Stereophotogrammetry of Serial Casts of Cleft Palate

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If a full conceptualization of the changing form and dimensions of the palatal vault of children with clefts is to be obtained, then an accurate method of three-dimensional measurement must be developed and applied. Previous studies on casts of the palate dealt mainly with height, depth, length, and changes in two-dimensional form, but not with changes in three dimensions.[1-6]

Since the contour of the earth's surface is being measured with exceptional accuracy by means of stereophotogrammetry, it was felt that similar techniques could be devised for the analysis of the cleft palate from plaster casts. To do so posed new and special problems. Although nontopographic photogrammetry had been developed for the study of small objects, new procedures had to be devised to conform to the small object where change in three-dimensional form was the major concern. Following these demands, a valid technique for taking close order stereoscopic pictures of palatal casts for photogrammetric analysis was devised together with a method for spatial orientation of the serial casts.

The methodology described herein offers a quantitative description of the three-dimensional surface of the palatal vault. In cleft palate it permits analysis of the changes in configuration of the palatal shelves resulting from developmental processes and as a consequence of surgery.

REVIEW OF THE LITERATURE

The essentials of stereophotogrammetry have been concisely described by Hertzberg, Dupertuis and Emanuel:[7]

> The basic principle of stereophotogrammetry is exactly that of binocular vision. The two eyes send slightly different images of an object to the brain, where they are interpreted in terms of depth as well as length and breadth. Similarly, if two binocular or stereophotographs of an object are juxtaposed so that the left eye sees the left photograph and the right eye sees the right photograph in proper relation, the perception of depth can be as clear as if the object were seen directly. By suitable optical devices, stereophotographs of nearly any size can be made to give the effect of relief.

Savara[8] and others[7,9] have reviewed the general principles of photogrammetry and their application to biological problems. As early as 1922, Mannsbach[10] demonstrated the usefulness of stereophotogrammetry in the study of orthodontic casts. Zeller[11,12] utilized the method to study the contours of the face and later the surface of tooth fillings.[13]

Three-dimensional analysis of tooth surface was described by Tham.[14] Thalmann-Degen[15] in 1944, and Bjorn, Lundquist and Hjelmstrom[16] in 1954 used contours to measure facial swellings. The advantage of measuring edema in this fashion is that no measuring apparatus need be applied against the body surface which might affect contour or hinder circulation.

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Lacmann,[17] possessed by a sense of humor, demonstrated the universal utility of stereophotogrammetry by studying not only a man's face but also the derrière of a cow. The application to animal husbandry was discussed by Leydolph[18] who published contours of cows and sheep.

In 1954 Berner[19] calculated the surface area of a human body by stereophotogrammetry. Similarly, Miskin[20] made use of the technique in determining body volumes and surface areas, as well as the assessment of body builds and local deformations, such as eye tumors in newborns.

Dupertuis *et al*[7] utilized stereophotogrammetry as an anthropometric tool to draw human body contours at one-half inch intervals and to determine body volumes. Their investigation was motivated to provide the Air Force with data to design form-fitting, protective garments for high altitude flight.

Artists made use of stereophotogrammetry in painting and sculpture.[21,22]

Photogrammetric principles were applied to intraoral radiodontia by Berghagen[23] in 1951; more recently McNeil has written on x-ray stereophotogrammetry.[24]

Method

The problem of studying changing small three-dimensional objects, as in serial plaster casts of a cleft palate, had not been attempted. The solution of this problem required a means for spatially orientating the casts so that stereophotogrammetric projections could be standardized and reproduced for consecutive serial casts.

The Photographic Technique

A. *Optics:* A Galileo-Santoni stereoplotter for contour mapping was employed. A speed graphic camera and a Schneider-super angulon lens with an equivalent focal length of 65 mm and a

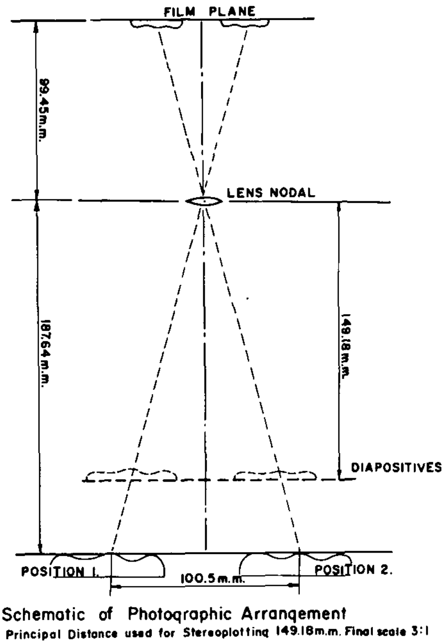


Fig. 1 Schematic outline of optical system in stereophotogrammetry.

principal distance of approximately 150 mm with an angular field of view of 100 degrees was chosen. The principal distance of the lens was selected to insure true geometry in the stereoplotting instrument. Figure 1 illustrates the optics involved in the stereophotography.

