not a non-grafted series available for comparison.

Jolleys and Robertson[47,48] concluded from their 5 and 11 year studies that no advantages existed for the procedure. Rather, the decreased anterior-posterior development, the increased incidence of crossbite and the decreased area of the upper jaw indicated maxillary growth limitations. Serial records disclosed that most of the grafts had deteriorated to a small strut of bone and that an alveolar notch remained in the cleft area. There was no evidence to support the idea that teeth will migrate into or spontaneously erupt into the rib graft. The changes in the occlusion and maxillofacial growth were much less between 5 and 11 years than between the age at placement of the bone graft and the age of 5 years. They abandoned primary alveolar grafting in 1968 when it became apparent that the procedure was of no benefit to the patient.

Friede and Johanson[49-51] noted a retardation of maxillary growth, as well as an increased frequency of both anterior and lateral crossbites. Compared with non-grafted and non-clefted cases, those patients who had received a primary alveolar graft exhibited a more severe maxillary retrognathia and vertical deficiency, which seemed to increase with age. In 40 percent of the bilateral and 50 percent of the unilateral cleft patients, the midfacial growth attenuation had reached such proportions that surgical advancement of the maxilla was necessary. Fusion of the suture between the premaxilla and vomer was suggested as the reason for the insufficient midfacial growth. Primary bone grafting was discontinued at their center in 1964.

Schmid et al.[52] implanted hip bone between the alveolar processes at the time of lip closure. Although future orthodontic treatment seemed necessary in all 87 cases, the authors concluded that primary osteoplasty is a valuable technique for maxillary stabilization. Malocclusions ranging from slight to medium deformities were mainly restricted to the cleft's immediate vicinity in sagittal and transverse directions and vertical shortening was rarely observed.

Hellquist and Ponten[53] evaluated the effects of infant periosteoplasty on facial morphology and dental occlusion at 5 and 7 years of age in 36 patients with complete unilateral clefts. In no instances had presurgical maxillary orthopedics or early bone grafting been employed. The results from their analyses of study models and radiographs indicated that the incidences of bimaxillary retrognathia and anterior crossbite were within the reported limits for other Scandinavian cleft lip and palate patients of the same age and cleft type.

Larson et al.[55,56] studied the incorporation of early bone grafts in unilateral and bilateral cleft patients with or without maxillary orthopedics. Using orthopantograms and occlusal films, the authors demonstrated that early bone grafting resulted in high bone density and alveolar bone height. The amount of bone in the grafted region was found to increase significantly from 7 to 13 years of age. This change was attributed to the migration of teeth into the graft site, making it work as functional alveolar process.

A cephalometric analysis of the soft tissue profile of the face indicated that the early bone grafted cases, with the exception of the soft tissue overlying the subnasal area, was within the limits of non-grafted cases. The reduced prominence of the region was attributed to the surgical technique (lip adhesion), which made the lip adherent to the alveolar crest.

Egbert[56] reported on the first 17 unilateral and bilateral cleft lip and palate cases who underwent primary alveolar grafting at James Whitcomb Riley Hospital for Children at Indiana University Medical Center. The average age of the patients was 4 and all were approximately three years post-graft. The data from his cephalometric studies was compared to age-matched non-grafted cleft patients and to age-matched non-cleft children. The results indicated that primary bone grafts, using the techniques described by Rosenstein, did not have significant adverse effects on maxillary anterior-posterior and vertical growth.

Using periapical radiographs and biometric data, Helms et al.[57] compared the success of grafts placed at three distinct stages of dentofacial development. The "primary" group consisted of 20 rib grafts placed at less than 1 year of age, the "secondary" group consisted of 19 iliac crest grafts placed when the permanent canine was 25-50 percent formed and the "delayed" group consisted of 18 iliac crest grafts placed after eruption of the permanent canine.

At the time of final evaluation, all patients were a minimum of 15 years of age and at least five years post surgery. Although Helms et al. found no significant difference in the presence of bony bridges, significantly greater bone attachment and ridge height were seen in the primary graft group. No significant differences were found regarding history of an anterior crossbite. Posterior crossbites were seen less frequently in the primary group than in the secondary or delayed groups. Following bone grafting and orthodontics, the primary group showed significantly fewer anterior and posterior crossbites. The incidence of teeth lost due to inadequate bone support was also significantly less for the primary group. Ridge augmentation or regrafts occurred more frequently in the secondary and delayed groups. The authors concluded that the primary graft results were equal or superior to those of the secondary and delayed groups. Secondary and delayed were of approximately equal success.

Primary alveolar grafts remain controversial, with only a few centers in the United States continuing to advocate the procedure. This is an interim report on the effects of primary bone grafts on maxillary and midfacial growth using the sequence and methods described by Rosenstein et al.[24,34-36]

METHODS AND MATERIALS

Clinical management of the cleft patient at Riley Children's Hospital may begin within two weeks of birth; and by 2 years of age, the four steps of palatal obturator fabrication, cheiloplasty, alveolar grafting and palatoplasty are completed. The sequencing and timing of these procedures have an important effect on long-term facial development. This treatment philosophy closely parallels the surgical regimen advocated by Rosenstein et al.[24,34-36]

Through cheiloplasty and use of the obturator, the alveolar segments are orthopedically molded into approximation. Generally, this alignment occurs by 6 to 9 months of age. This has been determined to be an ideal juncture to initiate primary bone grafting.

Under general anesthesia in the operating room, a 2.0 cm segment of the fourth or fifth rib is harvested and stored in saline. The maxillary labial vestibule is infiltrated with a local anesthetic containing vasoconstrictor and a small trapezoidal shaped mucosal flap extending from the apex of the cleft to the lip mucosa is created. Full-thickness incisions are then made from the apex of the cleft to the alveolar ridge crest. Using the periosteal elevator, subperiosteal pockets are developed on the labial aspects of the alveolus. The mucosal flaps on the palatal aspect of the alveolus are turned toward the palate and sutured. Longitudinal splitting of the rib is followed by slight contouring of the graft segment to conform to the curvature of the maxillary alveolus. The rib graft is then inserted into the labial pockets, and chips from the second half of the rib are packed behind the segment for reinforcement. The trapezoidal lip flap is then positioned to cover the labial aspect of the graft and sutured. Length of surgery is approximately two hours.

The surgery is a restricted soft tissue dissection and bone grafting limited to the alveolar level only. By utilizing this approach the vomeromaxillary suture is avoided, an area considered by many to be an important growth center. Thus, potential post-operative scarring and skeletal restrictions are minimized.

The 18 patients in this study, 15 males and 3 females, received primary alveolar grafts between September 7, 1983 and March 5, 1985. Thirteen had complete unilateral clefts and five had complete bilateral clefts of the lip and palate. For this study, the age of the patients ranged from 7 years 6 months to 8 years 6 months. The mean age of the group was 8 years, and all were at least five years post-graft. None had received orthodontic treatment. All children are routinely followed by the Indiana University Medical Center Craniofacial Anomalies Team.

A letter (Appendix A) explaining the purposes of the research and methods of data collection was sent to each patient's family. Statements allowing the opportunity to withdraw from the research at any time and protecting confidentiality were made. A guardian of the patient was asked to sign a voluntary consent form prior to the child's participation in the study (Appendix B).

At the time of appointment, the following procedures were completed: maxillary and mandibular impressions, wax occlusal registration and lateral cephalometric radiograph. All procedures were performed at the dental clinic at James Whitcomb Riley Hospital of Indiana University Medical Center.

PART I, CEPHALOMETRIC STUDY

For standardization of technique the film cassette was placed 12.5 mm from the child's midsagittal plane. All patients were asked to position their teeth in centric occlusion.

Each film was traced, and the following cephalometric landmarks were identified (Figure 1):

A point (A): The deepest point on the curvature of the anterior maxilla between the anterior nasal spine and the crest of the alveolar process; the most forward point of the maxilla. When A point was obscured due to distortion in the anterior maxillary area, the midpoint between the anterior nasal spine and the alveolar crest was defined as A point.

