Quantitative Analysis of Cleft Palate Casts

A Geometric Study

Samuel Berkowitz, D.D.S.
Jeffrey Krischer, M.S.
Samuel Pruzansky, D.D.S.
South Miami, Florida

Treatment planning in cleft lip and palate habilitation is contingent upon an understanding of the natural history of the palatal cleft defect and the face in which it exists. With the introduction of roentgenocephalography, clinical research focused on the examination of the developing affected face. Longitudinal facial growth studies ultimately helped explain many cause and effect relationships which existed between palatal surgery and subsequent facial development. However, there still remains an important deficiency in our understanding of palatal development which is essential to further refine and improve rehabilitative procedures.

The purpose of this report is to reconsider previously posed questions in the light of newer biostereometric techniques. Specifically, the following questions have been asked with respect to cleft lip and or palate.

1. Are the palatal shelves intrinsically deficient, adequate, or excessive in mass?
2. To what extent does the geometric relationship of the palatal shelves in one cleft compare with that of another in the same type of cleft? With other types of clefts? With normal palates?
3. To what extent are the palatal shelves displaced in space?
4. How are these parameters altered as a consequence of growth and surgical reconstruction?

The advent of advanced biosterometric techniques, (*1*, *2*) made it possible to analyze the size and shape of the palate in greater detail through intensive geometric survey. The data collected by this system can be reduced to a mathematical format and subjected to analysis by high speed computers.

This research has been sponsored by Mead-Johnson Laboratories, Evansville, Indiana and in part by the National Institute of Health (DE-02872) and Maternal and Child Health Services, Department Of Health, Education and Welfare.

Samuel Berkowitz, D.D.S., M.S., is Assistant Professor of Pediatrics, Director of Craniofacial Anomalies Program, University of Miami School of Medicine.

Jeffrey Krischer, M.S., is Special Research Fellow, National Center for Health Services Research and Development, Department of Health, Education and Welfare. Division of Engineering and Applied Physics, Harvard University.

Samuel Pruzansky, D.D.S., M.S., is Professor of Orthodontics in the Department of Pediatrics. Director of Center for Craniofacial Anomalies, Abraham Lincoln School of Medicine, University of Illinois.

In accordance with these objectives, we undertook a series of phased studies utilizing stereophotogrammetric analysis of serial casts of infants with cleft lip and palate with the following specific aims:

A. Test the reliability of the method for selecting the proper anatomical landmarks when extrapolating data from the stereophotographs.
B. Compare and contrast two and three dimensional surface area measurements with other descriptive measurements to determine if there are significant differences in their interpretive values.
C. Perform analytical photogrammetric analysis of serial casts in order to describe the changing geometry of the palatal vault in mathematical terms.
D. Determine whether the descriptive analyses revealed additional information relative to the geometric changes that follow in the course of time.
E. Determine by differential analysis if a constant geometrical relationship might exist between the size and shape of the lesser to greater palatal segment in a complete unilateral cleft lip and palate.

Method

A comprehensive review of the general methodology can be found in the literature. The special armamentarium essential to the study of dental casts has been described previously (*1*, *2*).

Materials

The following series of casts were selected from the longitudinal growth studies at the Center for Craniofacial Anomalies, Abraham Lincoln School of Medicine, University of Illinois.

Types of Casts Selected to Study

1. **Dizygotic Twins:** Discordant for cleft lip and palate (3 months)
   a) complete unilateral cleft lip and palate (brother)
   b) normal (sister)
2. *Complete Bilateral Cleft Lip and Palate:*
   Serial casts on one patient beginning at age 21 days and extending to age 3½ years.
3. *Complete Unilateral Cleft Lip and Palate:*
   Initial casts of nine patients in the unoperated state varying in age from one month to six months.
4. *Pierre Robin Syndrome:*
   Series of five casts in a single patient extending from 2 months to 6 years of age.

Glossary of Terms (Figure 1A, B, C and D)

The landmarks listed in this study will vary with the type of cleft being analyzed. For ease of listing they are all grouped together.

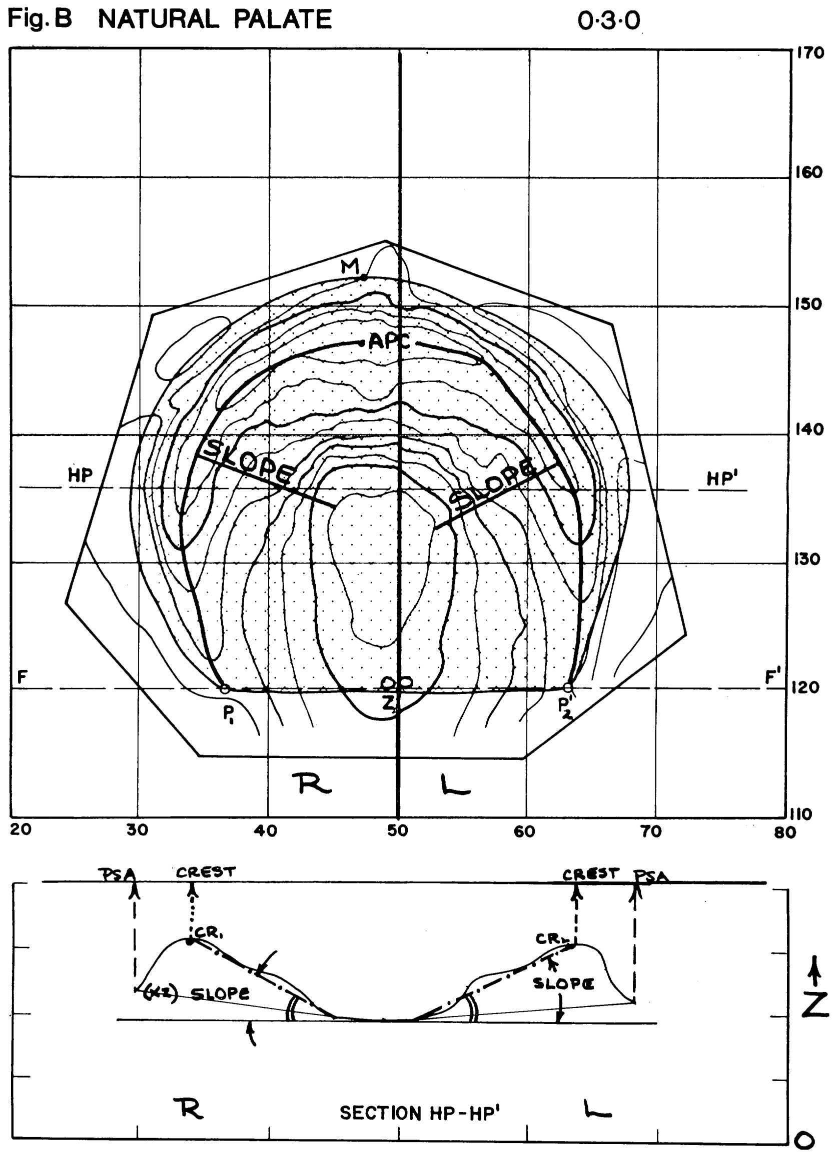

FIGURE 1A. Normal palate. Stereophotogrammetry permits sections of the palate at any area (HP) to be made without actually cutting the mold.

Points—($)^1$ = right side; ($)^2$ = left side

P_1 (P_2)	=	PTM = Sillmans Point = Posterior extent of alveolor crest
C_1 (C_2)	=	Cleft point on base line P_1–P_2
PW_1 (PW_2)	=	Greatest width point of palate on base line P_1–P_2. If it is abscent, than P_1 (P_2) is the most lateral landmark.
AC_1 (AC_2)	=	Most anterior point on the alveolar crest at the cleft.
M_1 (M_2)	=	Most anterior point of each palatal segment, may be AC in some instances.

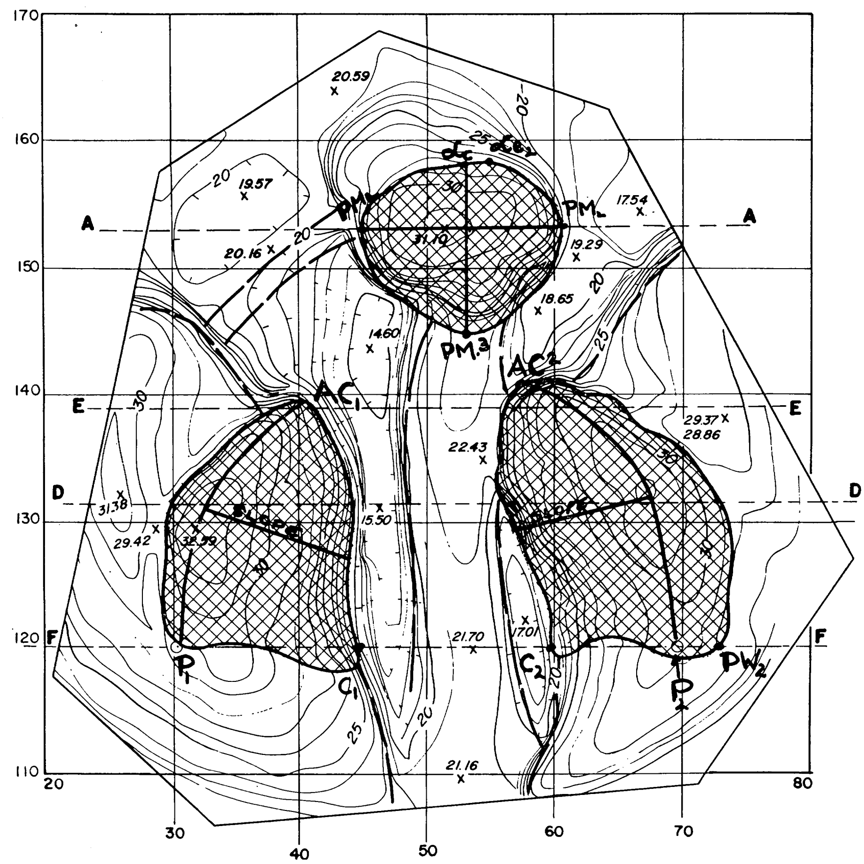

FIGURE 1B. Complete bilateral cleft lip and palate.

PM_1 = lateral point of premaxilla (right side)
PM_2 = lateral point of premaxilla (left side)
αC = The center of the premaxilla on the most anterior surface.
αE = The most anterior point of the premaxilla when it is off center. (May be c in some instances.)
PM_3 = The most posterior point of the premaxilla at the center.
CAP = Most anterior point of cleft space in isolated cleft palates.
APC = Anterior most point on alveolar crest.
PSA = Perimeter of palate.