Since optical calibration equipment was not available, the combined major and minor conjugates had to be computed to obtain a film image one half the size of the original model. A grid was placed in the stage plane area to permit computation of the exact scale and the final principal distances of the camera. The grid also served to check the accuracy of the horizontal plot. The principal distance was computed at 99.45 mm.

Projecting one and one-half times gave a final principal distance of 149.2 mm. This was later confirmed in the stereo-plotting instrument. The original negatives were projected at an exact ratio of 1:1.5 on to glass diapositives.

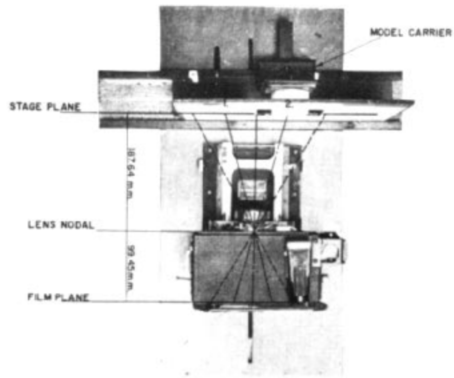


Fig. 2 Placement of casts for stereophotography.

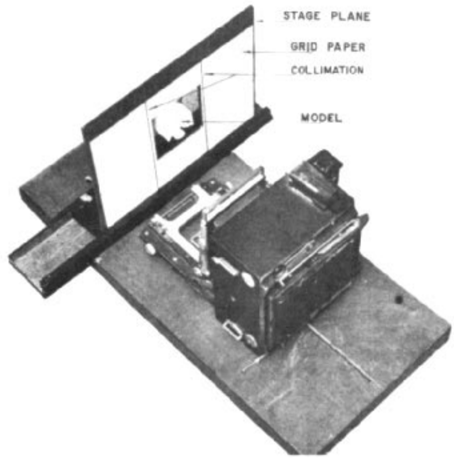


Fig. 3 Arrangement for stereophotographs.

The final plotting and drafting were at three times the original scale.

The following checks were made to determine the reliability of the 0.3 mm accuracy in both the vertical and horizontal dimension.

1. To check the horizontal accuracy a plot was made of the grid superimposed at the staging plane area. Linear accuracy was greater than .01 inch at three times the scale of the original. The plane surface of the grid plotted within .03 mm. of being flat.

2. Vertical accuracy was checked against the known thickness of coins, established with a micrometer, and placed in a vertical line at half-inch intervals. The degree of accuracy in either direction was directly related to the degree of stereoscopism. It was recognized that the system could be improved greatly by the construction of a camera and lens specifically designed for small objects by metrical photography. This is now being done and the results will be reported at a later date.

B. *Placement of the Casts for Stereoscopic Photography:* Figure 2 demonstrates a specially designed platform constructed to properly relate the camera to the palatal casts. The camera was fixed on a base at a known distance from a vertical extension called the *stage plane*. The establishment of this distance has been discussed above.

1. *The stage planes:* The vertical extension was made to move laterally a given distance (Fig. 3). A precision grid of one-tenth intervals was placed on the surface facing the camera. A three inch square window was cut in the stage plane in order to expose the cast model when attached to the model carrier. Collimation marks four inches apart were indicated on either end of the cut. The optical center of the lens could be aligned with either the right or left collimation marks according to the position of the stage plane. The position of the hole was purposely placed off center to the optical center of the lens in order to obtain maximum stereoscopic effect. A four inch separation between stereophotographs enabled maximum separation of the images on a 4 x 5 film surface.

2. *The model carrier:* This was made to slide forward and backward to the stage plane in order to properly align the face of the cast with the stage plane (Figs. 2 and 3). In this way the distance between the surface of the model and the lens was kept constant. The main purpose of the model carrier

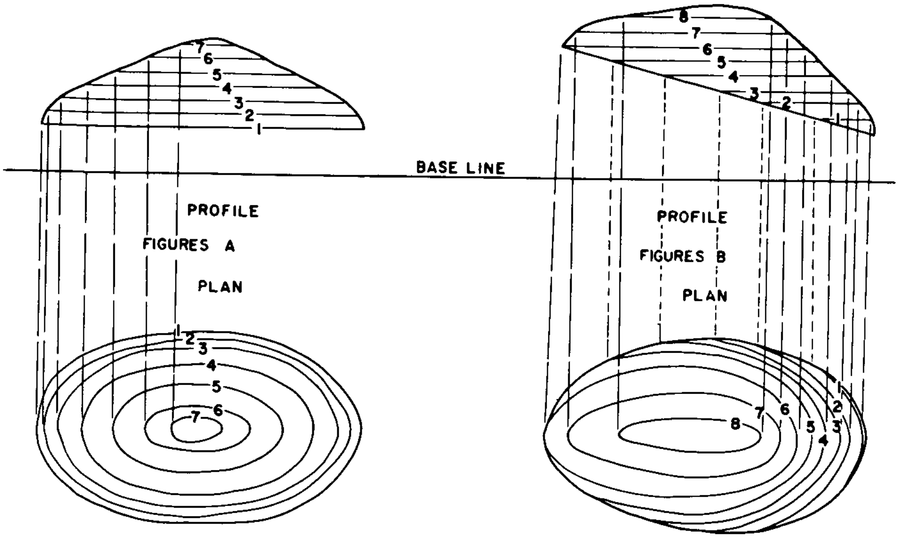


Fig. 4 Nature of plotting errors in failure to orientate casts.

was to keep the major conjugate constant at all times.