Anterior Nasal Spine (ANS): The anterior-most point of the anterior nasal spine. Due to the anterolateral displacement of the cleft segments, the anterior nasal spine is often deformed or obliterated. For the purpose of this investigation, when the anterior anterior nasal spine was poorly demarcated, the most anterior point of the maxillary basal bone was defined as anterior nasal spine.

Articulare (Ar): The point of intersection of the posterior margin of the ascending ramus and the external outline of the cranial base.

B point (B): The deepest point on the curvature of the mandibular alveolar process between the alveolar crest and pogonion; the most anterior point of the mandible in the median plane.

Basion (Ba): The most inferior point on the occipital bone, representing the anterior margin of the foramen magnum.

Gonion (Go): A constructed point formed by the intersection of lines tangent to the posterior border of the ascending ramus and the mandibular planes.

Menton (M): The most inferior point on the mandibular symphysis.

Nasion (N): The most anterior point of the naso-frontal suture.

Pogonion (Pg): The most anteior point on the midssagittal mandibular symphysis.

Sella turcica (S): The midpoint of the hypophyseal fossa.

The following angular measurements (Figure 2) were made:

SNA: establishes the horizontal location of the maxilla; the relationship of the maxilla to the anterior cranial base.

SNB: establishes the horizontal location of the mandible; the relationship of the mandible to the anterior cranial base.

ANB: indicates the horizontal relationship between the maxilla and mandible.

Ar-Go-Me: the angle of the mandible; the gonial angle and measure of ramocorporal growth

Ba-S-N: represents the cranial base angle.

The following linear measurements (Figure 3) were recorded:

ANS-Me: lower facial height.

Ar-Go: mandibular ramal height.

Ar-Pg: effective mandibular length.

Ba-N: cranial base depth.

Go-Me: mandibular body length (inferior-most).

Go-Pg: mandibular body length (anterior-most).

N-ANS: upper facial height.

N-Me: anterior facial height.

S-Ba: length of the posterior cranial base.

S-Go: posterior facial height.

S-N: the anteroposterior extent of the anterior cranial base.

The ratio N-ANS / ANS-Me was also determined. It is a description of upper to lower facial height. The 10 landmarks were digitized (Digitize Facial Bones version 1.0, S.Sudha, Indianapolis, IN). Five angular measurements, 11 linear measurements and 1 ratio of linear measurements were determined and recorded to the nearest 0.5 mm degree and 0.5 mm, respectively.

The data were compared to that of age-matched non-cleft children. The cephalometric standards were selected from the University of Michigan Growth Study by Riolo, Moyers, McNamara and Hunter[58] (Table I).

Descriptive statistics (mean, standard deviation, standard error of means) were calculated for all variables (Tables II and III). Due to the small sample size, all statistics were performed over unilateral clefts and bilateral clefts combined (Tables IV and V). The one sample t test was used to compare the cephalometric data of the Riley group with the University of Michigan standards. The male and female data were corrected for the male and female standards (means), respectively, then pooled for the t test due to the small sample size. The ratio (percentage) data were statistically transformed by the arcsine (angular) transformation before analysis, to satisfy assumptions on distribution and variance homogeneity.

PART II, ARCH SYMMETRY ANALYSIS

The maxillary study models were analyzed using a variation of the Relationship Measurement Method originally described by Kurt-W. Butow.[59] (See Appendix C for a detailed description of this method). This measurement system is a two-dimensional geometric analysis which may be used to evaluate occlusion and arch symmetry in three different ways. Since the analysis does not include the mandibular arch, inherited orthognathic problems may be ignored. Discrepancies in tooth position, such as ectopically erupted cuspids, may also be negated since the analysis considers the center of the alveolar ridge and not individual tooth positions.

Descriptive statistics (mean, standard deviation, standard error of means) were calculated (Table VI). Each side of the five bilateral clefts was separately analyzed. The data from the 10 "unilateral" clefts were included for analysis with the data of the 13 unilateral cleft patients.

The arch symmetry data were analyzed using the paired t test (Table VII). Theoretically, the ratios Lx/Lx', Ly/Lx' and H/H' should equal 1, that is, the two variables in the ratio are equal or their difference equals zero. The paired t test was, therefore, used to determine if the difference between the two sides was significant.

PART III, PALATAL SURFACE AREA

Maxillary study models made at the time of cheiloplasty (mean=3 months), alveolar bone graft (mean=9 months) and palatoplasty (mean=18 months) were obtained for the purpose of creating a time sequence analysis of the total palatal surface area. Therefore, each patient's set of records ideally consisted of four models. The study models were photographed with the technique used for the age 8 models (See Appendix C).

Cephalometric tracing paper was laid over each photo, and a line connecting the postgingival points was drawn along the vestibules (Figures 4-7). The lines were then traced and recorded (SigmaScan version 3.90, Jandel Scientific, Corte Madera, CA). Each photo was digitized twice. If a discrepancy was found to exist between the two readings, the two were averaged to minimize the tracing error. For each study model two surface area measurements were recorded. The values were averaged and categorized according to age and cleft type (Table VIII). The palatal surface area data were then plotted onto graphs. Since most patients dental records did not include study models during ages 2 through 7, data for this period was obtained from a study by Berkowitz at the University of Miami.[60] In addition to unilateral and bilateral cleft values, the Miami data contains normal palatal surface area values for non-clefted patients. The Riley data were therefore analyzed according to cleft type and in comparison to the growth trends of a non-cleft and non-grafted cleft group from Miami. Due to the low number of patients and lack of specific numerical data from Miami, visual comparison by graphed trends were made (Figures 8 and 9).

RESULTS

PART I, CEPHALOMETRIC ANALYSIS

Statistical comparison between the Riley cleft lip and palate patients and the University of Michigan standards[58] indicated that of the five angular measurements, Ar-Go-Me and Ba-S-N were significantly different (Table V).

Ar-Go-Me evaluated the angle of the mandible--the gonial angle. The mean for Ar-Go-Me for the Riley group was 135.47 degrees, compared to 129.05 degrees for the University of Michigan standards. The Riley group was significantly larger (t=5.89, p=0.0001).

The mean for Ba-S-N for the Riley sample was 132.99 degrees, compared to 129.50 degrees for the University of Michigan standards. Ba-S-N describes the cranial base angle. The Riley sample was significantly larger (t=2.08, p=0.05).

There were no significant differences between the two groups in the other angular measurements.

Statistical comparisons of the linear measurements demonstrated significant differences between the Riley group and University of Michigan standards. Eight of the 11 variables were found to be significantly different (Table VI).

N-Me is a measurement of anterior facial height. The mean for N-Me for the Riley sample was 108.15 mm, compared to 111.55 mm from the University of Michigan study. The Riley group was statistically smaller (t=-3.38, p<0.004).

Upper facial height was evaluated by the measurement N-ANS. The mean for the Riley group was 45.63 mm, compared to 49.05 mm for the

University of Michigan standards. Again, the Riley group was significantly smaller (t=-3.28, p<0.005).

Cranial base depth was examined by the measurement Ba-N. The mean for the Riley population was 102.01 mm, compared to 105.70 mm for the University of Michigan study. The Riley group was statistically smaller (t=-4.64, p=0.003).

S-N evaluated the anteroposterior length of the anterior cranial base. The mean for the Riley group was 71.38 mm, compared to 73.75 mm for the University of Michigan study. The Riley group was statistically smaller (t=-3.88, p=0.001).

S-Ba measured the length of the posterior cranial base. The mean for the Riley group was 39.32 mm, compared to 42.25 mm for the University of Michigan standards. Once again, the Riley sample was significantly smaller (t=-2.73, p=0.01).

Ar-Pg is a measurement of effective mandibular length. The mean for the Riley population was 95.10 mm, compared to 100.90 mm for the University of Michigan standards. The Riley group was statistically smaller (t=-4.84, p=0.0002).

Go-Me evaluates the mandibular body length (inferior-most). The mean for the Riley group was 61.95 mm, compared to 65.55 mm for the University of Michigan standards. The Riley population was statistically smaller (t=-2.99, p<0.009).

The anterior-most aspect of mandibular body length was evaluated by the measuremnt Go-Pg. The mean for the Riley group was 64.87 mm, compared to 70.80 mm for the University of Michigan standards. The Riley group was significantly smaller (t=-5.01, p=0.0001).