Lines

PW_1–PW_2 = Greatest posterior palatal width.
P_1–P_2 = Posterior palatal width (when PW_1–PW_2 is missing includes posterior cleft spaces if present).
P_1–C_1 (P_2–C_2) = Posterior hard palate width up to cleft
C_1–C_2 = Posterior cleft width.
Z = Bisector of P_1–P_2.
AC_1–Z (AC_2–Z) = Anterior cleft width when each is on either side of Z line (if one AC is on the same side as the other AC, then the cleft space is the shortest distance between segments).

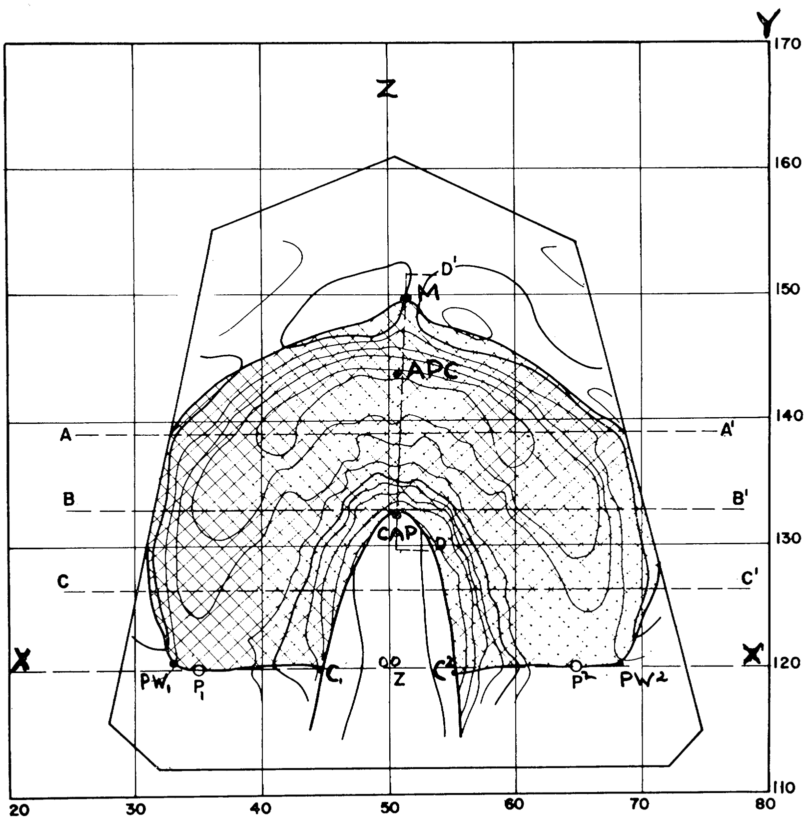

FIGURE 1C. Isolated cleft of the palate.

M_1–P_1P_2 (M_2–P_1P_2) = Relative Length (Two dimensional) and is perpendicular to base line.

AC_1–P_1 (AC_2–P_2) = Absolute Length (three dimensional) as measured along alveolar crest.

Slopes—are taken in three frames of space

a) XY = Palatal tilt toward the midline bisector A.

b) XZ = From alveolar crest to the cleft space.

Pos = posterior slope along line P_1–P_2.

Med = from the middle and perpendicular to the alveolar crest to the cleft space.

c) YZ = slope of the alveolar crest. This was also taken at three points; middle, anterior and posterior extensions.

d) PM_1–PM_2 = length of premaxilla.

e) αC–PM_3 = width of premaxilla.

f) CAP–P_1–P_2 = Antero-posterior length of cleft space (isolated clefts).

g) APC–P_1P_2 = Relative length of alveolar crest when alveolar crest is continuous.

Analytical Methods

The following measures were selected to describe the cleft palate as a changing and variable three dimensional form.

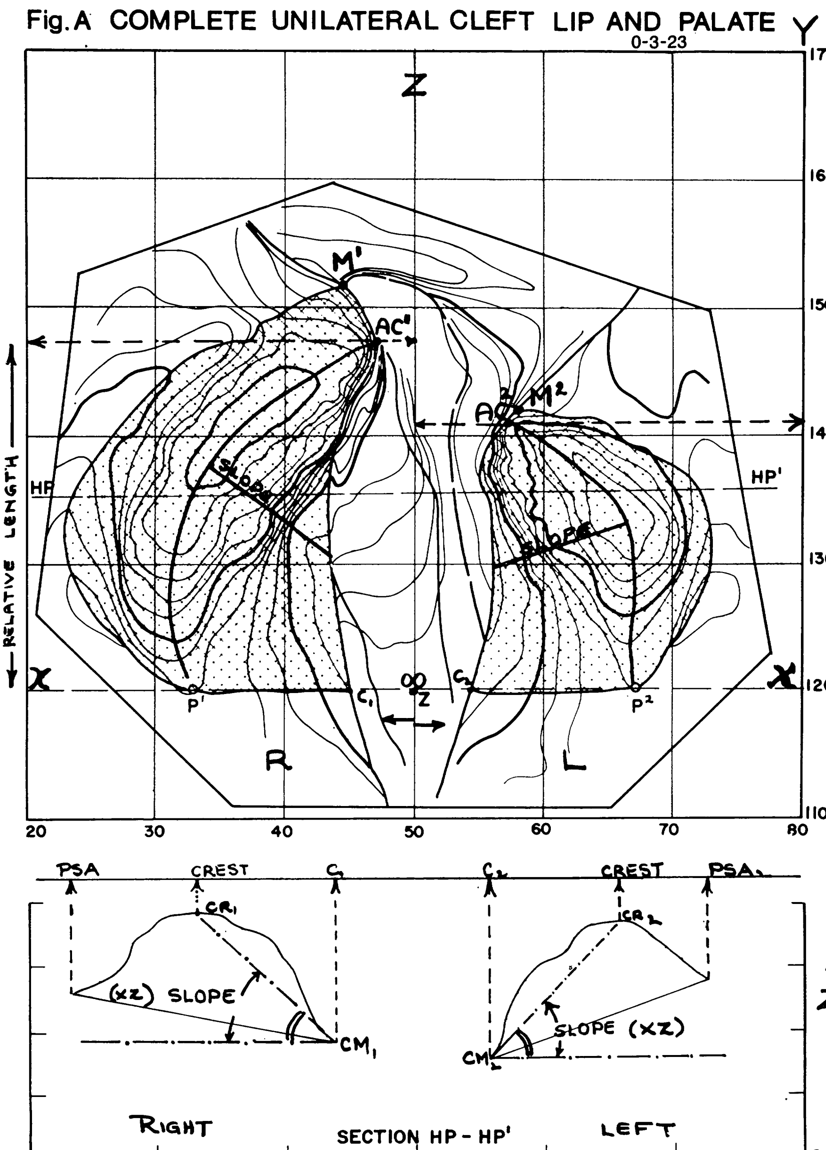

FIGURE 1D. Complete unilateral cleft lip and palate.

A) Degree of Curvature: (Figure 2) Reflects on the form of the arch. In a parabola it is defined as being the distance from the *Vertex* to its *Focus*. A parabola is fitted to the two posterior points on the alveolar crest (P_1–P_2) with its arch lengths equal to the sum of the absolute lengths of the palatal segments. The degree of curvature is a summary measure of the *form* of the parabola. As the number gets *larger*, the curvature is less,

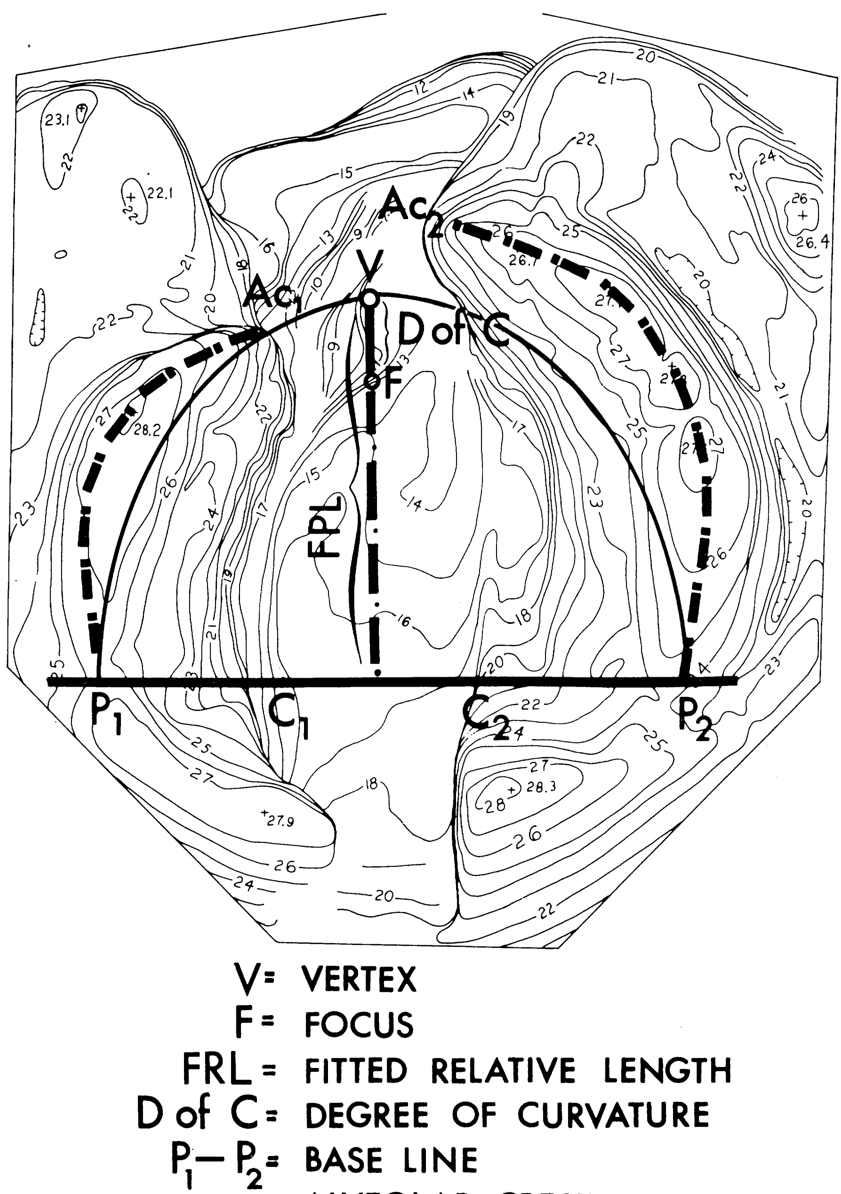

FIGURE 2. A parabolic curve fit for a complete unilateral cleft lip and palate. Points used in the geometrical analyses.

that is, the parabola becomes more *tapering*. Conversely, as the number becomes smaller, the parabola becomes more *ovoid*.