The second objective was to devise a method to obtain proper and constant spatial orientation of the palatal casts.

Figure 4 demonstrates the plotting errors that can be created by not constantly orientating the casts to the same reference line. The orthographic projection of the contours of the same objects A and B, where one object is tilted relative to the other, demonstrated the photogrammetric errors that will be created not only in the actual total length of the object B, but also between points on the surface of that object when compared with the same points on object A.

The variation in surface contour between objects A and B are relative to the degree of tilt in their bases. Errors in contours create errors in form and no geometrical comparison can therefore be made between these objects.

On the same day that palatal impressions were made of the infants, oriented frontal and lateral cephaloroentgenograms were also taken. It was therefore possible to transpose selected landmarks on the casts to the same landmarks on the lateral headplate. By choosing widely separated landmarks on the cast surface, the hard palate was related to reference lines within the skull. As long as the relationship of those skeletal points used for reference does not change, the spatial relationship of casts from one time period to another remains constant.

The anterior cranial baseline, sella-nasion (S-N), was chosen as the main skeletal reference line because of its relative stability during growth.

A constructed Frankfort Horizontal (FHc) was drawn six degrees from the SN line at S to enable palatal surface points to be projected to a line more parallel to the actual skeletal palate. Easily discernible, widely separated points were used whenever possible. Figure 5 demonstrates the linear projection of surface landmark points to the FHc line. These linear dimensions were recorded in the stereo-plotter.

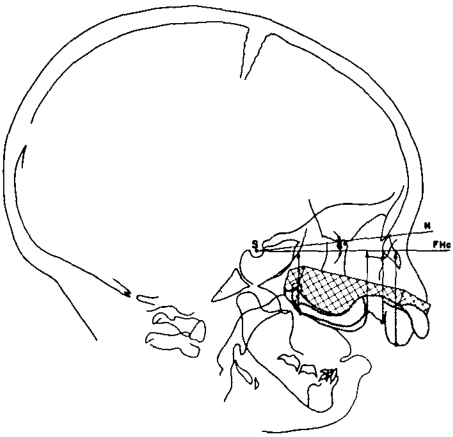


Fig. 5 See text.

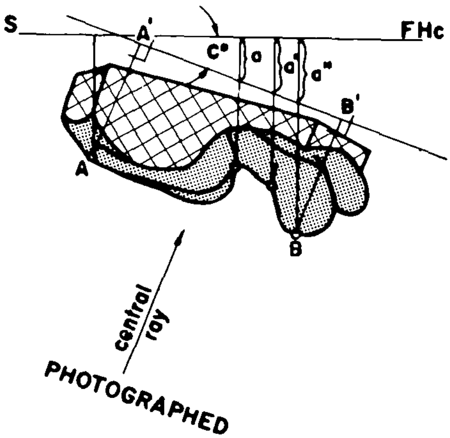


Fig. 6 See text.

In order that all casts be photographed at the proper angle and their palatal surfaces at right angles to the camera's central ray, it was necessary to create a base for the cast similar to the model base line that forms the constant angle C to the FHc line (Figure 6). The most anterior and posterior points on the palate were projected to the FHc line. The lines AA′ and BB′ were made of equal length and when A′ and B′ were connected a base line was formed which was at an angle of C degrees with the FHc line. With the angle C as a constant, each cast was related to the base angle as it related to the skull. Distortion introduced by the improper positioning of casts, as was previously discussed, was thereby eliminated. Lines AA′ and BB′ were made to be equal only in the first instance since they were usually unequal thereafter. All casts were leveled to the horizontal by the use of a carpenter's level. Stereophotographs were taken of all models which had their bases trimmed according to this technique.

After the diapositives were made, the stereoplotter was able to spatially orient the casts to the skull according to the actual linear projection measurements taken from the head plates. In this way the palate casts from every age period were spatially related to each other.

Materials

Series of casts were selected from the longitudinal growth studies at the Cleft Palate Clinic of the University of Illinois to demonstrate the application of the method to a variety of problems. The plaster casts utilized in this study were accurate reproductions[25] of the original casts made of alginate impressions. The following problems were selected for study:

1. A comparison of the palatal casts taken on three month-old unsimilar sex twins. The sister presented a normal palate and the brother an unoperated complete left unilateral cleft lip and palate. The purpose was to compare configuration in arch form between the two children.

2. A series of four casts was selected from the collection of a patient with complete bilateral cleft lip and palate to demonstrate the architectural changes incident to two-stage lip repair and velar reconstruction. The casts ranged in age from twenty-one days to three years, eight months and four days.