There were no significant differences between the two groups in the other linear measurements. No significant differences were demonstrated in the ratio of linear measurements.

During the data collection appointment, the Tell-Show-Do technique was used to reduce anxiety levels. However, due to the lack of patient compliance, a lateral cephlaometric film of diagnostic quality was unobtainable for one subject.

PART II, ARCH SYMMETRY ANALYSIS

The age 8 years maxillary study models were analyzed using the Relationship Measurement Method[59] to determine the amount of arch symmetry or collapse present. Thirteen unilateral cleft models and five bilateral cleft models were studied. Due to the limited number of patients in the sample population, the data were considered as one group (Tables VII and VIII).

The amount of lateral posterior crossbite was assessed by the Lx/Lx' ratio. In ideal arch symmetry the Lx/Lx' ratio should equal 1.00, demonstrating that each posterior segment is equidistant from the midline. The average ratio for the 23 unilateral cleft sides was 0.85, indicating a 15 percent arch collapse ($t=-5.66$, $p=0.0001$).

The degree of sagittal crossbite was determined by the Ly/Lx' ratio. Theoretically, the ratio should be 1.00. The Ly/Lx' ratio for the 23 cleft sides was found to be 0.75, revealing a 25 percent collapse from ideal symmetry in the anterior region ($t=-6.35$, $p=0.0001$).

In the canine region the arch segment/45 degrees measurement (H/H') demonstrated the amount of arch collapse when relating the greater to the lesser segment. An ideal ratio of 1.00 would indicate no arch collapse of the lesser segment. The average ratio for the 23 cleft sides was 0.76, revealing a 24 percent collapse of the lesser segment in the canine region ($t=-6.17$, $p=0.0001$).

PART III, PALATAL SURFACE AREA

Using maxillary study models, palatal surface area measurements were determined for the sample population at ages 3 months, 9 months, 18 months and 8 years. Average values were found at each age for both the unilateral and bilateral groups (Table IX). These values were plotted onto graphs for comparison with the non-grafted cleft and non-clefted data from the University of Miami study[60] (Figures 8 and 9).

At 3 months of age, a mean of 1092.35 mm^2 was found for the unilateral cleft group. The palatal surface area at 9 months and 18 months was 1110.60 mm^2 and 1226.00 mm^2, respectively. The mean for age 8 years was 1592.09 mm^2. A similar trend toward increasing values was seen for the bilateral cleft group. The palatal surface area at 3 months was 1137.21 mm^2, and at 9 months was 1227.52 mm^2. At 18 months of age, a mean of 1320.98 mm^2 was found and a mean of 1571.98 mm^2 was determined for the age 8 years.

FIGURES AND TABLES

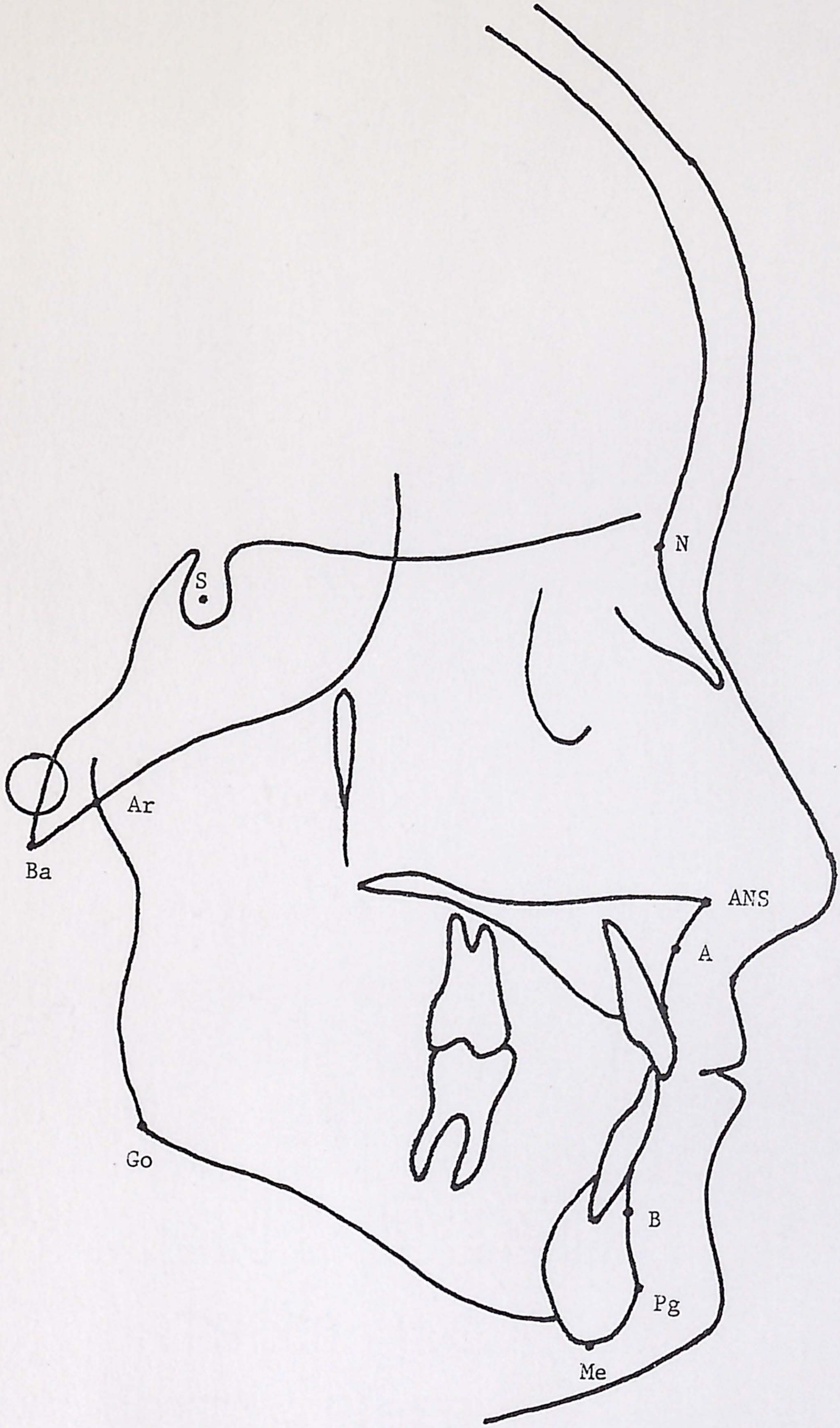

FIGURE 1. Sample cephalometric tracing showing landmarks used for evaluation of primary alveolar bone graft patients.

