A FUNCTIONAL THREE DIMENSIONAL CEPHALOMETRIC IMPLANT METHOD

Claude E. Quinio, D.F.M.P.

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"You don't know your friends, until you're in trouble"

French saying.

I wish to express my grateful thanks to:

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INTRODUCTION

As part of a continuing effort to improve our knowledge of the effects of orthodontic treatment, it would be desirable to have a long-term (five to ten year) evaluation of results after all retention appliances have been removed. In fact, even if adequate conventional records have been obtained, one is limited in the ability to separate treatment results from growth changes. One portion of the problem is the lack of stable anatomical landmarks, and another is the measurement error of points or landmarks which are selected.

Bjork's[1] development of the use of implants in patients and the resulting contribution to knowledge is possibly the single greatest advance in orthodontics. However, as Sarnat[2] stated, "the limitations (of the method) are the local reactions to implants and an insufficience of the three-dimensional information." His statement encompasses the following problems:

1. Local reaction may affect the stability of the implants. (Some aspects of this problem are currently being explored at the

University of Oregon Dental School.)

2. Two-dimensional radiographs of three-dimensional patients result in much distortion and measurement error, especially when measuring between landmarks not lying on the mid-sagittal plane.

3. Variability of head positioning results in successive films not always superimposing on the implants (Mc Donald[3]). This variability in long-term studies will result both from "operator variability," and from the fact that orthodontic patients normally keep growing. The problem of repositioning was solved by Bjork, using an x-ray cephalostat with a built-in image intensifier that permits television monitoring of the implants and, thereby, proper patient positioning before exposing the film. Schwartz,[4] Savara,[5] and Dahan[6] each described different three-dimensional cephalometric techniques. One common feature of their method is the use of two films, a possible source of introduced error.

A different method was subsequently investigated which included use of implants, simultaneous double-exposure (from two x-ray machines) on a single film, and permitted definition of the position of these implants within a three-dimensional coordinate system. The concept was elaborated by Sorenson and Hixon,* and the validity and reliability of the proposed method were experimentally investigated by Nixon and Cruikshank.[7] Their work was based on trigonometric solutions utilizing measurements taken from the double-exposed film and on known physical location and orientation of the x-ray machines to each other and to the film. While their concept seemed quite promising, the results obtained by Nixon and Cruikshank were inconclusive.

The primary obstacle in their work was the lack of an efficient method of handling the data contained on the film. The laborious computations required severely limited Nixon and Cruikshank's ability to adequately determine the precision obtainable by the proposed method. For the same reasons, the two investigators were not able to conclusively demonstrate whether or not the method would be feasible for accounting for patient orientation changes between subsequent films.

It was felt that if a valid method could be developed for measuring changes in landmark position between subsequent films using equipment

* Conversations at the University of Oregon Dental School 1968-1971.

readily available in most dental schools, and if an efficient data retrieval and processing system of high reliability were available, then a practical alternative to Bjork's system would be at hand. An additional advantage of the new system would be the ability to represent changes in a three-coordinate system. Our approach to the problem was as follows:

1. Reconstruct and test the basic instrumentation set-up utilized by Nixon and Cruikshank (positional relationships of the x-ray machines to the film and to each other).

2. Prepare appropriate computer programs so that data collected from the system could be surely and easily handled by the computer.

3. Construct and use an "implant phantom" for evaluating the capability of the system in vitro, especially in terms of its potential for use under expected typical clinical situations where repositioning of the patient on subsequent examination appointments would be a factor.

4. Evaluate the capabilities of the method in terms of our ability to detect and measure the direction and movement of a marker or implant in relation to three fixed implants under conditions of phantom placement variation, which would be analogous to variations expected to be encountered

in clinical situations.

REVIEW OF LITERATURE

When standardized x-ray cephalometrics were introduced by Hofrath (1931) and Broadbent (1931) (Sarnas[9]), it was recognized as the Rosetta stone for the "new" orthodontics. Some in other fields, remaining loyal to classic craniometry, rejected its great potential, but it quickly became a stimulating investigative tool for most researchers in orthodontics. As noted by Hixon, their initial optimism has given way to some reservations. In the effort to perfect the method, a great variety of research projects have been undertaken, in most cases without satisfactory results. However, no contribution, however slight it might seem, should be disregarded. An initial false start might be the catalyst enabling another researcher to solve the problem.