B) Fitted Relative Lengths: (Figure 2) This measurement is taken from the base line perpendicular to the *Vertex* (the most anterior point) of the created symmetrical arch. This is the relative length each palatal segment would have if the anterior cleft space was to be eliminated. In most instances this length is less than both existing relative lengths and suggests that each palatal segment is over expanded and each side needs to be brought medially (Figure 3). If the *fitted relative length* of a segment is greater than its *absolute length measurement* it emphasizes the extreme medial position of the palatal segment and points out that it needs to be moved laterally to form a more perfect arch form. If the *fitted relative length* is greater on one side and less on the other, then the palatal segments need to be moved in opposite directions.

C) Surface Areas: Comparisons were made between two-dimensional and three-dimensional surface areas to determine the reliability of diagnostic interpretation based on two-dimensional drawings or photographs.

D) Slopes: Measurements were made at three points (anterior, middle and posterior) on the alveolar crest of the palatal process in three axis of space (XY, ZX, YZ). It needs to be determined which slope measurement more truly reflects on the spatial relationship of the palatal segments for interpretive analyses.

E) Time Sequence Analysis: This demonstrates the rate that palatal form changes relative to time and recognizes the inherent capacity of biological structure to change under the influences of external forces.

Results

STUDY I—THE SELECTION OF LANDMARKS. This was one of the most difficult and time consuming tasks that needed to be performed. There was some error locating landmarks early in the study but as the photogrammatist became more acquainted with the subject the error factor was reduced and became negligible.

STUDY II—SURFACE AREA 1. *Complete Unilateral Cleft Lip and Palate* (Figure 4A, Table 1). Comparisons were made of the surface areas of the smaller and larger lateral palatal segments. The ratio of the smaller to larger segment ranged from .458 to .6575 using 2D surface area measurements and ranged from .527 to .835 using 3D surface area measurements. Significantly, the 3D measurements reveal a greater variation among surface areas than detectable by comparable 2D measurements. Hence, 2D measurements alone tend to under-describe the palate and suggest interpretations not supportable by more complete analysis. A main reason for the difference in interpretative value is that the two-dimensional measurements are taken from a projection to a horizontal plane. The tilting of the two palatal segments relative to the horizontal plane affects their projection. The three-dimensional measurements, however, are not based on a projection and therefore are a more accurate representation of the palate.

The ratio range of smaller to larger 3D surface area measurements, for all cases studied, is between 46% and 83% with most measurements falling

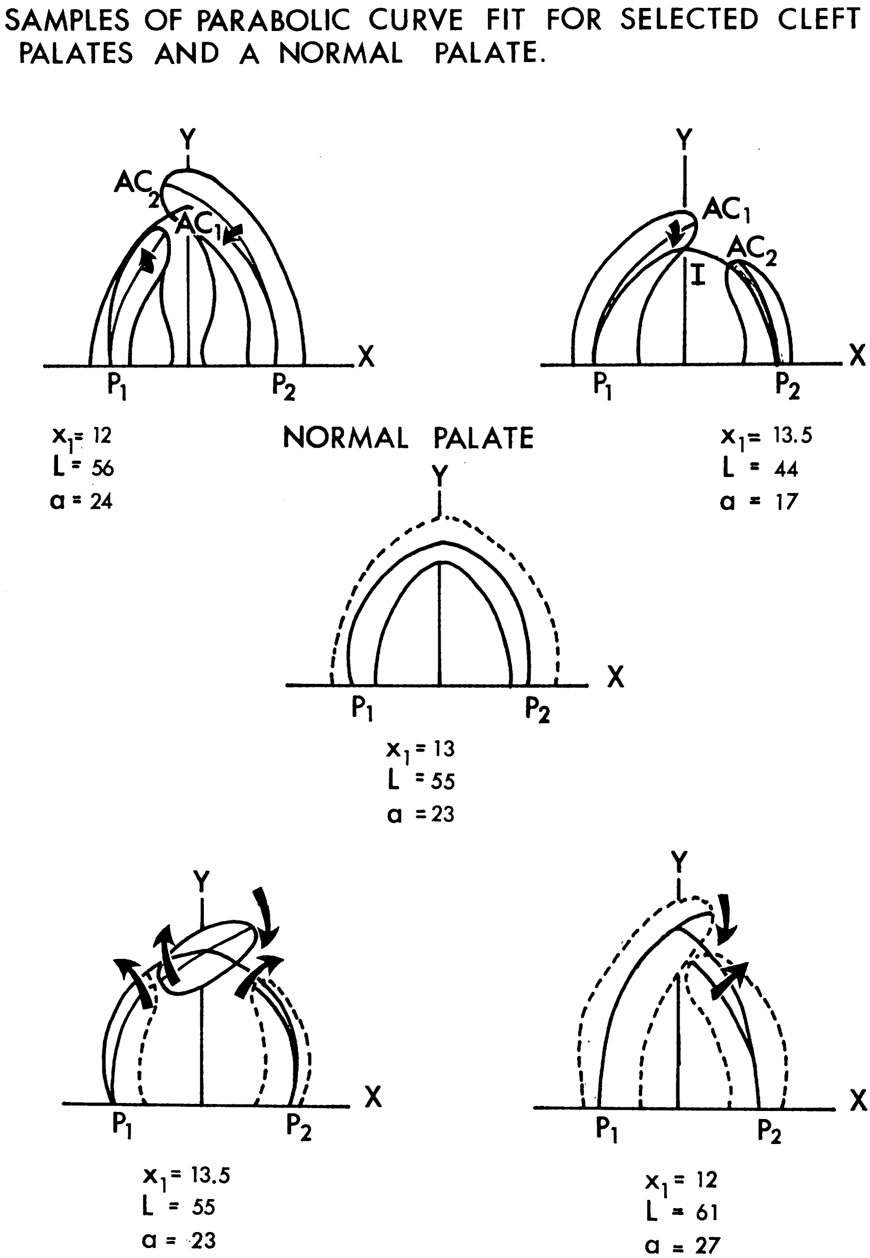

FIGURE 3. These diagrams describe how the lateral palatal segments must be moved in order to establish a "best parabola" based on the absolute lengths and the distance between P_1–P_2.

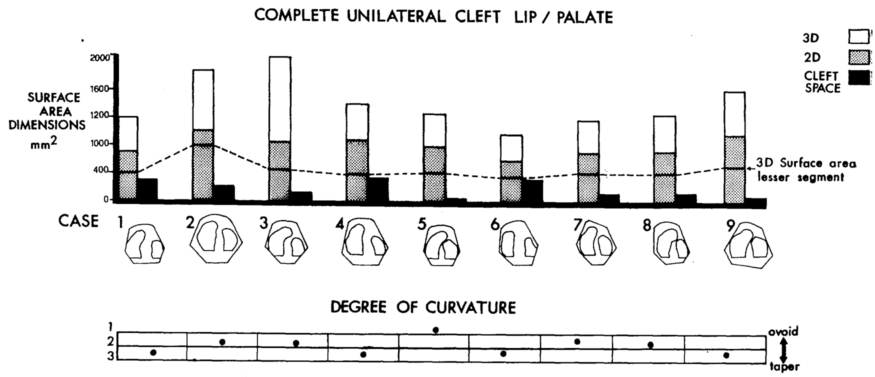

FIGURE 4A. Surface area dimensions. Two and three dimensional surface area measurements are compared. There is no direct relationship between the cleft space and the size of the palatal segments. In all but one case (#2) the 3D surface area of the lesser segments are nearly equal. The size of the lesser segment is not related to the size of the greater segment. B. Degree of curvature. In all but one case (#5) the degree of curvature falls between 2 and 3.

between 53% and 65%. The ratio of cleft space to total 3D surface area ranges from 10% to 30%.

2. *Dizygotic Twins* (Figure 6, Table 2). The results served to depict the type of error that can be encountered in extracting information from 2-plane photographic representations. For example, the 2D surface area of the lesser segment was approximately 30% less than the 3D measurement of the same area. The 3D total surface area of the normal palate equaled the 3D total surface area of the cleft palate while the 2D measurements showed the normal palate to be 20% larger than its cleft palate

TABLE 1. Complete unilateral cleft lip and palate. Comparisons of Surface Area measurements between a 3-dimensional object and its 2-dimensional projection drawing.

case no. age	*2-dimensional*				*3-dimensional*				*surface area 2-D/3-D*
	right	*left*	*smaller segment /larger segment*	*total surface area*	*right*	*left*	*smaller segment /larger segment*	*total surface area*	
1. 0-1-0	498.19	259.80	.52	757.98	802.94	430.45	.54	1233.39	.61
2. 0-3-15	621.34	374.53	.60	995.87	1090.39	847.38	.83	1856.76	.53
3. 0-2-0	571.69	264.80	.46	836.49	1135.19	842.38	.74	1977.56	.42
4. 0-3-0	578.89	276.23	.48	855.11	920.75	485.62	.53	1406.37	.60
5. 0-3-10	491.49	323.16	.66	814.65	755.3	546.66	.72	1301.97	.62
6. 0-0-20	405.00	228.87	.57	633.87	646.37	379.61	.59	1025.99	.62
7. 0-2-23	485.85	276.75	.57	762.60	691.37	446.92	.65	1138.29	.67
8. 0-3-0	515.12	235.87	.46	750.99	837.87	449.78	.54	1287.65	.58
9. 0-5-0	645.14	374.30	.58	1019.44	962.07	578.48	.60	1540.55	.66

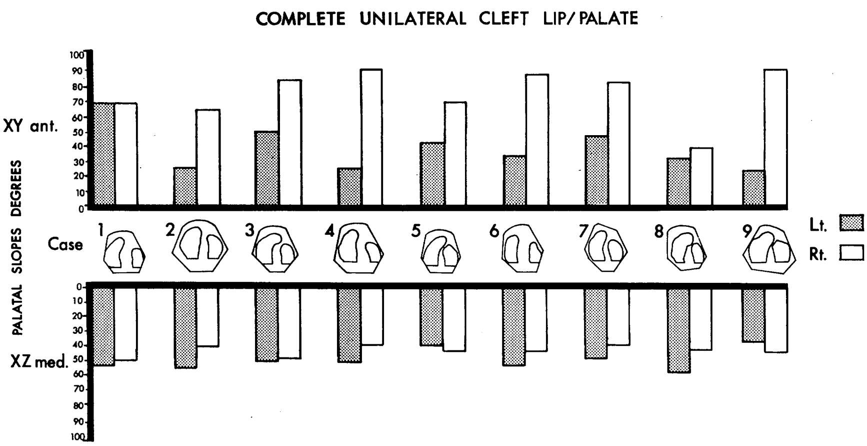

FIGURE 5. Slopes of the complete unilateral cleft lip and palate in the XY and XZ axis. In the XY axis the right larger segment is always more obtuse than the lesser segment. In the XZ axis the slopes at the middle of the palatal segment are almost the same with the lesser segment being slightly steeper.