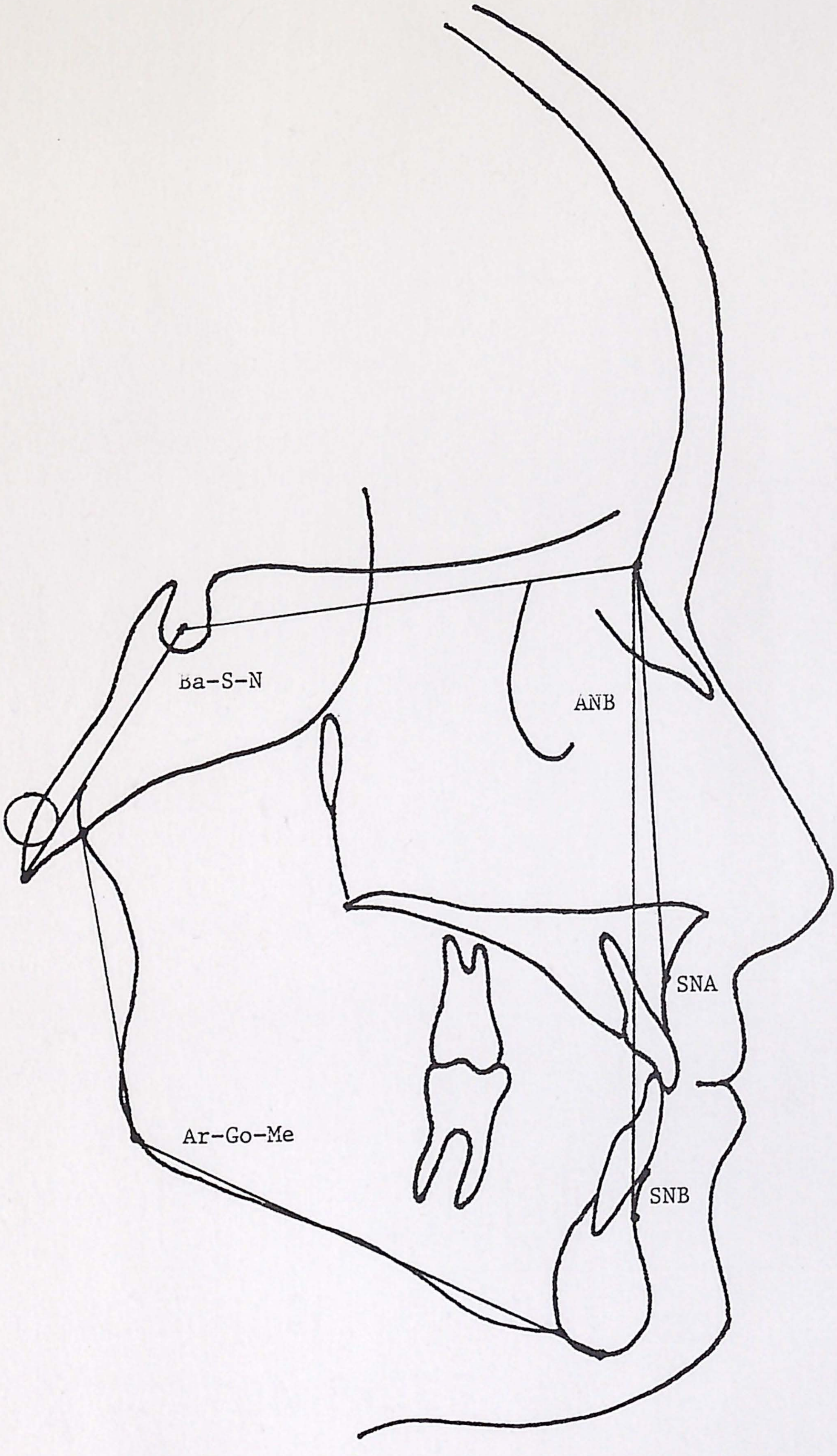

FIGURE 2. Sample cephalometric tracing showing angular measurements used for evaluation of primary alveolar bone graft patients.

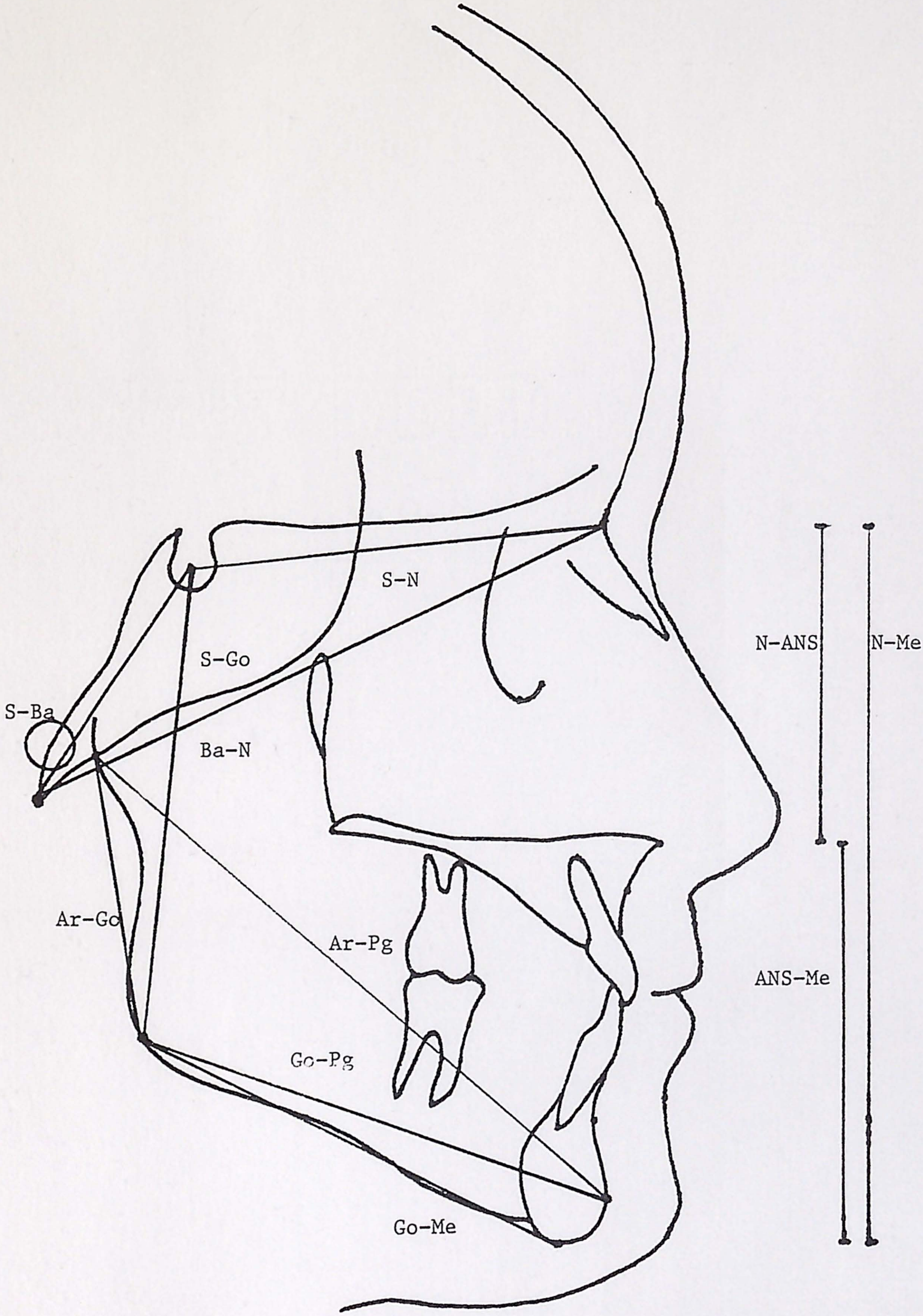

FIGURE 3. Sample cephalometric tracing showing linear measurements used for evaluation of primary alveolar bone graft patients.

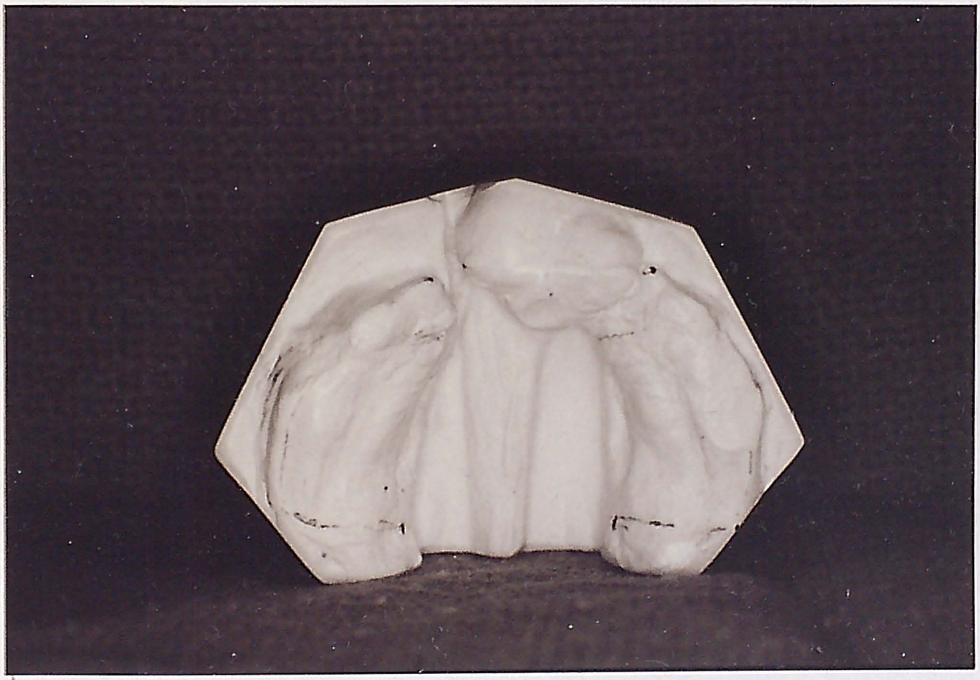

FIGURE 4. Typical maxillary model used for evaluation of palatal surface area at 3 months of age.