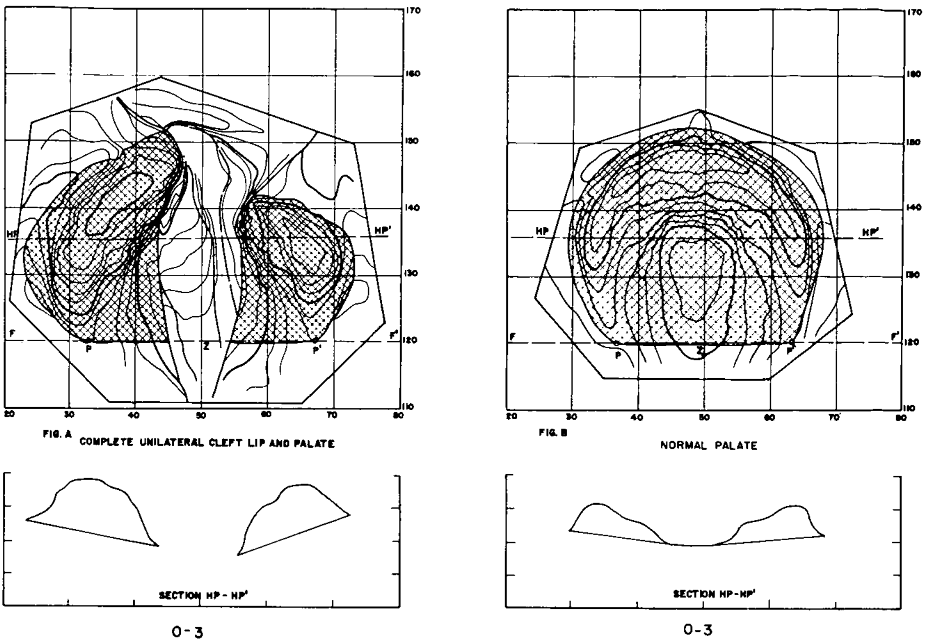


Fig. 7 Stereophotogrammetric tracings of palatal casts of dizygotic twins, age three months. The male twin demonstrates an unoperated complete left unilateral cleft lip and palate. The sister's palate is normal.

3. In the case of a Pierre Robin syndrome, six serial casts were selected to demonstrate spontaneous changes in the dimensions of the cleft coincident with changes in tongue posture. The casts ranged in age from two months and ten days to six years and one month.

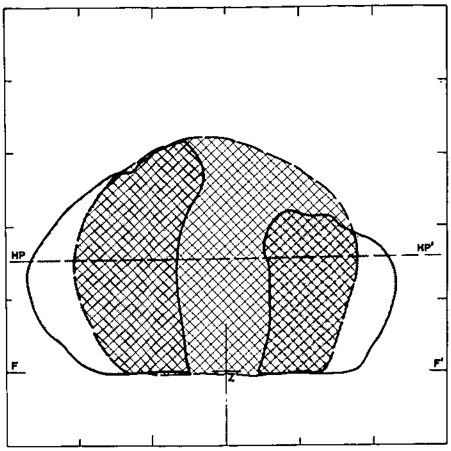
Results

Unsimilar Sex Twins, Normal Palate vs. Unoperated Complete Unilateral Cleft Lip and Palate (Figures 7 and 8): Despite the difference in sex and a possible difference in size, the availability of casts of the palate on an unoperated complete unilateral cleft lip and palate and that of a normal twin provided an opportunity to compare the topography of their palates. When the normal palate was compared to the cleft palate, either by separate measurements or by superimpositioning of their outlines, the following findings emerged:

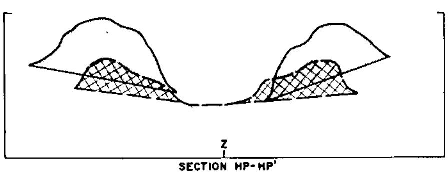
1. The anteroposterior lengths and widths of the palatal processes of both palates were approximately the same. In this instance, at least, the separation of the maxillary process from the vomer had not caused a lack in its growth impetus. The smaller segment was smaller simply because it was the lesser component of the total palate. When this smaller component was added to the larger segment, the sum of the cleft segments approximated that of the normal. No evidence of gross mesodermal deficiency could be found in this case.

2. The greater maxillary width of the cleft palate was related to the cleft space and the lateral displacement of both segments from the midline.

3. Even in the unoperated state, the palatal processes of the cleft palate tilted upward and medially to produce a greater narrowing in the apex of the vault. The angulation between the processes was 65° in the cleft as compared with 120° in the noncleft (Table I).



COMPOSITE OF BOTH MAXILLARY ARCHES SUPERIMPOSED ON F F' AND REGISTERED ON LINE Z



COMPOSITE OF BOTH PROFILES SUPERIMPOSED ON Z LINE AND REGISTERED ON POINT ZERO (THE LOWEST PART OF THE PALATE)

Fig. 8 Superimposed tracings of the casts shown in Fig. 7.