Several researchers have devised useful improvement in the x-ray techniques of making cephalometric measurements. In order to reduce radiation hazards, Cohen and Hammond[10] suggested that the useful beam of x-rays emerging from the tube be limited near the source by a 2 mm.

thick lead diaphragm. Further, Franklin[11] recommended the introduction of a cylinder to obtain a more precise reduction of the exposed area. This not only lessened the amount of the patient's radiation exposure but improved the sharpness of the image by reducing the secondary radiation. Thurow[12] and Hixon[13] in extensive presentations, solved other technical problems such as optical blurring and choice of screen.

Of particular interest is that relating to the development of techniques for three-dimensional cephalometrics. The primary concern was material which would prove helpful in regard to the location on the film of the origin of the coordinates axes. This point had to be where that ray from the focal spot of the x-ray tube which is normal to the plane of the x-ray film intersects the plane of the film. Moffit[14] described an extremely interesting approach to that problem in a report based on a joint study by himself and Baumrind. They called this spot the "principal point," and they determined its position by the intersection of four lines produced by the images of four wires contained in four plastic studs positioned in each corner of a lucite base plate precisely parallel to the plane of the film. Those studs were themselves perpendicular to the plane of the base.

Another major problem in three-dimensional cephalometrics has been the enlargement and distortion inherent to the reproduction on a plane of a three-dimensional object. This subject was treated comprehensively by Hixon.[12] Savara[5] described a technique for measurement of anatomically accurate landmarks. His method required location of each landmark on both frontal and lateral films and the calculation of three-coordinate values for each. The coordinates were corrected for enlargement and thus the distance between two landmarks, derived by a distance formula utilizing corrected values, was free from distortion. Savara, Miller and Singh[15] dealt with the analysis of errors in cephalometric measurement of three-dimensional distances of the maxilla, using trigonometric methods and computer facilities.

An aspect of cephalometrics which has proved perennially troublesome has been the difficulty of comparing two films of the same patient at different periods of time. The literature was extremely prolific on this issue. The great number of reference planes, lines, and angles described and suggested was not surprising when it is admitted that there is no such thing as a fixed point in a growing organism. The difficulty of repositioning the patient identically in successive films, even with the most sophisticated cephalometer, as well as the lack of stability of anatomical landmarks in growing children, explain the imprecision of the conventional comparative methods. The degree of reliability of natural landmarks has been thoroughly investigated by Baumrind,[16] and, as an example, he stated that the standard deviation for total error in locating nasion was the surprising amount of 1.46 mm. Herren[17] filled the "meati acustici externi" with an x-ray contrast medium which is non-toxic and resorbable and measured the bitympanal distance on a frontal film. He had a sample of 30 cases, and series of "photographs" were taken at intervals. The standard deviation of the measure was .46 (unit not specified). Herren soberly declared it clear that this bitympanal distance was the most accurate measurable basis of reference so far obtained in a headplate! In an article on bone-level determination of edentulous jaws, Kaaber[18] described a cephalostat equipped with inflexible ear rests and adjustable nose, neck, and chin rest, making a given position reproduceable. Individual acrylic ear plugs and bite plates were used as supplementary stabilizing equipment and a standardized radiographic technique was employed. His results are very accurate, but the age of his patients eliminated the factor of change due to growth. Further comment on the limited usefulness of Kaaber's work comes from Steiner[19] reporting an experiment showing that patients <u>can</u> move in relationship to the ear posts when successive pictures are taken within a matter of minutes of each other. In that experiment, the patient was not removed from the head holder nor were the adjustments changed.

In contrast to the proponents of rigid positioning described above, Mills[20] applied a grid method (using the image of a plumb line on the film) to the concept of "a natural head position," in an attempt to achieve a reproducible position. Since it is well-known that the natural head position is a naturally unstable reference, Mills did not have a great deal of success.

Garn[21] summarized the discouraging challenge to cephalometrics: all of its researchers thus far, while energetically measuring relationships of landmarks, had failed to identify any truly unchanging reference point from which to measure. "The stability of lines of references is extraordinarily difficult to prove in a growing system but it is possible to measure change of one line to another. No reference to a change is acceptable without the base from which measurements are made. It must be recognized that this base of reference may also have undergone change."