FIGURE 5. Typical maxillary model used for evaluation of palatal surface area at 9 months of age.

FIGURE 6. Typical maxillary model used for evaluation of palatal surface area at 18 months of age.

FIGURE 7. Typical maxillary model used for evaluation of palatal surface area and arch symmetry at 8 years of age.

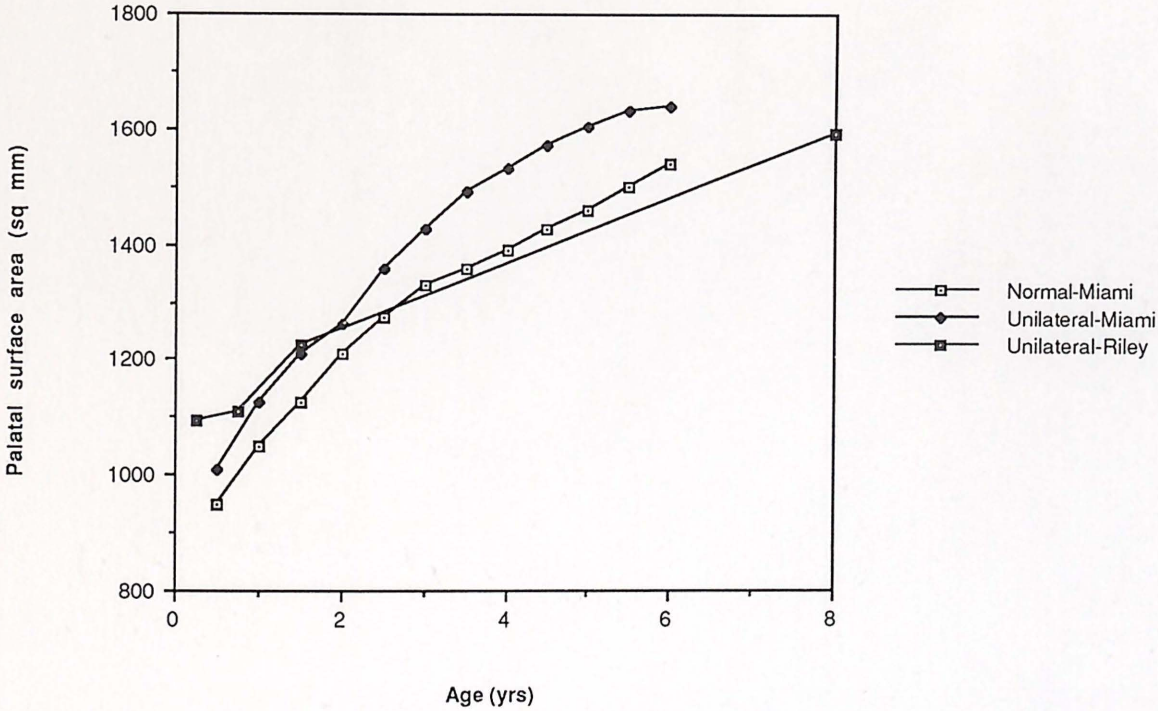

FIGURE 8. Time sequence analysis of palatal growth in normal and complete unilateral cleft lip and palate patients.

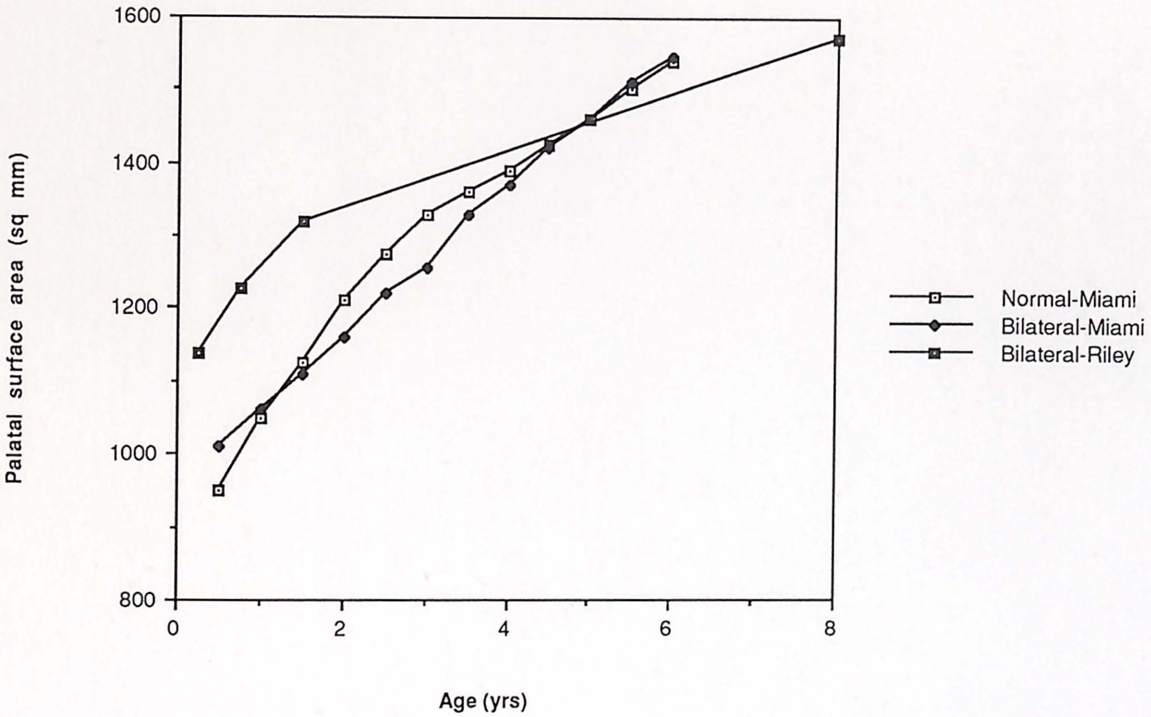

FIGURE 9. Time sequence analysis of palatal growth in normal and complete bilateral cleft lip and palate patients.

TABLE I

Control standards from the University of Michigan Growth Study for children age 8 years

	$\bar{X}$	S.D.
Angular Measurements (degrees)		
SNA	81.10	3.2
SNB	76.50	3.0
ANB	4.35	2.3
Ar-Go-Me	129.05	4.6
Ba-S-N	129.50	4.8
Linear Measurements (millimeters)		
ANS-Me	65.05	4.3
Ar-Go	41.10	3.3
Ar-Pg	100.90	4.4
Ba-N	105.70	4.6
Go-Me	65.55	3.7
Go-Pg	70.80	3.6
N-ANS	49.05	2.9
N-Me	111.55	5.5
S-Ba	42.25	3.0
S-Go	68.20	4.2
S-N	73.75	3.0
N-ANS/ANS-Me	75.00	

TABLE II

Descriptive statistics of angular measurements for Riley primary alveolar bone graft patients

Variable	$\bar{X}$	S.D.	S.E.M.
SNA	79.72	5.86	1.42
SNB	75.06	4.55	1.10
ANB	4.66	3.11	0.75
Ar-Go-Me	135.47	4.25	1.03
Ba-S-N	132.99	7.60	1.84

TABLE III

Descriptive statistics of linear measurements and ratio of linear measurements for Riley primary alveolar bone graft patients

Variable	$\bar{X}$	S.D.	S.E.M.
ANS-Me	64.60	4.58	1.11
Ar-Go	40.04	5.09	1.23
Ar-Pg	95.10	5.66	1.37
Ba-N	102.01	4.37	1.06
Go-Me	61.95	5.12	1.24
Go-Pg	64.87	5.14	1.25
N-ANS	45.63	4.81	1.17
N-Me	108.15	6.69	1.62
S-Ba	39.32	5.08	1.23
S-Go	66.68	5.75	1.39
S-N	71.38	3.86	0.94
N-ANS/ANS-Me	71.00	8.92	2.16