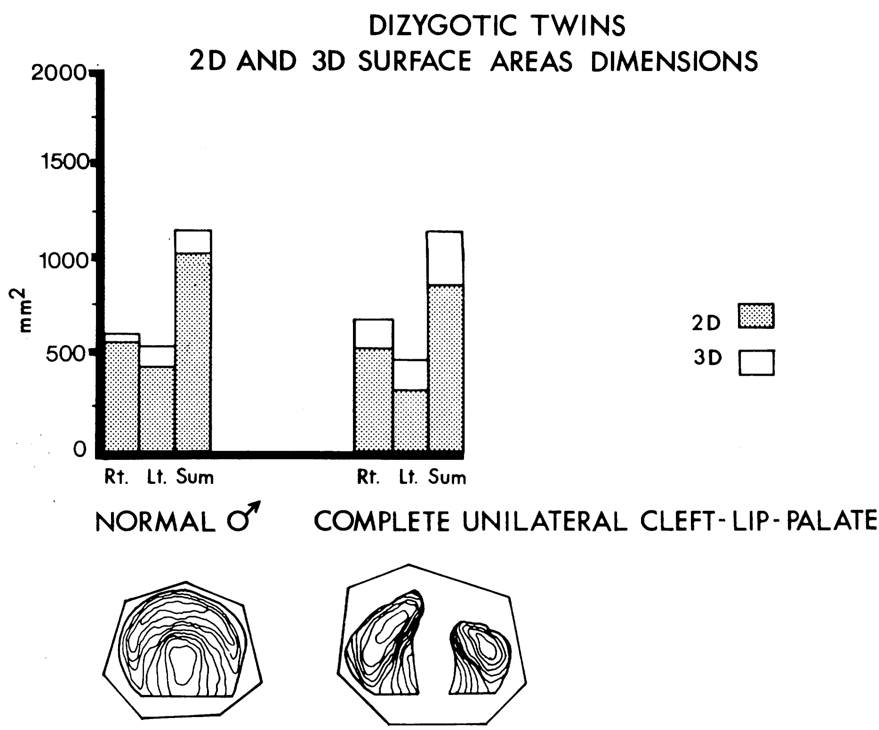

FIGURE 6. Dizygotic twins; 2D and 3D surface area dimensions. The total 3D surface area of the normal and complete unilateral cleft lip and palate are nearly the same. The total 2D surface area measurements when compared suggest that the cleft palate surface area is significantly smaller.

TABLE 2. Dizygotic twins. Comparisons of surface area measurements between a 3-dimensional object and its 2-dimensional projection drawing.

Ages: 0-3-0	*2-dimensional*			*3-dimensional*			*comparisons*	
							2-dimensional	*3-dimensional*
	right	*left*	*total*	*right*	*left*	*total*	*left/right*	*left/right*
normal	553.66	451.48	1005.14	619.19	544.94	1164.13	.815	.881
complete unilateral cleft lip and palate	505.78	298.23	804.01	705.27	444.27	1149.89	.591	.631
unilatera/normal							.80	.98

twin. If reliance has been placed on the 2D method, the results would have been interpreted to signify a deficiency in palatal development in the case of the cleft. While the surface area of the normal palate as seen in the 2D photograph was only 15% smaller than its 3D measurement, the surface area of the cleft palate as seen in the photograph was approximately 30% smaller than its 3D measurement. The greater reduction in the cleft palate measurements resulted from the increased steepness of both palatal segments which produced a foreshortening with resultant distortions in the projected images.

3. *Bilateral Cleft Lip and Palate:* (Figure 7, Table 3). The measurements of the premaxilla were found to be unreliable because of the insufficient number of coordinate points selected to describe its contour. The 3D surface area of the palatal segments doubled in 1½ years. Between 1½ and 3½ years there was approximately a 25% increase and at 3½ years the palatal 3D measurements were ⅔ greater than those calculated in 2D drawings.

4. *Pierre Robin:* (Figure 8, Table 4). The 3D surface area increased 50% in the first year and by three years it was 70% larger. The 2D cleft space area decreased only slightly during the same period of time. In a previous report on the same case, it was observed that there was a change in the cleft space configuration. The configuration not only became longer as the palate lengthened, but narrowed as well. Thus, we observed concurrent phenomenon: the cleft narrowed and elongated as the palate grew. At the same time, the total area of the cleft decreased only slightly. These findings suggest that appositional growth at the margin of the clefts can contribute to the reduction of cleft space.

STUDY III—GEOMETRICAL ANALYSIS. *Fitted Relative Lengths.* This measurement reflects the distance from the base line, P_1–P_2 to the vertex of

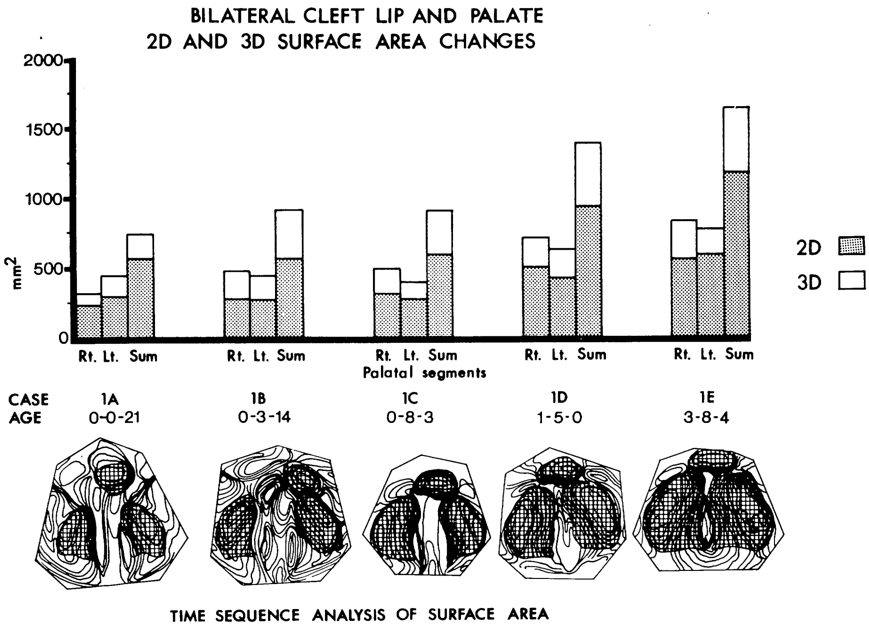

FIGURE 7. Serial changes in surface areas. The greatest rate of change occurred between the 8th month and 1½ years. Between 21 days and 1½ years, the 3D surface area nearly doubles. Between 1½ and 3½ years there is an approximate increase of 25%.

the curve and generally falls somewhere between the *absolute* and *relative lengths*. It is the constructed relative length in a parabola fitted to pass through the points P_1 and P_2 with arch length equal to the absolute length.

Degree of Curvature (D of C). This measurement described the shape of the arch. Ovoid arches in this study had small numbers, between 0.50 and 1.5. As the measurement increased so did the taperedness of the arch.

(1) *Bilateral Cleft Lip and Palate and Complete Unilateral Cleft Lip and Palate Casts: Chart I.* The D of C of 4.9 seen in the earlier casts of

TABLE 3. Bilateral cleft lip and palate. Comparisons of Surface Area measurements between a 3-dimensional object and its 2-dimensional projection drawing.

case no. age	*2-dimensional surface area*				*3-dimensional surface area*			
	right	*left*	*smaller segment/ larger segment*	*total*	*right*	*left*	*smaller setment/ larger segment*	*total*
1A. 0-0-21	220.56	283.06	.78	503.62	299.42	449.18	.67	748.60
1B. 0-3-14	289.91	281.11	.97	571.02	450.07	425.74	.95	875.81
1C. 0-8-3	318.54	289.67	.91	608.20	497.59	408.43	.82	906.02
1D. 1-5-0	507.36	423.33	.83	930.69	723.81	673.81	.93	1397.62
1E. 3-8-4	574.89	595.29	.97	1170.18	848.28	791.84	.93	1640.12

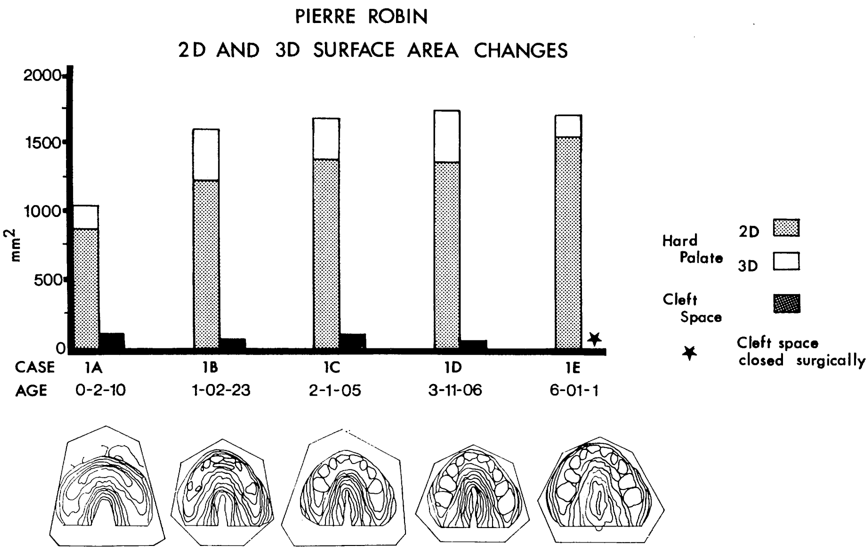

FIGURE 8. Serial surface area changes. The greatest rate of change occurs during the first year. The 3D surface area increases 50% in one year and by 3 years it is 70% larger. After one year the rate of increase rapidly diminishes. The cleft space area diminishes only slightly.

the bilateral series was a measure of the protrusion of the premaxilla and therefore, suggested the existence of highly tapered arches. By the age of three years the D of C was 2.0 which was comparable to that found in unoperated complete unilateral cleft lip and palate cases. The increase in length of the palatal segments relative to the restrained forward position of the premaxilla in space accounts for the change in values and is reflected also in the increasing values of the fitted relative length.

(2) *The Pierre Robin Casts: Chart II.* The D of C was relatively small and depicted an ovoid arch. The measurements ranged from 1.1 to 1.5. In a previous study each stage was graphically superimposed, and one can clearly view the progressively changing arch form from ovoid to tapering.