Complete Bilateral Cleft Lip and Palate (Figures 9-13): Each of the separate contour drawings was revealing in the demonstration of the three-dimensional architectural disorientation of the palatal segments. The effect of two-stage lip repair on the position of the premaxilla was further dramatized by the contour drawings. The superimposed tracings demonstrated the minimal amount of arch collapse, the increments of growth, and the change in palatal contour from the grossly abnormal toward an approximation of the normal.

Considering each of the casts separately, transverse section of the unoperated palatal cast revealed that the palatal processes were tilted upward and medially with the ventral surface of the vomer projecting below the medial edge of the palatal segments.

After one and a half years, the height of the vault increased fifty percent, and the distance between the right and left alveolar crests increased (Table II). The anteroposterior length of both palatal processes shows the greatest rate of increase during the first year and a half. The premaxilla, under the re-

TABLE I

DIZYGOTIC TWINS

Type of Palate		Antero-Posterior Length	Greatest Width	Greatest Vault Height	Angle Between Palatal Processes	Palate Width Across Tube-rosities P-P'	Width of Cleft Space on P-P' line	Width of Cleft Space at Greatest Maxillary Width
Normal		32.0	38.3	6.1	120°	26.6	—	—
Complete Unilateral Cleft Lip and Palate	Right Maxillary Process	31.6	20.0	10.0	65°	12.0	9.0	12.6
	Left Maxillary Process	22.0	17.4	10.6		12.6		

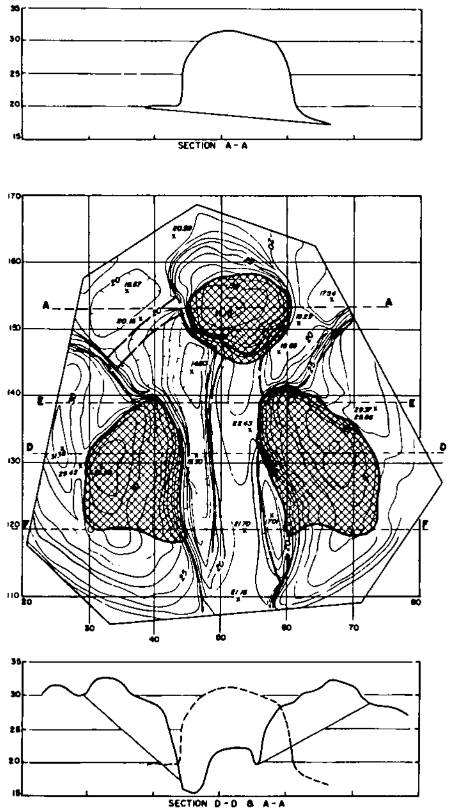


Fig. 9 Palatal cast of unoperated complete bilateral cleft lip and palate, age twenty-one days.

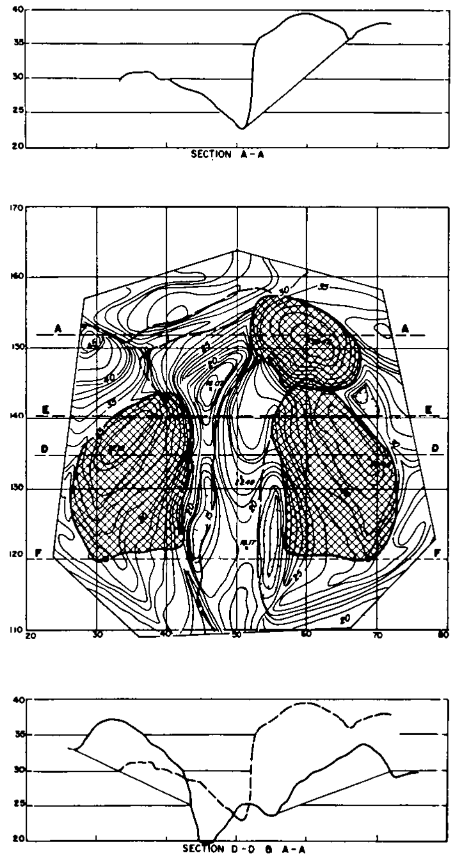


Fig. 10 As in Fig. 9, but following repair of the lip on the left side, age three months, fourteen days.

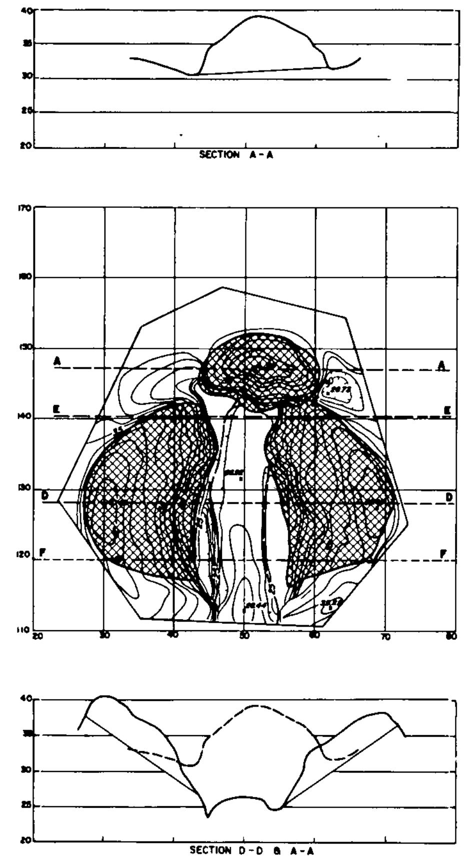


Fig. 11 Continued from Fig. 9: Following repair of the lip on the right side, age eight months, three days.