TABLE IV

Composite means of cephalometric measurements for patients studied

	University of Michigan Study	Riley Patients
Angular Measurements (degrees)		
SNA	81.10	79.72
SNB	76.50	75.06
ANB	4.35	4.66
Ar-Go-Me	129.05	135.47
Ba-S-N	129.50	132.99
Linear Measurements (millimeters)		
ANS-Me	65.05	64.60
Ar-Go	41.10	40.04
Ar-Pg	100.90	95.10
Ba-N	105.70	102.01
Go-Me	65.55	61.95
Go-Pg	70.80	64.87
N-ANS	49.05	45.63
N-Me	111.55	108.15
S-Ba	42.25	39.32
S-Go	68.20	66.68
S-N	73.75	71.38
N-ANS/ANS-Me	75.00	71.00

TABLE V

Statistical comparison of angular measurements between Riley primary alveolar bone graft patients to University of Michigan growth study

Variable	t-Test of Means	P-Level
SNA	-0.93	<0.37
SNB	-1.20	<0.25
ANB	-0.14	<0.89
Ar-Go-Me	5.89	0.0001
Ba-S-N	2.08	0.05

TABLE VI

Statistical comparison of linear measurements between Riley primary alveolar bone graft patients to University of Michigan growth study

Variable	t-test of Means	P-Level
ANS-Me	-1.43	<0.18
Ar-Go	-1.39	0.18
Ar-Pg	-4.84	0.0002
Ba-N	-4.64	0.0003
Go-Me	-2.99	<0.009
Go-Pg	-5.01	0.0001
N-ANS	-3.28	<0.005
N-Me	-3.38	<0.004
S-Ba	-2.73	0.01
S-Go	-1.90	<0.08
S-N	-3.88	0.001
N-ANS/ANS-Me	-1.59	0.13

TABLE VII

Descriptive statistics of arch symmetry for
Riley primary alveolar bone graft patients

Variable	$\bar{X}$	S.D.	S.E.M.
Lx	30.14	4.50	0.94
Lx'	35.54	1.51	0.31
Ly	26.59	7.02	1.47
H	25.38	5.52	1.15
H'	33.90	4.65	0.97
Lx/Lx'	0.84	0.13	0.03
Ly/Lx'	0.75	0.19	0.04
H/H'	0.76	0.18	0.04

TABLE VIII

Statistical analysis of arch symmetry for primary alveolar bone graft patients

Variable	t-Test of Means	P-Level
Lx/Lx'	-5.66	0.0001
Ly/Lx'	-6.35	0.0001
H/H'	-6.17	0.0001

TABLE IX

Palatal surface area: Mean area for Riley primary alveolar bone graft patients at ages 3 months, 9 months, 18 months and 8 years

Age	Unilateral (mm^2)	Bilateral (mm^2)
3 months	1092.35	1137.21
9 months	1110.60	1227.52
18 months	1226.00	1320.98
8 years	1592.09	1571.98

DISCUSSION

There is a great diversity of opinion regarding the effects of primary alveolar bone grafting on facial growth. Based on the results of varying surgical techniques, opponents claim that early repair of the alveolar cleft limits maxillofacial growth and development. Advocates of the procedure believe, however, that primary alveolar grafts effectively establish maxillary arch continuity, provide resistance to forces that cause the arch to collapse toward the midline, and do not significantly attenuate midfacial growth.

Primary alveolar bone grafts remain controversial, with only a few centers in the United States performing the technique and timing of grafting. It was, therefore, important to assess and report on the effects of primary alveolar bone grafts on maxillofacial growth for the Riley cleft population.

PART I, CEPHALOMETRIC STUDY

Seventeen variables were compared between the Riley cleft lip and palate patients, and age-matched non-cleft patients from the University of Michigan Growth Study by Riolo, Moyers, McNamara and Hunter.[58] These measurements provide relevant skeletal information about jaw sizes and their relationship to each other, as well as to the cranial base.

The cranial base is an area of reference for the comparison of the spatial relationships of the other components of the craniofacial complex. It is, therefore, important to determine the normalcy of the cranial base if it is to be used for such an evaluation. In the present study the length of the anterior cranial base (S-N), the cranial base depth (N-Ba), and posterior cranial base (S-Ba), were found to be statistically smaller than the University of Michigan non-cleft group. These findings are in agreement with Ross,[42] who reported a shorter cranial base and claimed that the cleft defect affects not only the maxillary complex but other cranial structures as well.

In addition, cranial base angle (Ba-S-N) of the Riley sample was found to be significantly larger than the University of Michigan study. This is in agreement with Moss,[61] who reported a flattening of the cranial base angle in his cleft sample. This finding conflicts, however, with that of Ross[42] who reported no significant difference in cranial base angle between cleft and non-cleft patients. Bjork[62] has noted that the cranial base angle is subject to considerable individual variation. As a result of the variation in cranial base length and flexure, growth of this area may lead to increases in either facial depth or facial height, depending on the direction and amount of flexure. The standard deviation value of 7.60 found for the measurement Ba-S-N in the present investigation is similar to Bjork's study.

The anterior cranial base often serves as a reference area in the assessment of the relative spatial postioning of the maxilla and mandible. The cephalometric measurements SNA and SNB represent the relative positon of the maxilla and mandible, respectively. The difference between the two angular measurements (ANB) describes the relationship of the maxilla to the mandible. The present study revealed no significant differences in SNA, SNB and ANB between the Riley bone grafted group and the University of Michigan standards. These findings suggest that primary alveolar bone grafting does not alter the maxillomandibular relationship, implying no adverse effects on maxillary growth. Furthermore, the measurements from the Riley group follow a trend similar to the data of Rosenstein et al.[36] in an evaluation of their primary bone grafted patients at 8 years of age.

Statistically significant differences were found, however, between the mandibular morphology of the Riley sample and the University of Michigan study. The gonial angle (Ar-Go-Me) of the Riley group was significantly larger than the non-cleft standard. This change is created by the downward and backward rotation of the mandible and results in its retropositioning relative to the other structures in the craniofacial complex. The Riley group also manifested significant differences in effective mandibular length (Ar-Pg), and corpus length, Go-Me and Go-Pg. The mandibular ramal height (Ar-Go) was not significantly different between the Riley and University of Michigan groups.

Anterior facial height, N-Me, and anterior upper facial height, N-ANS, were found to be significantly smaller than the control standards. However, anterior lower facial height (ANS-Me) and the linear ratio N-ANS/ANS-Me were not significantly different between the two groups. These findings are similar to those of Rosenstein et al.,[36] and show that although the maxilla appears to contribute as much to anterior facial height as the standard, the percent contribution is less. Rosenstein et al. accounted for this by the fact that the steeper mandibular plane angle in their sample population positions the anterior aspect of the mandible more vertically. Posterior facial height (S-Go) was not statistically different. Since Ar-Go was similar for the Riley and University of Michigan samples, it follows that S-Go was not significantly different.

It has been previously shown that cleft patients have skeletally smaller craniofacial complexes.[42] The Riley group exhibited measurements that were overall statistically and proportionately smaller than the University of Michigan standards. Therefore, these values are due to the smaller skeletal size of the Riley sample. Due to the proportionate relationship between maxilla and mandible, the overall skeletal trend for the Riley patients correlates with known delayed development of the cleft craniofacial skeleton.[42] Furthermore, the differing mandibular measurements may be explained by Krogman,[63] who supports a reciprocal relationship between the components of the craniofacial midline. Mandibular compensations may occur in response to alterations elsewhere in the craniofacial complex. These changes synergistically maintain a normal functional relationship between the maxilla and mandible.