TABLE 4. Pierre Robin syndrome. Comparisons of Surface Area measurements between a 3-dimensional object and its 2-dimensional projection drawing.

case no. age	*2-dimensional surface area*			*3-dimensional surface area*		
	hard palate	*cleft space*	*celft space/ hard palate*	*hard palate*	*cleft space*	*cleft space/ hard palate*
1A. 0-2-1	868.97	79.26	.09	1053.53	79.26	.08
1B. 1-3-0	1220.19	60.88	.05	1578.83	60.88	.04
1C. 2-10-0	1367.78	72.41	.05	1984.84	72.41	.04
1D. 3-11-0	1378.89	65.56	.05	1708.78	65.56	.04
1E. 6-1-0	1554.33	.00	.00	1733.69	.00	.00

CHART I. Bilateral cleft

IDENTIFICATION AGE	BILAT. CLEFT 1A 0-00-21	BILAT. CLEFT 1B 0-03-14	BILAT. CLEFT 1C 0-08-03	BILAT. CLEFT 1D 1-05-00	BILAT. CLEFT 1E 3-08-04
ANT CLEFT WIDTH	18.000	23.667	15.000	10.667	10.667
POS CLEFT WIDTH	15.133	35.890	10.770	11.508	3.000
TOT WIDTH (P12)	38.030	37.786	35.723	37.336	35.014
P1-PC1 WIDTH	15.269	0.000	21.863	15.422	16.774
PW1-P1 WIDTH	3.655	19.925	1.000	0.000	3.000
P2-PC2 WIDTH	16.587	2.236	16.335	20.638	18.693
PW2-P2 WIDTH	1.667	0.000	0.000	6.474	0.000
PW1-PW2 WIDTH	52.311	58.051	49.968	54.043	41.468
ABSOLUTE LEN RT	24.492	33.437	29.917	36.612	42.958
ABSOLUTE LEN LT	30.491	22.625	29.943	33.392	44.037
RELATIVE LEN RT	20.304	24.083	24.352	28.443	33.242
RELATIVE LEN LT	21.587	20.616	23.345	25.495	32.098
DEGREE OF CURV.	4.987	4.697	3.565	3.140	2.010
FITTED RFL. LEN	18.125	19.000	22.375	27.750	38.125
SURFACE RT (3D)	299.416	450.067	497.593	723.811	848.282
SURFACE LT (3D)	449.183	425.741	408.429	673.806	791.841
SURFACE RT (2D)	220.556	289.909	318.536	507.356	574.894
SURFACE LT (2D)	283.060	286.111	289.671	423.333	595.289
CLFT SPACE AREA	283.768	337.607	242.815	183.044	144.838
PREMAXILLA WIDTH	15.811	17.804	17.000	19.003	18.333
PREMAXILLA HT.	31.000	39.000	38.800	40.000	50.000
PREMAXILLA LEN.	7.311	13.000	11.000	7.683	10.000
PREMAXILLA DIST	9.000	0.000	2.000	0.000	3.000
PREMAX AREA (3D)	241.831	302.319	189.433	215.937	158.724
PREMAX AREA (2D)	143.741	167.519	137.724	147.467	145.503
XY SLOPE POS RT	0.000	78.690	78.690	82.405	53.746
XY SLOPE MED RT	71.565	76.866	80.538	66.571	66.571
XY SLOPE ANT RT	59.036	42.709	39.289	34.695	29.358
XY SLOPE POS LT	-75.069	75.069	71.565	78.690	-86.186
XY SLOPE MED LT	-64.983	-82.405	-63.435	-76.866	-57.653
XY SLOPE ANT LT	-23.199	-51.340	-24.228	-35.538	-15.255
XZ SLOPE POS RT	-37.694	0.000	-47.663	-32.969	-28.610
XZ SLOPE MED RT	-41.583	-49.728	-49.794	-56.725	-41.091
XZ SLOPE ANT RT	0.000	0.000	0.000	0.000	0.000
XZ SLOPE POS LT	36.870	26.565	36.870	48.366	21.991
XZ SLOPE MED LT	52.997	43.831	41.186	47.663	33.311
XZ SLOPE ANT LT	0.000	53.366	0.000	0.000	0.000
YZ SLOPE POS RT	16.699	21.801	11.310	21.801	21.801
YZ SLOPE MED RT	-5.711	21.801	-5.711	0.000	0.000
YZ SLOPE ANT RT	-38.660	-63.435	-59.036	-63.435	-45.000
YZ SLOPE POS LT	16.699	21.801	11.310	0.000	20.807
YZ SLOPE MED LT	5.711	18.778	-5.711	0.000	8.531
YZ SLOPE ANT LT	-80.538	-4.574	-33.690	-45.000	-36.870

CHART II. Pierre Robin

IDENTIFICATION	PIERRE-ROBIN 1A	PIERRE-ROBIN 1B	PIERRE-ROBIN 1C	PIERRE-ROBIN 1D	PIERRE-ROBIN 1E
AGE	0-02-10	1-02-23	2-01-05	3-11-06	6-01-01
ANT CLEFT WIDTH	0.000	14.000	8.000	0.000	0.000
POS CLEFT WIDTH	10.853	5.000	6.412	4.123	0.000
TOT WIDTH (P12)	25.338	30.667	29.017	32.333	33.333
P1-PC1 WIDTH	6.521	12.235	12.839	15.345	16.780
PM1-P1 WIDTH	6.333	3.000	1.000	1.667	3.333
P2-PC2 WIDTH	11.511	17.060	14.239	16.338	18.654
PM2-P2 WIDTH	3.371	1.054	2.848	0.000	0.000
PM1-PM2 WIDTH	38.589	38.349	37.338	37.473	38.768
ABSOLUTE LEN RT	38.970	48.870	42.118	49.731	51.096
ABSOLUTE LEN LT	40.294	42.374	49.246	48.227	49.416
RELATIVE LEN RT	30.017	35.000	35.128	40.000	40.012
RELATIVE LEN LT	30.037	35.000	35.228	40.000	40.012
DEGREE OF CURV.	1.103	1.416	1.253	1.460	1.514
FITTED REL. LEN	36.375	41.500	42.000	44.750	45.875
SURFACE RT (3D)	505.245	753.291	821.206	861.412	930.542
SURFACE LT (3D)	547.366	825.625	1163.637	847.318	803.274
SURFACE RT (2D)	417.434	596.844	674.444	699.444	825.556
SURFACE LT (2D)	451.534	623.351	693.333	679.444	727.778
CLFT SPACE AREA	79.259	60.883	72.407	65.556	0.000
PREMAXILLA WIDTH	0.000	0.000	0.000	0.000	0.000
PREMAXILLA HT.	0.000	0.000	0.000	0.000	0.000
PREMAXILLA LEN.	0.000	0.000	0.000	0.000	0.000
PREMAXILLA DIST	0.000	0.000	0.000	0.000	0.000
PREMAX AREA (3D)	0.000	0.000	0.000	0.000	0.000
PREMAX AREA (2D)	0.000	0.000	0.000	0.000	0.000
XY SLOPE POS RT	56.310	61.928	82.405	82.405	61.928
XY SLOPE MED RT	53.746	47.862	82.405	63.435	76.866
XY SLOPE ANT RT	0.000	34.287	28.179	45.000	0.000
XY SLOPE POS LT	68.199	86.186	59.036	68.199	82.405
XY SLOPE MED LT	-60.461	-64.537	-80.538	-82.405	-69.864
XY SLOPE ANT LT	0.000	82.405	-46.975	-36.870	-53.746
XZ SLOPE POS RT	-29.358	-30.141	-23.199	-23.199	-14.621
XZ SLOPE MED RT	-45.744	-40.389	-33.366	-40.079	-23.199
XZ SLOPE ANT RT	0.000	-15.255	0.000	0.000	0.000
XZ SLOPE POS LT	30.510	21.371	30.964	26.030	12.529
XZ SLOPE MED LT	42.166	34.902	28.317	32.550	18.759
XZ SLOPE ANT LT	0.000	16.699	0.000	0.000	0.000
YZ SLOPE POS RT	11.310	21.801	11.310	11.310	11.310
YZ SLOPE MED RT	5.711	0.000	5.711	0.000	0.000
YZ SLOPE ANT RT	-30.964	-38.660	0.000	-30.964	-11.310
YZ SLOPE POS LT	5.711	30.964	11.310	11.310	0.000
YZ SLOPE MED LT	5.711	8.130	5.711	0.000	0.000
YZ SLOPE ANT LT	-30.964	-38.660	0.000	-30.964	-11.310

CHART III. Dizygotic twins

IDENTIFICATION	NORMAL DIZYGOTIC	UNILAT DIZYGOTIC
AGE	0-03-00	0-03-00
ANT CLEFT WIDTH	2.667	14.333
POS CLEFT WIDTH	0.000	9.333
TOT WIDTH (P12)	26.667	34.333
P1-PC1 WIDTH	13.824	13.007
PW1-P1 WIDTH	0.000	0.000
P2-PC2 WIDTH	13.824	13.424
PW2-P2 WIDTH	0.000	0.000
PW1-PW2 WIDTH	27.647	35.765
ABSOLUTE LEN RT	54.637	41.510
ABSOLUTE LEN LT	43.817	29.542
RELATIVE LEN RT	33.956	33.136
RELATIVE LEN LT	33.956	23.000
DEGREE OF CURV.	0.961	2.508
FITTED REL. LEN	46.250	29.375
SURFACE RT (3D)	619.186	705.273
SURFACE LT (3D)	544.941	444.616
SURFACE RT (2D)	553.656	505.776
SURFACE LT (2D)	451.483	298.231
CLFT SPACE AREA	10.444	318.505
PREMAXILLA WIDTH	0.000	0.000
PREMAXILLA HT.	0.000	0.000
PREMAXILLA LEN.	0.000	0.000
PREMAXILLA DIST	0.000	0.000
PREMAX AREA (3D)	0.000	0.000
PREMAX AREA (2D)	0.000	0.000
XY SLOPE POS RT	86.186	71.565
XY SLOPE MED RT	31.477	64.983
XY SLOPE ANT RT	29.358	39.289
XY SLOPE POS LT	71.565	82.405
XY SLOPE MED LT	-80.538	-80.538
XY SLOPE ANT LT	-27.897	-41.987
XZ SLOPE POS RT	-12.680	-17.969
XZ SLOPE MED RT	-11.560	-47.490
XZ SLOPE ANT RT	0.000	0.000
XZ SLOPE POS LT	12.680	17.526
XZ SLOPE MED LT	30.606	41.009
XZ SLOPE ANT LT	0.000	0.000
YZ SLOPE POS RT	0.000	30.964
YZ SLOPE MED RT	5.711	11.310
YZ SLOPE ANT RT	0.000	-33.690
YZ SLOPE POS LT	0.000	11.310
YZ SLOPE MED LT	11.310	26.565
YZ SLOPE ANT LT	-18.435	-53.130

(3) *Dizygotic Twins: Chart III*

cast	*D of C*	*arch form*
complete unilateral cleft lip and palate	0.96	ovoid
normal twin	2.5	taper

This unilateral cleft lip and palate measurement was very similar to other measurements found in the *nine unilateral cleft lip and palate cases.* The tapering form resulted from the relatively short A-P dimension of the lesser segments and the relative smallness of the P_1–P_2 measurement. This explanation was more greatly appreciated in the graphic superimposing of tracings of the normal and cleft casts. The fitted relative length of 29mm suggested that the larger segment was laterally displaced and, therefore, needed to be brought medially. Although the linear length (relative lengths) measurements of right and left sides in the normal twin are not equal, the absolute length measurements of this discrepancy is caused by graphic interpretation: the Z line divides the palate in two equal sections in a single plane while the absolute lengths are not constrained to one plane.