In summary, we would agree with Garn that stable reference points have not yet been described and the location of such a reference base would be a worthy objective.

MATERIALS AND METHODS

Two x-ray machines were used in this study. Both were capable of developing over 90 kvp. at 50 milliamperes. They were positioned so that their emissions crossed each other in the region of the patient's face (between the ear posts) to give two images falling on a routine size 10 x 12 inch film. In order to compute by triangulation the distance between implants utilizing measurements taken from the radiographs, it was necessary to know precisely the distances between the sources of the x-ray and the film, and between the two x-ray sources. For future convenience, these potential variables were made constant by permanently fixing the x-ray emitters so that their position could not accidentally be changed throughout subsequent testings. The head holder served only to approximately position the patient and therefore did not need to be rigidly fixed. To facilitate the mathematical derivations, the film was assumed to lie in the vertical plane; the first verification tended to confirm this assumption. The point on the surface of the film hit by the ray which pierces it at right angles was arbitrarily chosen as being the origin of the Cartesian system of coordinates. The equipment (Fig. 1) was set up to insure that this ray would pass approximately through the middle of the ear posts. These two criteria partially indicated where to locate the first emitter. Its distance from the film was selected so that the image of the part of the head it formed did not cover more than 2/5ths of the film area. This made possible the conventional skeletal and soft tissue tracings. The position of the second emitter was estimated from a scale draft which indicated that the main beam should form an angle of approximately 30 degrees with that of the first emitter, and that both beams should define a plane almost horizontal. The precise location of this machine had to satisfy the two following requirements:

1. The image had to represent at least all the implants plus those anatomical features which one might be interested in studying. (Proper collimating of the diaphrams were set up to take care of unnecessary exposure.)

2. A theoretical line joining its focal spot to the focal spot of

the first emitter had to be parallel to the surface of the film. (The fulfillment of this condition determined the correct distance of the second machine from the film.) Then, two lines traced on the film and joining the double images of two very small metallic spheres (one mm. diameter) placed in a random manner between the ear posts showed that they were parallel to each other (Fig. 2 line AB//A'B'//EE').

A line parallel to those mentioned above, and passing through the point which was previously selected as the origin of the axes of coordinates, designated the "X" axis of the coordinates. The "Y" axis was then constructed by making a line having a 90° angle with the "X" axis and lying in the vertical plane. To reduce the amount of error when positioning the second machine, it was important to place the small metallic spheres as far from the film as possible so that the double image formed would be the maximum width apart that the film size permits. During the trials which pertained to the preceding adjustments, the angulation of the beam was kept constant when moving the emitter towards or away from the film. A new component was added to the original apparatus. It consisted of a grid made of two .016 diameter wires intersecting at right angles and fixed in front of and as close as possible to the cassette. The cross point was placed so that its image coincided with the point chosen to be the origin of the system of coordinates, and one of the wires was placed parallel to the line joining the images of the small metallic spheres. These crosswires thus formed an image which represented the "X" and "Y" axes on the film. The "Z" axis was identified as that which was perpendicular to the "X" and "Y" axes at their cross point, which meant that it coincided with the central ray of the emitter.

The focal spot was not a point source of x-ray's emission, and the ensueing blurring effect could not be ignored. For example, it proved very difficult to reliably measure the length of a piece of wire from its image on a radiograph, due to the blurred image of its extremities. However, the measurement of a distance limited by two spherical balls was more easily and more precisely made as the ability to locate the center of the image of a spherical object was insignificantly affected by the blurring; therefore, it is most desirable to utilize spherical implants in systems such as this.

The programmable desk calculator used was a "Monroe 1655" (Fig. 3).

For each implant, three measurements were taken on the film which showed the image of the crosswires ("X" and "Y" axes of coordinates) and the double image of each implant. Added to these measurements was a fourth parameter which was the difference between two of them. These four values were:

1. The distance from the image of the implant given by one of the emitters to the "Y" (vertical) axis. This distance was called "a."

2. The distance from the image of the same implant given by the second emitter to the "Y" axis. This distance was called "b."