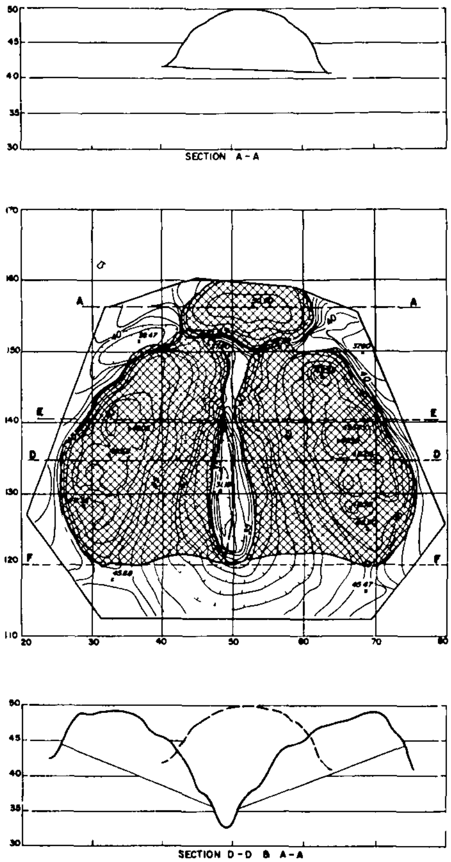


Fig. 12 Continued from Figure 9: The palate following repair of the velum, age three years, eight months and four days.

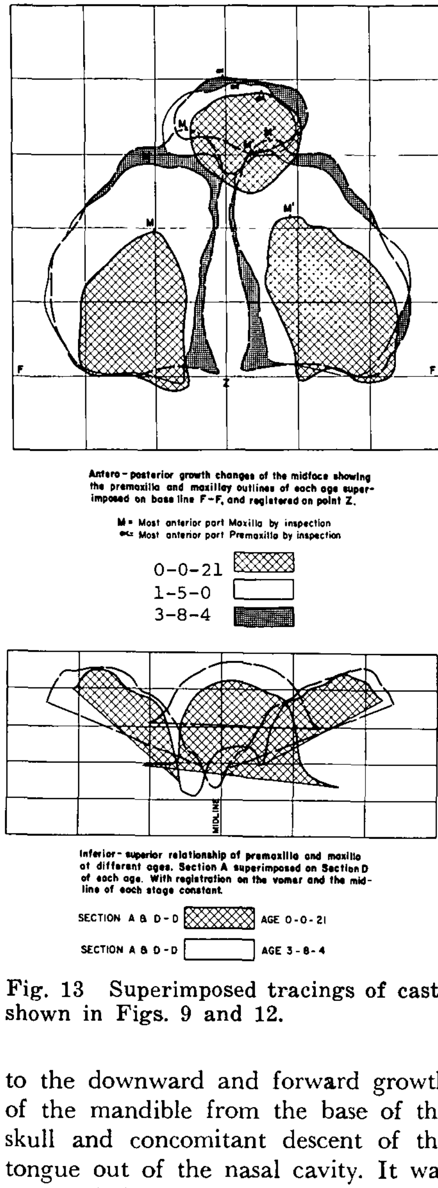


Fig. 13 Superimposed tracings of casts shown in Figs. 9 and 12.

straining influence of the reconstructed lip, exhibited little forward movement. The ventroflexion of the premaxilla on its vomer stalk was evident. The alveolar processes, by their progressive forward growth, approximated the premaxilla and reduced the size of the anterior cleft space.

Pierre Robin Syndrome (Figures 14-17): From an examination of the individual contour tracings it was apparent that a considerable spontaneous change in the configuration of the cleft had occurred. On the basis of the roentgencephalometric studies[26] this spontaneous narrowing of the cleft was related to the downward and forward growth of the mandible from the base of the skull and concomitant descent of the tongue out of the nasal cavity. It was reasoned that, with the removal of the plunging action of the tongue, the molding action of the buccinator—superior constrictor complex became effective in approximating the previously displaced palatal shelves. That this phenomenon, rather than growth at the medial aspect of the palatal shelves, was the dominant factor is suggested by the analysis of the change