MODEL ANALYSIS

The Relationship Measurement Method[59] was used to evaluate the arch symmetry of maxillary models. The results indicated that at age 8 years there was a 15 percent lateral posterior crossbite, 25 percent anterior crossbite and a 20 percent collapse in the canine region. While these findings are less than ideal, they may be accounted for by existing dental development. Ectopically erupted teeth, as well as congenitally missing teeth, affect alveolar growth and are common to the cleft population. Such asymmetry in tooth number and position would induce alterations in the maxillary skeletal position of the lesser segment that may only reflect innate bone volume differences. Another variable in growth pattern interpretation is that prior to the bone graft procedure, although the greater and lesser segments are in approximation, their alignment may not be in the form of an ideally symmetrical arch. Arch asymmetry may also occur as the result of transverse scarring from the subsequent palatal procedure. Consequently, ratios of 1.0, indicating ideal symmetry, may not be a realistic achievement for the cleft population.

Due to the lack of maxillary models from ages 18 months to 8 years, and unavailability of of specific numerical data from the University of Miami study,[60] only visual comparisons of the Riley palatal surface area measurements could be made. The graphs indicate that the growth patterns of the Riley unilateral and bilateral cleft groups follow trends similar to those of the normal and non-grafted cleft groups in the Miami study.

The age of 8 years was determined to be an important time to monitor the patients' progress because it denotes the beginning of the second stage of the mixed dentition. Although the permanent incisors and first molars are in position, the permanent canines and premolars are unerupted. The age of 8 is also prior to the pubertal growth spurt. Moreover, for the purpose of this study, the age of 8 years effectively identified the earliest group of patients who had received primary alveolar bone grafts at Riley Hospital.

Although 35 patients were originally identified for this study, there were only 18 available participants. A considerably larger sample would have been preferred. Since this was a retrospective study, the sample size was fixed.

One difficulty encountered in attempting long-term follow-up was locating the patients, several of whom had moved and left no forwarding address. Similarly significant is that, for the purpose of patient convenience, efforts were made to coordinate the data collection appointment for this study with the patients' annual evaluation by the craniofacial team at Riley Hospital. Patient compliance with the treatment protocol of annual visits to Riley Hopital varied, however, and this also contributed to the loss of subjects. Longitudinal studies involving larger sample sizes would improve the practical application of the statistical analysis.

Although study models were available for the mean ages of 3 months, 9 months and 18 months, only five patients had study models taken at age 4. Dental records taken at this age on a consistent basis would be useful for future analyses since it is a time during which the deciduous dentition should be fully erupted. Comprehensive time sequence analyses of arch symmetry and palatal surface area could then be constructed for the Riley patients.

In addition to crossbite tendencies, it is important to determine whether there is a significant decrease in orthodontic treatment time for patients who receive primary alveolar bone grafts. Studies examining the incidence of those requiring secondary grafts and/or orthognathic surgery would be useful as well.

Assessments of alveolar bone height and quality, similar to that by Helms et al.,[57] are also needed. Using periapical radiographs, success of the primary alveolar graft procedure could be examined in terms of the area's ability to support the erupting and existing dentition.

It is also desirable to have future evaluations of growth and development based on the patient's biological age rather than chronological age. Skeletal wrist films could be used to determine the patient's skeletal age, and thus, variability resulting from differing levels of maturation could be more closely controlled.

Finally, an evaluation of the Riley primary alveolar bone grafted sample following the completion of their adolescent growth spurt is needed. A post-pubertal analysis would provide a more thorough assessment of the long-term effects of the primary alveolar bone graft procedure.

SUMMARY AND CONCLUSIONS

Bone grafting of the alveolar cleft has long been considered to be an important part of the surgical regimen for the cleft lip and palate patient. Considerable controversy exists, however, over the optimal timing of the procedure and its effect on maxillofacial growth. The present study evaluated the effects of primary alveolar grafting on maxillary and midfacial growth by considering three parameters: lateral cephalometric data, arch symmetry and palatal surface area.

The sample population consisted of 18 of the earliest cleft lip and palate patients who received primary alveolar bone grafts at Riley Hospital. The average age of the children was 8 years, and all were a minimum of five years post-grafting.

The lateral cephalometric radiographs were traced and five angular, 11 linear, and 1 ratio of linear measurements were then determined. The data were statistically compared to age-matched non-cleft children from the University of Michigan Growth Study.[58] The maxillary study models and a variation of the Relationship Measurement Method originally described by Butow[59] were used to objectively evaluate the arch symmetry of the sample population at 8 years of age. Palatal surface area measurements were calculated from study models made at the ages of 3 months, 9 months, 18 months and 8 years. Due to the low number of patients and lack of specific numerical data for statistical comparison, the surface area data for the Riley group were assessed by graphs only.

There appear to be significant differences in maxillofacial growth and development between the Riley sample population and the non-cleft lip and palate patients in the University of Michigan Growth Study. The cephalometric analysis indicated that the Riley group was smaller than the control population in craniofacial size but exhibited proportionate maxillomandibular relationships. These findings indicate the similarity between the Riley sample and other cleft patients who are known to have smaller skeletal development. The arch symmetry data demonstrated that at 8 years of age there was a 15 percent lateral posterior crossbite, 25 percent anterior crossbite and 24 percent collapse in the canine region. These findings were significantly different from ideal or perfect symmetry. However, missing teeth, poor initial arch alignment, or transverse palatal contraction due to scarring may all account for this observation.

The palatal surface area measurements of the Riley population were visually analyzed through graphs. The growth patterns of the Riley unilateral and bilateral cleft groups are similar to those of the normal and non-grafted cleft groups in a study by Berkowitz at the University of Miami.[60]

These findings strongly suggest that the effects of primary bone grafting on early dentofacial development, using the techniques described by Rosenstein et al.,[24,34-36] does not induce growth attenuation. Further studies are indicated to determine whether these trends will continue during and after the postpubertal growth phase. It is hoped that this study will offer insight into determining the success of the surgical regimen for cleft lip and palate children at Riley Hospital.

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APPENDIXES

APPENDIX A

Dear______________________,

Children born with clefts of the lip and palate have certain functional and esthetic needs which require a special surgical regiment. Clinical management of the cleft patient at Riley Childrens Hospital may begin within two weeks of birth and by two years of age, the four steps of palatal obturator fabrication, cheiloplasty, alveolar grafting and palatoplasty are completed. It is believed that the sequencing and timing of these procedures have an important effect on long-term facial development.

The Craniofacial Anomalies Team of Indiana University has established an age-based protocol for the collection of dental records. Your child's facial growth will be periodically monitored through the use of radiographs and dental study models. Both procedures will be completed at the dental clinic at Riley Hospital.

As a graduate student with a special interest in cleft lip and palate children, I will be conducting a portion of this study in partial fulfillment of the criteria for a master's degree. Please call the Riley Dental Clinic at (317) 274-3865 to schedule an appointment. The duration of the appointment will be approximately 20 minutes.

Thank you for your cooperation. I look forward to meeting you and your child.

Sincerely,

Leslie K. Tanimura, D.D.S.

Graduate student in
Pediatric Dentistry

APPENDIX B

CONSENT FOR TREATMENT FOR RESEARCH PURPOSES

I, ______________________________do hereby authorize Leslie K. Tanimura, D.D.S., and /or her designated assistants to perform procedures, ask questions and make evaluations concerning___________________________. I understand that the purpose of these procedures will be to assist Dr. Tanimura in a research study on the effects of primary alveolar bone grafting in cleft lip and palate patients. I agree that the data shall be used, and that I will not receive any benefit, financial or otherwise, from her research. Dr. Tanimura agrees that in exchange for my cooperation, the procedures will be done at no cost to me.

Specifically, Dr. Tanimura will be performing the following dental procedures: maxillary and mandibular impressions for study models, wax bite registration and a lateral cephalometric radiograph.

Dr. Tanimura agrees that my name and/or other identifying information will not be used in any public form. I understand that I may withdraw my child at any time and for any reason from Dr. Tanimura's study. If I request the results of Dr. Tanimura's research, she agrees to provide them to me at no cost.

____________________________ ____________________________
Patient's Guardian Leslie K. Tanimura, D.D.S.

___________ ___________ ____________________________
Date Time Witness

APPENDIX C

RELATIONSHIP MEASUREMENT METHOD OF ARCH ANALYSIS

Each maxillary model was positioned and photographed so that the occlusal plane was parallel to the film. Drawings were made by placing cephalometric tracing paper over the photographs.