3. The distance between both images. This was called "c." Without measurement, error "c" would be equal to"a"minus "b."

4. The distance of either of the two images to the "X" (horizontal) axis. As previously mentioned, both images were equally distant from this axis. This distance was called "d" (Fig. 4).

These four values "a," "b," "c," and "d" constituted the input of our program (Fig. 5). The output was the coordinate values "X," "Y," and "Z" of the considered implant. The capacity of the calculator was not large enough to incorporate the small program which processed the coordinates of each implant and displayed the distances between any two of them. This computation had to be done with a separate program, but the simplicity of the distance formula did not formally require programming. The decision to use it or not depended on the number of films to be analyzed. The comparison of two subsequent films consisted of a trial superimposing one film's set of several implants onto a set of homologous implants in another film. A rather complicated mathematical procedure was developed to achieve this transfer and consequently evaluate the movement or lack of movement of some landmark. The comparison of two films required such an amount of time (even with the help of the electronic desk calculator) that a computerized solution appeared to be necessary for any practical research.

The input consisted of the coordinates of four implants or of three implants plus that of a marker, and the output indicated how closely the implants of one film superimposed on the homologous implants of another film, or the degree of movement of the marker.

The plastic "implant phantom" (Fig. 6) was a triangular plate of rigid plexiglass into which were superficially inserted three small metallic spheres (one mm. diameter) forming triangle. The sides of the triangle were 49.75 mm., 42.30 mm., and 51.50 mm. Inside the triangle was a fourth implant called marker No. 4, or "i," placed near the geometric center of the triangle, and a fifth marker "I" that was outside the area of the triangle and was made up of a wire that extended above the plane of the plexiglass.

The base of the plexiglass triangle was prolonged by two extensions lying in the same plane and supporting two perpendicular parts which could be compared to the ears. They were used to position the phantom in the cephalostat and were designed so that several different orientations were possible. This phantom, as such, was used to obtain the following data: (a) to account for alteration in the patient's position in repeated exposures, and (b) to test for accuracy of superimposition of markers No. 4 and 5 on their homologues when the set of implants "A," "B," and "C" was mathematically superimposed on a homologous set in successive films. This was done by transposing the three implants to the same plane as the homologous implants, superimposing the geometric centers, and finally rotating the triangle until the implant "A" fell on a line connecting the homologous "A" to its geometric center.

RESULTS

Ten films were taken and the position of the model was deliberately altered with the exception of one duplication. With an experienced operator, the program written for the programmable electronic desk calculator Monroe 1655 handled the data from one film in approximately one and a half minutes while this computation, with the same calculator but without programming, took five hours.

The comparative "calculated" distances between implants, when both films were taken with the "phantom" in the same position, were as follows:

	BC:	BA:	AC:
1st film	51.429 mm.	49.373 mm.	42.113 mm.
2nd film	51.368 mm.	49.136 mm.	42.119 mm.
Difference	.061 mm.	.237 mm.	.006 mm.

The distances measured on the model were:

BC: 51.5 mm. BA: 49.75 mm. AC: 42.3 mm.

The averaged distances for the totality of the films were:

BC:	BA:	AC:
51.277 mm.	49.651 mm.	42.177 mm.
S.D.: .278	S.D.: .265	S.D.: .08

It was decided that these first results were sufficiently precise to carry on the second part of the experiment with the same values for the first emitter-film and the emitter-emitter distances which were 1609 mm. and 807.52 mm. In the discussion, it will be shown what magnitude of changes in the calculated distances between implants may result from a change in these distances. The second experiment consisted of a check of the superimposition method. The detailed results of these experiments and their statistical interpretation are the object of another paper.*

An additional experiment was run using a phantom which contained the same three implants plus one other which was located in two different positions in successive films (markers No. 6 and 7). It was thus possible to evaluate the precision of the transfer for two strictly identical sets

* Henry S. Dennis, Certificate Paper, University of Oregon Dental School, 1972.

of implants and, also, that of the computation of the amount of movement of one mobile marker by superimposition of a set of three stable implants. The direction and magnitude of movement of the marker relative to the three fixed implants was compared to the actual direction and distance the marker was moved. This experiment was an "essay of transposition method" and the computer facilities were not used. The difference between the calculated and the true displacement was .38 but the rationale was not accurate enough and a different derivation had to be set up for the computer program.