TABLE II
COMPLETE BILATERAL CLEFT LIP AND PALATE

Age	Greatest Antero-Posterior Length in mm		Maxillary Width at Levels				Width of Cleft at Levels			Greatest Width of Premaxilla	Greatest Vault Height	Width Across Tube-rosities P-P'	Distance Between Alveolar Crests Across Line D-D'
			D		F		E	D	F				
	Right	Left	R	L	R	L							
0-0-21	19.3	21.3	14.3	17.0	14.3	13.0	14.6	11.6	15.3	15.7	10.0	39.9	34.3
0-3-14	23.7	25.6	16.0	16.3	12.6	12.7	11.6	12.3	14.3	17.6	10.6	35.7	39.0
0-8-3	22.3	23.0	16.0	16.0	12.7	11.6	10.0	12.0	13.3	18.0	14.0	34.0	39.0
1-5-0	28.3	29.6	21.0	21.3	12.3	12.3	2.7	8.6	11.7	18.3	15.3	36.0	39.3
3-8-4	33.0	31.6	21.3	23.3	17.3	18.3	1.0	4.3	2.7	18.6	14.3	37.0	39.3

TABLE III
PIERRE ROBIN SYNDROME
Hard Palate Measurements

		Maxillary Width at Levels			Width of Cleft		Length of Cleft	Anterior Palate to D	Maxillary Height		
Ages	Antero-Posterior Length Along Z	A-A'	B-B'	C-C'	C-C'	F-F'			B-B	C-C'	Distance Between P-P'
0-2-10	29.3	36.0	38.6	40.0	8.0	10.6	12.6	16.6	8.0	6.6	30.0
1-3	38.6	35.6	43.0	45.6	3.3	5.0	16.6	18.6	8.3	10.0	32.0
2-1	38.0	35.0	45.3	50.0	2.3	6.0	19.3	18.3	8.3	9.3	29.0
2-10	39.0	34.3	41.0	50.0	1.6	6.0	21.6	17.3	9.0	13.0	32.0
3-11	39.0	31.0	43.0	47.6	1.3	2.3	20.6	18.3	10.0	10.6	34.0
6-1	39.0	33.0	43.6	50.0	—	—	—	—	7.3	7.6	35.0

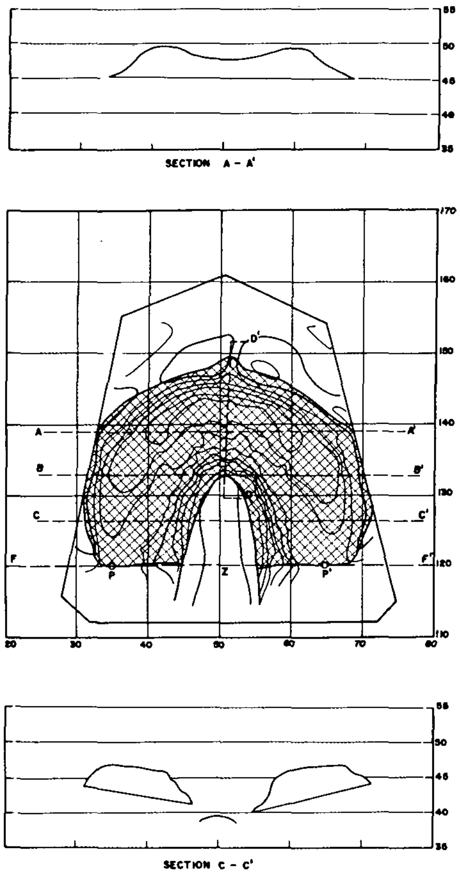


Fig. 14 Palatal cast of Pierre Robin syndrome: age 2 months, 10 days.

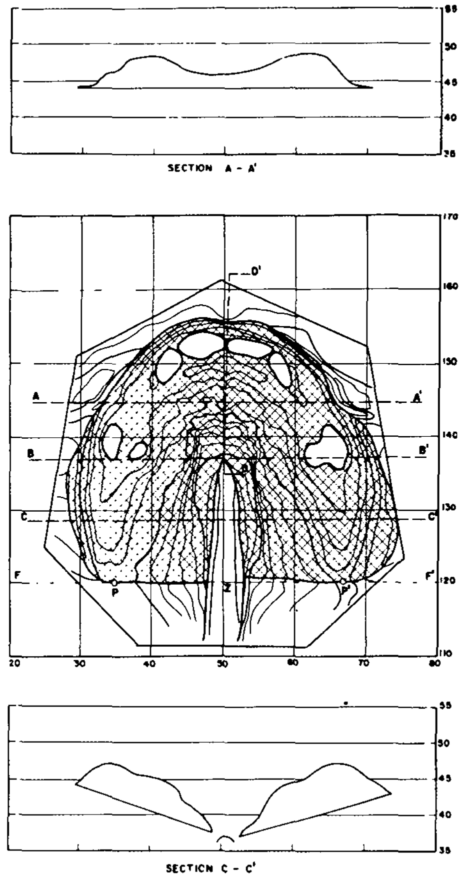


Fig. 15 As in Fig. 14, age 1 year, 3 months.