(4) *Unilateral Cleft Lip and Palate Casts:* (Figure 4B) Charts IV and V. Most D of C measurements fell between 1 to 3. Only one measurement was between 1 and 2. These clefts reflect a slightly more tapered form when compared to an isolated cleft palate, as seen in the Pierre Robin casts. The *fitted relative length* measurements fell between both absolute length measurements and was very close to that of the lesser segments. The 'best fit' parabola for all of the unilateral cleft lip and palate casts calls for the larger segments eventually to move medially while the lesser segments are to be moved laterally.

Slopes

Time Sequence Analysis

a) *Pierre Robin Series* (Figure 9) Both sides of the palate as measured on the line P_1–P_2 became progressively flatter with time. Since this represented the posterior extension of the hard palate it was intimately involved with the cleft space.

b) *Bilateral Cleft Lip and Palate Series* (Figure 10) This graph showed changes in the XZ plane and demonstrated the lac of definite order in slope behavior of the right and left palatal segments. The medial and posterior slope changes of both segments showed no similarity in behavior. The best one can say is that the arches tended to become flatter with time. (Figure 11) The behavior of the left palatal segment in the XY plane appeared to be more erratic than that of the right segment. This appeared to reflect on the effect of two stage lip closure where the left side was closed first. The net effect, however, was for the two palatal segments to tip medially with the right side tipping the most.

Slopes—Unilateral Cleft Lip and Palate Series:

a) XZ—Measurements taken at the middle of the right segment fell between 40 to 50 degrees, while the posterior slopes range between 20 to 50 degrees. The slope taken at the middle of the left segment ranged between 40 to 57 degrees. There appeared to be greater similarity in slopes measurements at the posterior palate (on line P_1–P_2) when compared to the slopes through the middle of each segment. However, considering slopes at both areas of each segment, the range of variation remains great.

b) XY—When measured by their anterior points the right segments appeared to be more vertical than the left sides. The more acute left segment ranged between 23 to 71 degrees with most measurements falling below 45 degrees. The right segments are mostly over 60 degrees.

CHART IV. Unilateral cleft

IDENTIFICATION	UNILAT. CLEFT 1	UNILAT. CLEFT 2	UNILAT. CLEFT 3	UNILAT. CLEFT 4	UNILAT. CLEFT 5
AGE	0-01-00	0-03-15	0-02-00	0-04-00	0-03-10
ANT CLEFT WIDTH	14.333	14.333	10.667	18.333	8.000
PUS CLEFT WIDTH	13.000	11.837	9.667	12.000	8.233
TUT WIDTH (P12)	32.333	31.682	31.397	33.700	22.091
P1-PC1 WIDTH	12.023	17.320	16.456	17.440	14.810
PW1-P1 WIDTH	3.358	5.099	1.414	3.320	2.539
P2-PC2 WIDTH	10.173	15.055	15.771	15.990	10.541
PW2-P2 WIDTH	2.721	0.000	0.000	0.000	9.718
PW1-PW2 WIDTH	41.275	49.310	43.308	48.750	45.841
ABSOLUTE LEN RT	41.468	49.293	49.239	43.058	44.770
ABSOLUTE LEN LT	26.863	35.411	25.661	30.661	33.280
RELATIVE LEN RT	33.377	37.643	33.956	36.582	33.956
RELATIVE LEN LT	21.587	27.857	22.091	24.352	23.345
DEGREE OF CURV.	2.293	1.662	1.896	2.281	0.837
FITTED REL. LEN	28.500	37.750	32.500	31.125	36.438
SURFACE RT (3D)	802.941	1009.388	1135.185	920.751	755.314
SURFACE LT (3D)	430.447	842.375	526.777	485.620	546.657
SURFACE RT (2D)	498.189	621.337	571.694	578.889	491.489
SURFACE LT (2D)	259.795	374.533	264.800	276.230	323.156
CLFT SPACE AREA	315.986	286.465	175.046	371.649	83.790
PREMAXILLA WIDTH	0.000	0.000	0.000	0.000	0.000
PREMAXILLA HT.	0.000	0.000	0.000	0.000	0.000
PREMAXILLA LEN.	0.000	0.000	0.000	0.000	0.000
PREMAXILLA DIST	0.000	0.000	0.000	0.000	0.000
PREMAX AREA (3D)	0.000	0.000	0.000	0.000	0.000
PREMAX ARFA (2D)	0.000	0.000	0.000	0.000	0.000
XY SLOPE POS RT	71.565	71.565	0.000	78.690	75.069
XY SLOPE MED RT	66.571	71.565	55.008	78.690	73.301
XY SLOPE ANT RT	71.565	63.435	83.660	0.000	66.038
XY SLOPE POS LT	0.000	86.186	86.186	75.069	30.964
XY SLOPE MED LT	-76.866	-71.565	-82.405	-75.069	88.091
XY SLOPE ANT LT	71.565	-23.199	-50.194	-24.228	-41.987
XZ SLOPE POS RT	-25.115	-45.881	-35.218	-41.186	-39.289
XZ SLOPE MED RT	-49.950	-45.343	-49.764	-41.424	-45.843
XZ SLOPE ANT RT	0.000	0.000	0.000	0.000	0.000
XZ SLOPE POS LT	29.982	46.975	44.061	51.147	71.565
XZ SLOPE MED LT	53.253	54.689	50.877	52.896	42.236
XZ SLOPE ANT LT	0.000	0.000	0.000	0.000	0.000
YZ SLOPE POS RT	11.310	11.310	11.310	5.711	0.000
YZ SLOPE MED RT	5.711	5.711	0.000	5.711	8.531
YZ SLOPE ANT RT	-53.130	-59.036	-69.444	-50.194	-63.435
YZ SLOPE POS LT	5.711	0.000	16.699	0.000	21.801
YZ SLOPE MED LT	5.711	0.000	5.711	2.862	0.000
YZ SLOPE ANT LT	-63.435	-78.690	-45.000	-59.036	-45.000

CHART V. Unilateral cleft

IDENTIFICATION AGE	UNILAT. CLEFT 6 0-00-20	UNILAT. CLEFT 7 0-02-23	UNILAT. CLEFT 8 0-03-00	UNILAT. CLEFT 9 0-05-00
ANT CLEFT WIDTH	19.000	9.667	12.333	7.333
POS CLEFT WIDTH	13.920	7.333	11.333	8.667
TOT WIDTH (P12)	30.813	26.352	28.340	35.000
P1-PC1 WIDTH	8.180	14.072	12.958	18.066
PW1-P1 WIDTH	3.903	3.236	2.040	3.162
P2-PC2 WIDTH	15.350	15.065	14.533	17.962
PW2-P2 WIDTH	1.667	1.414	0.000	3.606
PW1-PW2 WIDTH	43.020	41.120	40.864	51.463
ABSOLUTE LEN RT	38.804	41.333	46.669	46.699
ABSOLUTE LEN LT	26.480	28.405	27.772	33.586
RELATIVE LEN RT	30.265	34.234	35.022	35.440
RELATIVE LEN LT	22.561	23.537	23.409	26.000
DEGREE OF CURV.	2.178	1.400	1.518	2.227
FITTED REL. LEN	27.250	31.000	33.063	34.375
SURFACE RT (3D)	646.371	691.365	837.870	962.070
SURFACE LT (3D)	379.615	446.922	449.779	578.476
SURFACE RT (2D)	405.000	485.854	515.124	645.136
SURFACE LT (2D)	228.867	276.749	235.867	374.303
CLFT SPACE AREA	360.089	155.972	152.655	91.198
PREMAXILLA WIDTH	0.000	0.000	0.000	0.000
PREMAXILLA HT.	0.000	0.000	0.000	0.000
PREMAXILLA LEN.	0.000	0.000	0.000	0.000
PREMAXILLA DIST	0.000	0.000	0.000	0.000
PREMAX AREA (3D)	0.000	0.000	0.000	0.000
PREMAX AREA (2D)	0.000	0.000	0.000	0.000
XY SLOPE POS RT	68.199	78.690	75.069	78.690
XY SLOPE MED RT	71.565	73.301	78.690	63.435
XY SLOPE ANT RT	86.186	80.538	38.660	0.000
XY SLOPE POS LT	-75.069	0.000	-86.186	64.983
XY SLOPE MED LT	-73.301	-80.538	-76.866	-78.690
XY SLOPE ANT LT	-33.690	-48.366	-30.964	-27.553
XZ SLOPE POS RT	-22.249	-41.987	-49.600	-38.830
XZ SLOPE MED RT	-43.059	-40.795	-43.668	-45.630
XZ SLOPE ANT RT	0.000	0.000	0.000	0.000
XZ SLOPE POS LT	45.000	48.013	48.013	40.972
XZ SLOPE MED LT	52.524	47.305	57.609	39.806
XZ SLOPE ANT LT	0.000	0.000	0.000	0.000
YZ SLOPE POS RT	0.000	0.000	-3.434	0.000
YZ SLOPE MED RT	8.531	10.758	4.004	1.718
YZ SLOPE ANT RT	-50.194	-36.870	-56.310	-56.310
YZ SLOPE POS LT	-4.574	5.711	0.000	0.000
YZ SLOPE MED LT	-2.291	6.843	0.000	0.000
YZ SLOPE ANT LT	0.000	-59.036	-68.199	-60.255

Discussion

As a tool in biometrics, stereophotogrammetry is the science of producing a reliable digital representation of a scene by means of measurements taken from photographs of that scene. This method permits increased sophistication in data reduction by electronic computers leading to results of exceptional precision. The data acquired from a comprehensive analysis of casts, when interpreted in biologic terms, permits a better understanding of the natural history of all cleft palates. As mentioned earlier, the added information can be used in deciphering the mechanism which determines success or failure of the rehabilitative process.