DISCUSSION

It is possible that comparable results could have been obtained using the Bolton-Broadbent equipment and the same phantom, but it seemed preferable, in a clinical situation, to use a single film, as there is always a question whether there is movement of the patient's head between the frontal and the lateral exposures. This movement is undesirable, as it is a possible cause of error in the calculation of the coordinate values. Moreover, a sophisticated cephalostat is thus not needed, and, instead, a very simple head holder can be used.

One cannot emphasize too strongly the anticipated advantage of having a fixed system of coordinate axes. This system eliminated the problem of identical repositioning of the patient in a head holder on subsequent visits. This, therefore, increased considerably the reliability of the comparison of two films taken at different times because it facilitated the mathematical superimposition of the implants from one film to another.

Theoretically, it was possible to transfer the values from one system of coordinates to another by traced axes of coordinates on each film. However, this would have required that the differences between the two systems be defined. This, in turn, would have led to very complicated calculations. Therefore, it was deemed preferable to utilize the fixed system of coordinates rather than to rely on a technique which required complicated calculation and which might contribute to unnecessary error.

If one does not want to depend on an identical repositioning in the head holder between successive films, he has to be aware that three implants might not be sufficient to be used as a reliable basis of reference for superimposition of two films. At the beginning of this study, the acceptance of Bjork's statement that implants inserted in appropriate regions have proved to be stable along with the possibilities offered by the computer, led to the attempt to superimpose a set of three implants onto a homologous set and, thereby, study the movement of some artificial landmark such as very small filling in a tooth. In fact, as the computation of the distance between implants is independent of the position of the head in the cephalostat it was important to consider that, with a set of three implants, it is at least possible that the movement of one of them within the bone might occur without changing its distance from the other two. Though such movement would, of course, alter the plane of the triangle formed by the implants, such an occurence could be mis-interpreted as a movement of the head in the cephalostat. The necessity to avoid this possible confusion implies that four implants should be used. Analyzing the possible movement of these implants within the bone requires an easy adaptation of the existing program of the computer based on the following rationale:

The geometric center of a triangle formed by three of the four implants is transferred mathematically to coincide with the geometric center of the triangle formed by the homologous implants of another film, then a double rotation will accomplish the best fit of the triangles in a common plane and the discrepancy between paired implants will be quantitated. These quantities are the output of the computer. The superposition will be considered acceptable or not according to the degree of accuracy required. By using four implants all in supposedly stable positions in a common bone, any change beyond measurement error in the fourth implant, over a period of time, would indicate that one of the four implants did move. It would not be easy to determine if it were the fourth implant or one of the three used as the reference triangle, but it would not make any difference, as the assumption would be shown to be in error.

When one considers only the calculation of the distance between implants, it is not particularly important to determine the true values of their coordinates, as a very small error of calibration of the film-emitter distance would affect each homologous coordinates by the same amount and consequently should not generate a significant difference in the computation of the implants were very far apart from each other. With the desk calculator program it is very easy to evaluate how the results vary when constants such as emitter-film and emitter-emitter distances are modified. Using 1625 mm. instead of 1609 mm. as focal spot-film distance and 812 mm. instead of 807.52 mm. for the target-target distance the following results were obtained:

BC: 51.7936 mm. BA: 50.0696 mm. AC: 42.1605 mm.

whereas, for the film with the original constants, the values are:

	BC: 51.5920 mm.	BA: 49.6845 mm.	AC: 42.1069 mm.
differences:	.2016 mm.	.3851 mm.	.0536 mm.

The statistical interpretation of these figures is not the purpose of this study, but it must be emphasized that the precision of the method could be increased without much difficulty. A better reading of the films and a much more refined image of the "X" and "Y" axes could be very easily obtained. A better location of the origin of the coordinates axes added to a more precise calculation of the emitter-film and emitter-emitter distances should contribute without much difficulty to reduce significantly the errors.