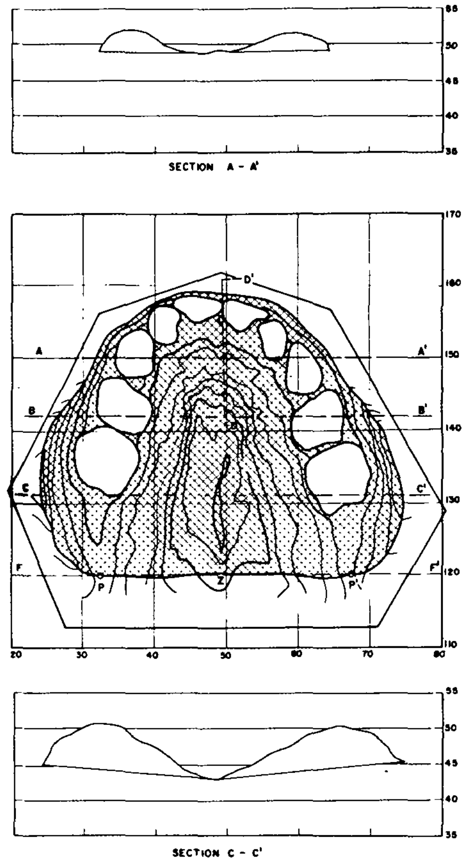


Fig. 16 Case in Fig. 14 continued: Following repair of velum and then the hard palate, age 6 years, one month.

in the widths of the cleft. The greatest change took place between two months and one year of age and remained relatively stable thereafter despite the continuing increments in palatal width and length. The shape of the hard palate changed from an ovoid to a tapered form with a decrease of 3 mm in cross-sectional measurement at the level A-A′ (the anterior one third of the hard palate). There was a slight increase of 5 mm at level B-B′ and an increase of 10 mm at level C-C′, the posterior third of the hard palate.

In six years, a thirty percent increase in the anteroposterior length of the hard palate was recorded with almost all of this increase occurring during the first year of life.

The cleft space demonstrated its greatest rate of narrowing during the first year. This narrowing progressed evenly throughout the total length of the cleft.

The total length of the cleft in the hard palate increased 4 mm as the palate increased 10 mm in its anteroposterior dimension. The hard palate, anterior to the cleft, increased 2 mm in length. After age 2-10, there was neither a change in the length of the cleft space nor a change in total anteroposterior length of the hard palate.

The maxillary height increased from 7 mm to 10 mm from ages 0-2-10 to 3-11. After age 3-11, an actual decrease in height of approximately 3 mm was recorded. This decrease was due to the surgical closure of the hard palate and the concurrent lowering of the vault.

The distance between P and P′ revealed a steady increase of approximately 5 mm or a gain in width of fifteen percent (Table III).

The superimposed tracings demonstrated the constancy in the form of the vault space until the final closure of the palate. With soft tissue closure there was a flattening and lowering of the vault roof due to the downward and medial approximation of mucoperiosteal flaps.

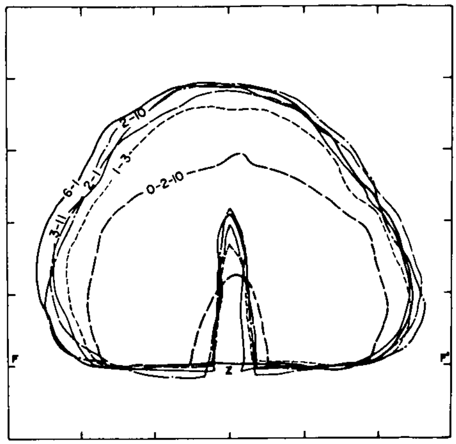


Fig. 17 Case in Fig. 14 continued: Superimposed tracings of palate.

Projected Investigations

The ultimate goal is to quantify specific areas and the volume within a delineated anatomical space. From the problem-oriented point of view, such investigations would be designed to answer the following questions:

1. Within a single type of cleft, such as a complete unilateral cleft lip and palate, what is the variance in the amount of tissue in each palatal segment? Is there a constant relationship between the size of the smaller segment to that of the larger?

2. What are the increments in the area of a palatal shelf as a result of growth?

3. What are the changes in the shape and volume of the palatal vault as a result of palatoplasty, palatal expansion or orthodontic treatment which would modify the area in which the tongue is postured?

4. How does one describe and measure the changes in the peculiar dysmorphosis of the palate pathognomic to the premature synostoses of the cranio-

facial sutures, as in Crouzon's and Apert's syndrome?

Summary

The principles of stereophotogrammetry, as developed in cartography, have been reviewed and their application to biological problems discussed.

A technique for nontopographic stereophotogrammetry permitting three-dimensional studies on serial plaster casts of the palate has been developed and presented.

The application of this technique to the study of cleft palate was shown by a comparison of casts on unsimilar sex twins, the sister possessing a normal palate and the brother having a complete left unilateral cleft lip and palate. Serial casts on a complete bilateral cleft lip and palate were analyzed to demonstrate the molding action of two-stage lip repair and velar closure. Similarly, a series of palatal casts on a child with Pierre Robin syndrome was illustrated to demonstrate spontaneous narrowing of the palatal cleft and growth of the palate.

The technique provides a critical method for three-dimensional evaluation of the serial changes in the configuration of the palatal vault. The ultimate objective is to quantify the variations in the amount and shape of structures present in infancy and the changes incident to growth and surgery. Quantitative description of the area and volume of the palatal vault is of special interest insofar as it may affect tongue posture.

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