A line known as the alveolar arch is drawn along the center of the alveolar ridge from one postgingival point to the other. The postgingival points (P and P') are the drop-off points of the left and right posterior tuberosities. The x-axis is the line that unites points P and P'. At point P, the x and y axis' perpendicularly intersect. Point x/2 is located halfway between the postgingival points. A line parallel to the y-axis is then drawn through y/2. Y/2 is the next created point. It is the same distance on the y-axis from point P as x/2 is from point P along the x-axis. A horizonatal line parallel to the x-axis, which passes through y/2, is drawn. A 45 degree line crossintersects with the horizontal y/2 line and the perpendicular x/2 to create pont K; K= (x/2)/(y/2). It is a constant point.

The distance on the x/2 line between the arch and point K defined the segment Ly. The distance from the normal or noncleft side of the arch to point K, along the horizontal Y/2, is defined as Lx'. The distance from the cleft sided arch to point K on the same y/2 line is defined as Lx. The distance along the 45 degree line from the cleft sided arch to point K is the distance H. It is named the arch segment-45 degrees. Note that the intersection of the alveolar line does not indicate a specific tooth allocation. This type of graph may be laid out mathematically:

LATERAL CROSSBITE

The distance Lx is equal to the distance Lx' in an ideal parabola (Lx=Lx'), indicating arch width symmetry. A lateral posterior crossbite occurs when the relationship between Lx/Lx' decreases. Consequently, palatal rotation of the lesser segment results. If Lx/Lx' is greater than one, then a buccal lateral posterior crossbite is found.

SAGITTAL CROSSBITE

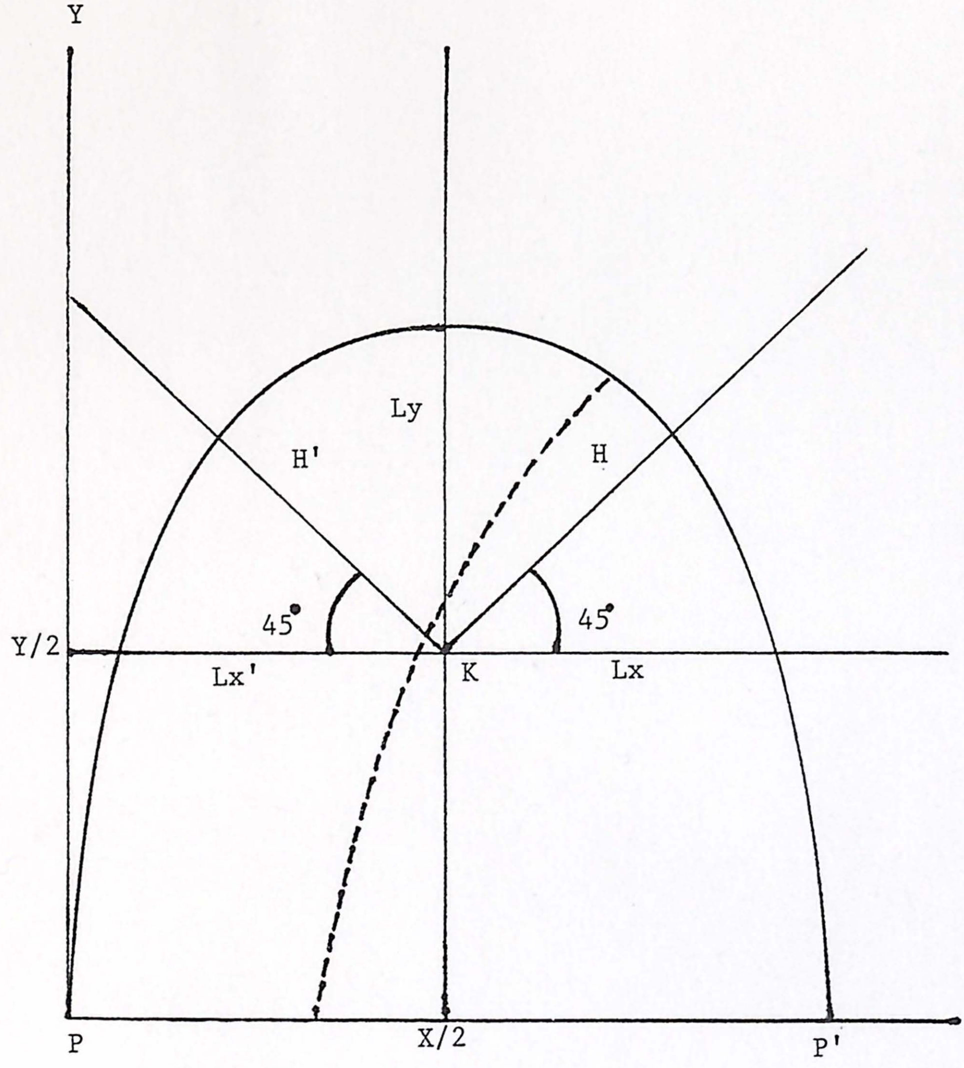
In an ideal parabola, the distance Lx plus Lx' adds up to 2Lx' (Lx + Lx' = 2Lx'), again, indicating arch width symmetry. A decrease in the relationship Ly/Lx' indicates an anterior crossbite.

ARCH SEGMENT-45 DEGREES

The distances H and H' should ideally be equal, indicating arch symmetry in the canine region. If H is less than H', then the canine region on the lesser segment is in crossbite. The distance H is also an indication of the position of the lesser segment.

BILATERAL CLEFT LIP AND PALATE MODELS

Measurements from the normal or non-cleft side of the unilateral cases were averaged and used to generate a set of values to which the bilateral cases may be compared. Mean values were found for both males and females. The measurements of the non-cleft side of the unilateral cases are, therefore, used with the unilateral cases as an intrapatient comparison, as well as for an interpatient analysis with the bilateral cases. Both right and left cases will be separately analyzed to allow for any asymmetry of the premaxilla.



Arch Symmetry Analysis

ABSTRACT

THE EFFECTS OF PRIMARY ALVEOLAR BONE GRAFTING ON MAXILLARY GROWTH AND DEVELOPMENT

by

Leslie K. Tanimura

Indiana University School of Dentistry,
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This investigation served as a follow-up of the unilateral and bilateral cleft lip and palate patients who underwent primary alveolar bone grafting at James Whitcomb Riley Hospital of the Indiana University Medical Center. The sample consisted of 18 patients, 15 males and three females, who received primary alveolar grafts between September 7, 1983 and March 5, 1985. Thirteen had complete unilateral clefts, and five had complete bilateral clefts of the lip and palate. The mean age of the group was 8 years, and none had received orthodontic treatment.

The statistical analysis of the lateral cephalometric radiographs revealed significant differences in maxillofacial growth between the Riley sample population and the non-cleft, age-matched patients in the University of Michigan Growth Study.[58] The Riley data were, overall, statistically and proportionately smaller than the normal population. These findings are due to the smaller skeletal size of the Riley group.

Arch symmetry measurements indicated that at 8 years of age there were significant differences from ideal or perfect symmetry. Due to existent dental development and scarring from the palatal procedure, these findings were expected. Ideal symmetry may not be a realistic achievement for the cleft patients.

Palatal surface area values were visually analyzed through graphs. The growth patterns of the Riley population were similar to those of the normal and non-grafted cleft groups in a study from the University of Miami.[60] The data supports the theory that primary alveolar bone grafting, as performed at James Whitcomb Riley Hospital, does not result in growth attenuation.

CURRICULUM VITAE

Leslie Kyoko Tanimura

June 20, 1964	Born in Los Angeles, California
May 1985	BS, University of Southern California, Los Angeles, California
May 1989	DDS, University of Southern California, Los Angeles, California
July 1989-June 1991	Residency, Pediatric Dentistry, Indiana University, Indianapolis, Indiana
July 1991-June 1992	Fellow, United Cerebral Palsy Research and Education Fellowship, Indiana University, Indianapolis, Indiana
	Assistant Professor, Pediatric Dentistry, Indiana University, Indianapolis, Indiana

Professional Organizations

American Academy of Pediatric Dentistry
American Dental Association
California Dental Association