Huddart (*4, 5*) and Mazaheri (*6*) developed techniques to study changes in linear dimensions and arch form by the use of electrostatic photocopiers which graphically reproduced the form of the cast. Mazaheri made his linear measurements directly from the graphic representation. Huddart (*5*), in 1971, was able to improve on the analysis of the technique by con-

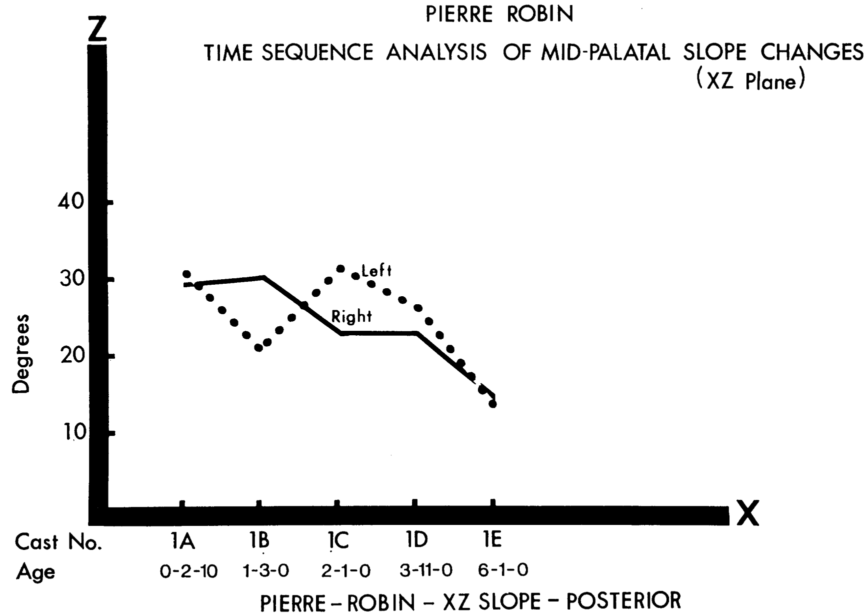

FIGURE 9. The posterior border of the hard palate becomes progressively flatter with time.

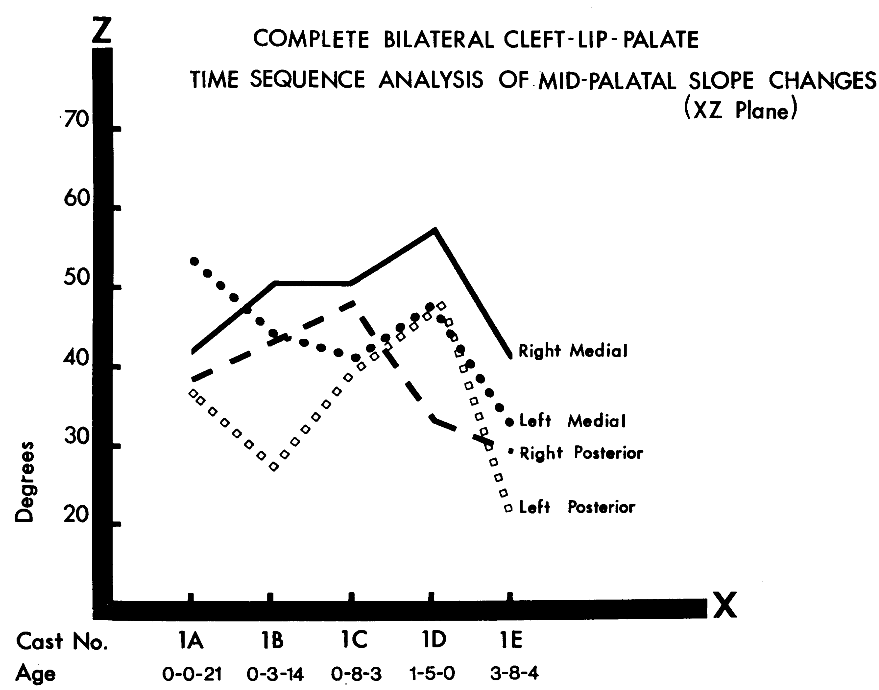

FIGURE 10. No definite order of behavior appears between XZ slopes of both palatal segments. The best one can say is that the arches tend to become flatter with time.

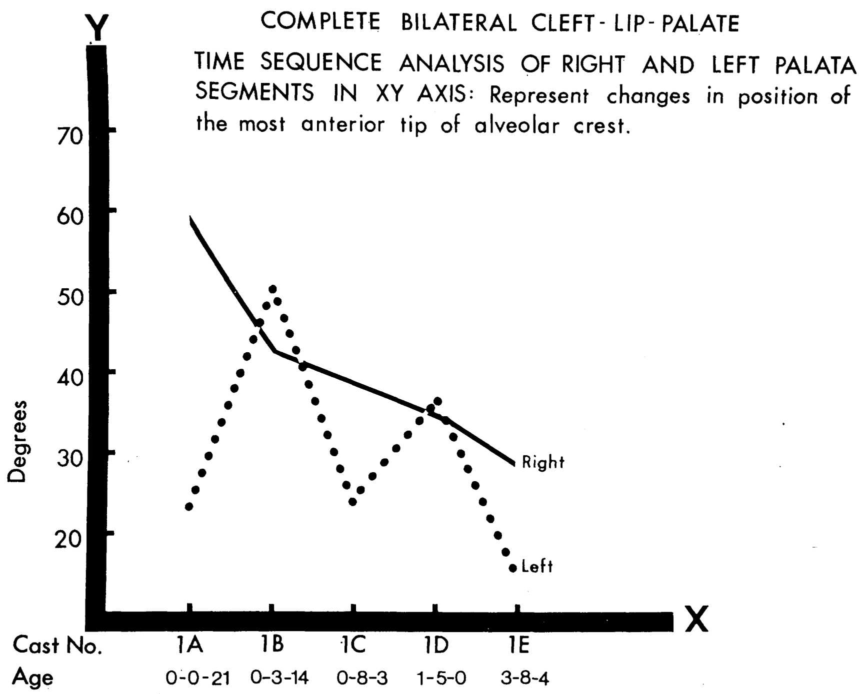

FIGURE 11. The behavior of the left palatal segment appears to be more erratic than that of the right segment. This may reflect on the closure of the lip in two stages with the left side being closed first. Both anterior points of each palatal segment became more medially located with the right segment tipping the most.

verting the diagram obtained from the photocopier of XY coordinates (a 2-dimensional representation) on paper tape. This tape could then be fed into an electronic computer for analysis. He states that this is a reliable system for recording linear dimensions between selected landmarks. His test for reliability is the reproducibility of the measurements using the same techniques. Huddart, in still an earlier article (*4*), advocated the use of the photocopying technique to measure surface areas as well as do linear measurements. He made extensive comparisons between surface area measurements of bilateral, unilateral and normal palates as taken from photocopies.

His conclusions relating to surface area between cleft types may be erroneous because it is impossible, with geometric safety, to translate a 3-dimensional object to a 2-dimensional surface representation without suffering errors due to projections and a significant loss of information. There is always significant foreshortening of the image when this translating is done. The amount of tissue lost in projection is directly related to the steepness of the slopes of the palatal segments. The steeper the slope, the greater the error in calculation. This was recorded in all of our cases when 2D and 3D findings were compared. In some cases the error was as great

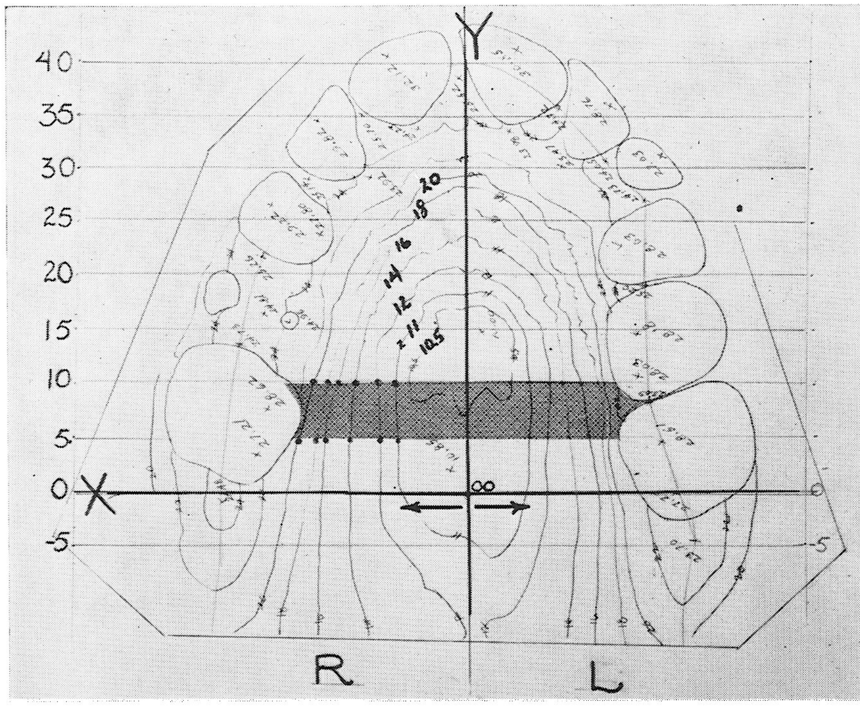

FIGURE 12. The palatal contour is divided into equal sections along the Y axis. Each section bisects contour lines and creates coordinate points which are recorded and stored for use by the computer. Each point has 3 values (in the X, Y and Z axis). 00 point is the location on the X axis at the bisector point with the Y axis.

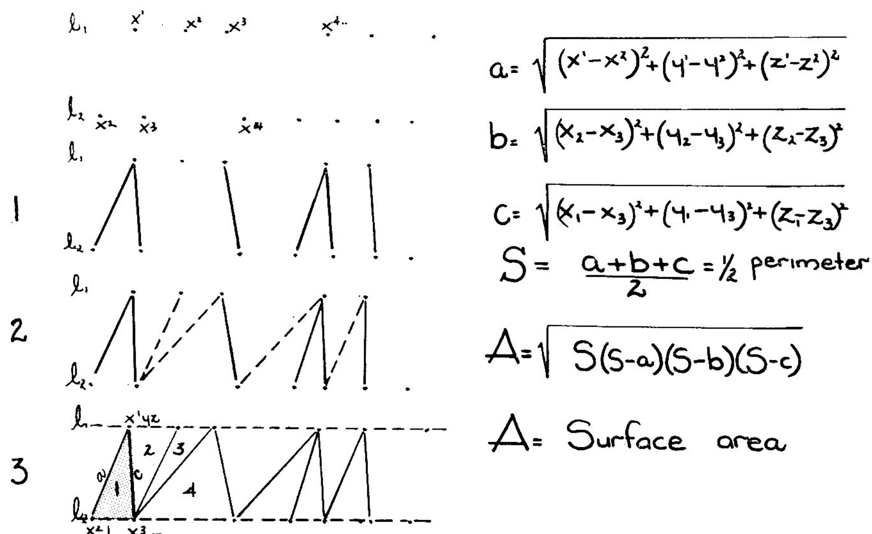

FIGURE 13. The computer is programmed to separate the coordinate points and then connect the points in such a fashion as to create continuous triangles within each section. By knowing the location of each point in the X, Y and Z axis, the lengths of each triangular leg can be calculated. The surface area of each section is determined and then all surface area measurements of the remaining sections are totaled. The accuracy of this method is related to the number of Coordinate Points that are chosen. They in turn determine the size and number of triangles used in computation.

as 20–30%. The only time a normal palate was compared to a cleft palate was in the *Dizygotic Twin Study*. A 10% difference in surface area was found to exist between 2D and 3D measurements of the normal palate. This can be compared to a difference in 2D to 3D measurements of more than 30% in surface area of the unilateral cleft palate. Since the 3D surface areas in both cases are almost identical, one could suppose that there is no tissue deficiency in the cleft palate. An opposite conclusion would have been reached if one used 2D measurements alone.