CONCLUSIONS

The principal goal of this study was to verify the feasibility, validity, and the reliability of a radiographic method set up to define the position of implants in a three-dimensional system of coordinates. More specifically, the ability to measure the real distance between any two of a set of implants was anticipated irrespective of the patient's head in a cephalostat. Once these objectives were attained, the evaluation of the movement of the implants in bones through time became possible. The results were encouraging. As far as the feasibility is concerned, it has been demonstrated that this method did not require sophisticated or costly equipment and that its utilization was not limited to specially trained operators. Any dental school running a research program with implanted patients can set up this equipment very easily. The validity of the method is closely tied to that of the use of implants, because the first concern, when implanting patients, should be to have the proper tools to check the stability of these implants. It is doubtful if any two-dimensional method can give the same quality and the same quantity of information as this. Another positive result lies in eliminating the need to depend on identical repositioning of the patient during successive exposures. The reliability study done by Henry S. Dennis* showed that this equipment and the method it permits compares favorably with other three-dimensional methods. It seemed important to emphasize that the main factor contributing to this reliability was the decision to stay away from any kind of craniostat for identical repositioning of patient between successive films; indeed such trial appeared to be not only unnecessary but even not feasible.

It has been explained how it is possible to determine accurately whether or not implants are stable and it seems that the future development of this study could be to test this stability in a clinical situation. Every time implants prove to be stable they constitute a valuable reference basis to evaluate the movement of any markers fixed to the teeth permanently or adaptable to them in an exactly repeatable manner. It should not be very difficult to study the movement of apices, the center

* University of Oregon Dental School

of rotation of the teeth, the effect of head gear on molars, and the respective contribution of the upper and lower teeth to the relapse of overbite, as well as the effect of a bite plane.

SUMMARY

Equipment to measure distances between implants has been described. It consisted of two emitters, the main beams of which form an angle of approximately 30 degrees and intersect in the region of the patient's face. Two images were obtained on a single 10 x 12 inch film. The position of each implant was expressed in "X," "Y," and "Z" values in a fixed Cartesian system of coordinates which made it easy to derive the distances between any pair of implants of the same film. A computerized program was designed which expresses these values in a common coordinate system so that the position of implants can be compared in subsequent films.

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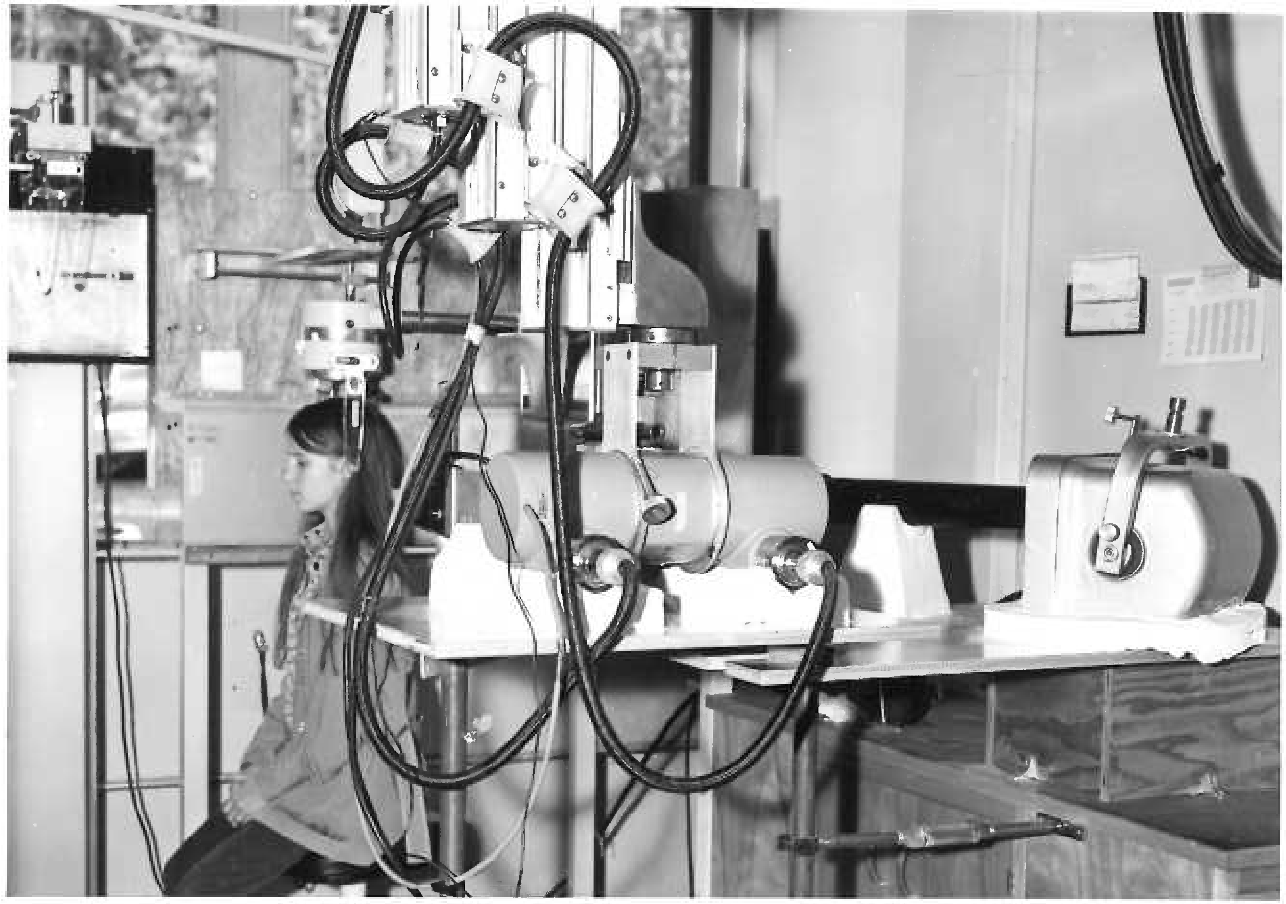

Fig. 1 X-ray Set-up

a) Both x-ray machines and their permanent fixation.
b) Head holder not vertically adjustable.
c) Patient seated on an adjustable stool.

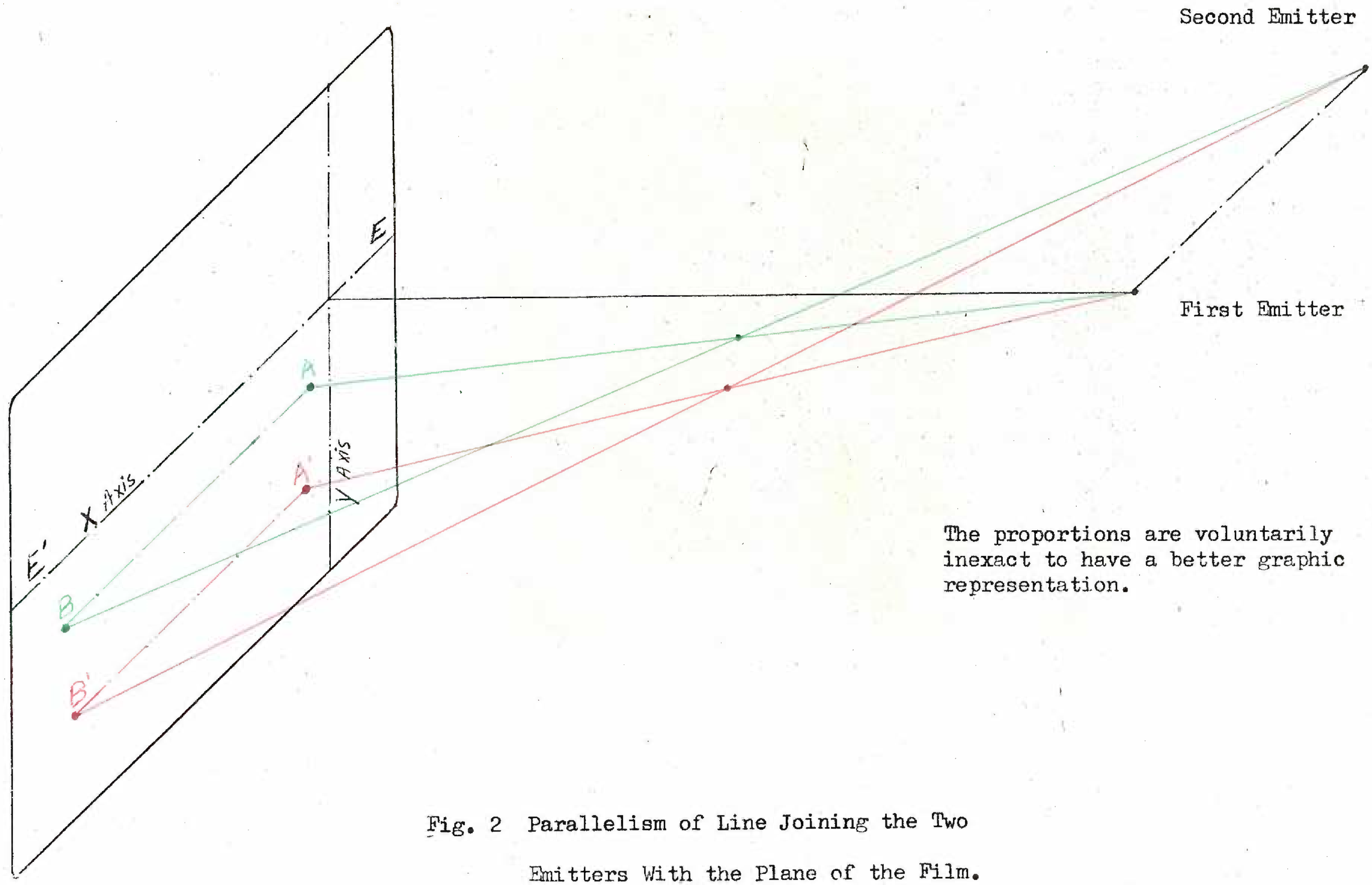

Fig. 2 Parallelism of Line Joining the Two Emitters With the Plane of the Film.