Huddart may have been correct in selecting the posterior arch slope to be on the line passing between Sillman's right and left point (P_1–P_2) to depict the inclination of the palatal segments. This line corresponds to the posterior limit of the hard palate and connects PTM of right and left sides. In this study, the slope drawn through the middle of the palatal segments does not correspond to the slope found on line P_1–P_2. It still has to be determined which of the two areas more accurately reflects the true slope characteristics of the palatal segments. In this study we used both areas for slope determination but in a future study, using a larger sample, we will try to determine whether it is necessary to consider one or both in describing the geometrical characteristics of the palatal segments.

As in a previous study, we have again demonstrated that the differences in the *absolute* and *relative lengths* of the palatal segments reflect on the inclinations of each segment in the XY axis. The greater the inclination of palatal segment, the smaller their *relative lengths*.

It must be stressed that the Absolute Length is three dimensional and includes measurements in the vertical dimension (Z axis) as well as in the XY axis. The steeper the alveolar crest (the YZ slope) as one measures along the crest, the longer the *absolute length.*

Stockli (*7*) also used a photoelectric copier to analyze changes in arch form in a series of complete unilateral cleft lip and palate. He drew some interesting conclusions which we hope to test in our more complete second study which will follow. He stated that no clinical correlation could be found between preoperative arch form and arch form of the postoperative phase. He concluded that the configuration of initial arch form proved to be a poor prognostic criterion for predicting arch form development. Perhaps the difficulty in predicting the final arch form results from the limitation of the measuring systems employed and the parameters included.

We fully support his statement that a 2-dimensional measuring system is limited and cannot be classified as a comprehensive measuring system for the gathering of all information needed to explain the special relationship of the palatal segments in the region of the alveolar cleft.

Pruzansky and Aduss (*8*) have defined a number of variables, not visible in the casts alone, which can influence arch form.

Time Sequences Studies. Many of the linear or surface area dimensional changes must be considered in relation to changing geometric form. Small or no change in linear lengths or distances between points over a period of time may be misleading when considered in isolation but meaningful when related to the changes in size and shape of the palatal arch. This was already discussed in the Pierre Robin series when it was observed that the cleft space area does not change significantly but its shape does.

The second cast of the bilateral cleft lip and palate series, which represents the first stage of a two step lip closure procedure, shows that the anterior and posterior cleft dimensions and cleft space area actually increase. This needs to be related to a 15% increase in total palatal surface area. After the second side is closed and the lip is completely reunited the anterior and posterior cleft space widths are greatly reduced by the medial movement of both palatal segments. This results in a smaller anterior and posterior cleft dimension and an approximately 35% decrease in cleft space area. The total surface area of the hard palate increased approximately 10% during this same time. Between eight months and one year of age the cleft space area decreased by 25% while the surface area of the hard tissue increased by 60%. Between the age of one and three years the cleft space was further reduced by 15–20% while the total hard tissue surface area increases 12–15%. The *Time Sequence Analysis* reveals that the hard tissue increased the first year by 60% and by three years of age the total surface area increase was 80% over its original size. During this period of time the cleft space decreased 40%. The reduction in cleft space is due to both the medial movement of the palatal shelves and the increase in hard tissue as a result of growth.

It has been suggested by Coupe, and Subtelny (*9*), who used cephalometric laminagraphy, that patients with bilateral clefts of the palate tended to show distinctly the greatest degree of deficiency when compared to the other classes of cleft palates. These conclusions will be tested in a future study when a greater number of serial cases will be analyzed. This conclusion has important treatment implications and deserves clarification and verification.

Degree of Curvature. The most difficult problem in recording changes in palatal arch form was solved by determining its *Degree of Curvature*. The *Degree of Curvature* summarizes the two perimeter measurements: *Absolute length* and *posterior width* (P_1–P_2) To describe the shape of a parabola (assuming that arches take this form) it is necessary to determine its *focus*. The arch length of the parabola is equal to the sum of the absolute lengths of the palatal segments as measured along the alveolar crest. (See Fig. 5.) Since a parabola is the locus of points (a set of points) drawn equidistant from a focus point and another line, the focus point and its vertex are directly related and dependent. The *Vertex* of a parabola is defined as being its highest point.

The *degree of curvature* is a by-product of the perimeter lengths which create the arch form, and represents the distance from the *Focus* of the parabola to the *Vertex*. As the distance (degree of curvature) between the

Vertex and the *focus* gets smaller it implies that the parabola is more ovoid in shape. Conversely, as the degree of curvature increases in length it reflects on the parabola becoming more tapered.

The *fitted relative length* is the shortest distance from the base line to the Vertex of that curve. This measure best describes the changes between posterior arch width and the absolute antero-posterior palatal dimension and therefore, reflects on changes in arch form caused by palatal growth and closure of the cleft space by medial movement of the palatal segments.

The Significance of the Fitted Relative Lengths. In most instances this measurement will be less than the absolute lengths and greater than the *relative* lengths. Should the *Fitted Relative Length* be less than the *Absolute* and *Relative lengths,* the palatal width (P_1–P_2) must be excessively wide. In the bilateral cleft lip and palate series, ages 0-0-21, 0-3-14 and 0-8-3 show a smaller fitted relative length, however, it gets progressively larger. From ages 1-5-0 to 3-8-4 it increases greatly and falls between the other two measures as one would ordinarily expect.

Computerized Determination of Palate Surface Area (Figures 12, and 13). A point on a three dimensional surface can be located by knowing its position in three frames of space designated by the X, Y and Z axis. The X axis is perpendicular to the other two axis and locates points in the vertical dimension. Stereophotogrammetry can determine X, Y and Z co-ordinates for hundreds of points on the palate surface. The surface area was divided into measured strips on the XY axis. The co-ordinate points which compose the outline of the strip are used to triangulate the strip. The surface area of each triangle is computed and then the total areas of each strip are added together. This method has been tested for accuracy and has been found to be extremely reliable. The greater the number of points and the closer the points, the more triangles will be formed and the smaller each triangle will be. Thus, each triangle will more truly reflect the surface contour that it describes. A computer is absolutely necessary to use the method of triangulation for surface area determination even for a medium sized experiment, since approximately 150 points have been selected for each palatal segment.

Geometrical analysis using stereophotogrammetric techniques has definitely uncovered information that, heretofore, has gone undetected and unappreciated. How this information can best be used and what diagnostic significance it may possess still needs to be determined. A larger study, using over 800 casts, will be soon completed and it is anticipated that a clearer insight into palatal development will result from a more comprehensive examination of surface anatomy.

An additional by-product that can be anticipated is the revision of the system by which clefts are classified. The present cleft palate classification system is based on the location and extent of clefting through the lip, alveolus and palate. Despite its utility, it still falls far short as a comprehensive classification in that it tells nothing about the great variations in geometrical form that exists within even similarly classified clefts. Since Friede and Pruzansky (*11*), have demonstrated the significance in neonatal palatal form and size as a predictor for future palatal growth and development, it then follows that geometric data should be used as part of a subclassification system within specific cleft types. Anatomical variation needs to be extended still further by relating differences in form observed in infancy to future palatal growth and development, and by correlating it to the type and timing of surgical repair. Only in this manner can the concept of individualized treatment planning be more fully realized in clinical practice.

Summary

Analytical stereophotogrammetry permits a comprehensive three-dimensional study of the anatomy and changing form of cleft palate casts. The extrapolated data (reliable digital representation of a scene) are amenable to mathematical analysis and permit insight into geometrical changes in form and mass of the palate that occur as a reflection of growth and treatment. The resulting data provided a more comprehensive description of developmental changes that occur in different types of cleft palates.

Determination of a surface area measurement and some linear dimensions from 2-dimensional projections were shown to be unreliable because of the distortion of the projected image. Conclusions drawn from linear dimensional changes alone, without considering the slopes of the palatal segments can be erroneous and misleading.

The Degree of Curvature and Fitted Relative Length are two excellent measures for describing changes in arch form.

The spectrum of structural variation, even within a single cleft type, has been shown to be considerable. Such variability needs to be related to clinical decisions and in the evaluation of treatment.

Acknowledgements: Glenn Claybough Ph.D. and Mr. Larry Elliot, representatives of Mead Johnson Laboratories, for their support and encouragement.

Sheldon Axler Ph.D., Princeton University, for writing computer programs to determine surface area measurements.

Elmore Kerkela, who provided the technical design assistance and supervision in taking the stereophotographs and having the contours performed to specification.

Robin Herron Ph.D., Biosteriometrics Laboratory, Baylor College of Medicine.

References

1. BERKOWITZ, S., and PRUZANSKY, A., Stereophotogrammetry of serial casts of cleft palate, *Angle Orthodont. 38*, 136–149, 1968.
2. BERKOWITZ, S., Stereophotogrammetric Analysis of casts of normal and abnormal palates, *Amer. J. Orthodont. 60,* 1–18, 1971.

3. HUDDART, A. G., Maxillary arch dimensions in bilateral cleft lip and palate subjects, *Cleft Palate J. 7*, 139–155, 1970.
4. HUDDART, A. G., The application of computers to the study of maxillary arch dimensions, *British Dental J. 130*, 397–404, 1971.
5. MAZAHERI, M., HARDING, R. L., COOPER, J. A., MEIRER, J. A., and JONES, T. S., Changes in arch form and dimensions of cleft patients, *Amer. J. Orthodont. 60*, 19–32, 1971.
6. STOCKLI, P. W., Application of a quantitative method for arch form evaluation in complete unilateral cleft lip and palate, *Cleft Palate J. 8*, 322–341, 1971.
7. PRUZANSKY, S., and ADUSS, H., Prevalence of Arch Collapse and Malocclusion in complete unilateral cleft lip and palate, *Trans. of the European Orthod. Soc.*, 1–16, Nov. 1967.
8. COUPE, T. B., and SUBTELNY, J. D., Cleft palate deficiency or displacement of tissue, *Plastic reconstr. Surg., 26*, 600–612, 1960.
9. KRISCHER, J. P., BERKOWITZ, S., and PRUZANSKY, S., The Cleft Palate; An analysis of features for pattern recognition, In Press.
10. HERRON, R. E., Stereophotogrammetry, in biology and medicine, *Photographic Applications in Science, Technology and Medicine, 5*, 26–35, 1970.
11. FRIEDE, H., and PRUZANSKY, S., Longitudinal study of growth of bilateral cleft lip and palate from infancy to adolescence, *Plastic reconstr. Surg., 49*, 392–403, 1972.