Fig. 3 Programmable Desk Calculator Monroe 1655

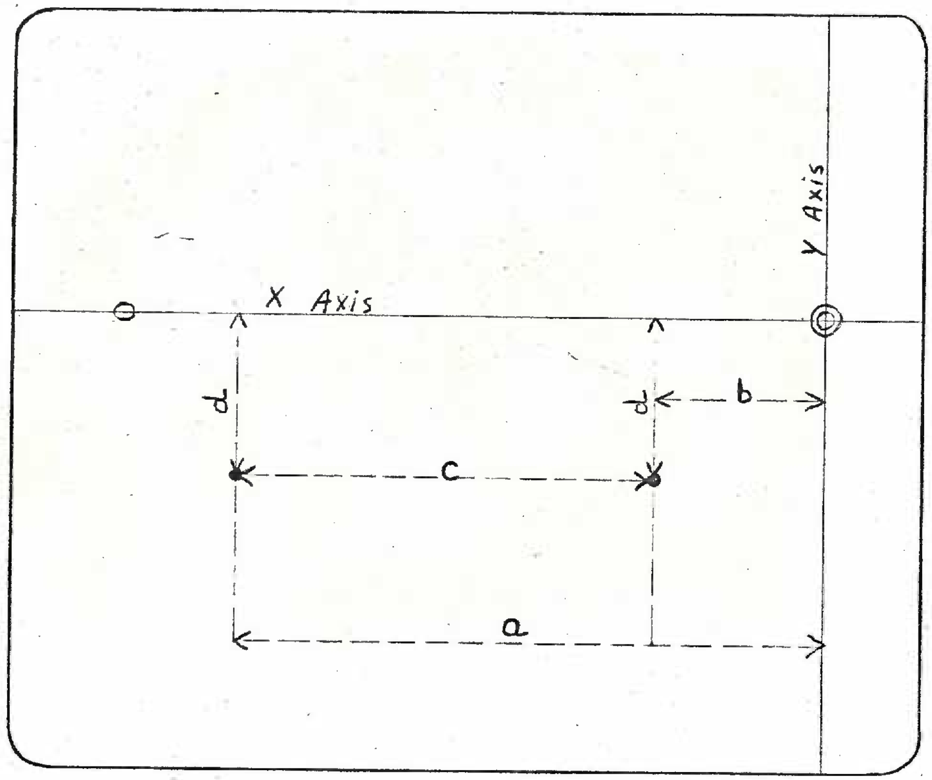

Fig. 4 Schematic Drawing of a Film Showing "a" "b" "c" "d", Input of the Computer

PROGRAM

NO. ________ PAGE ____ OF ____

DATE ________ MODEL ________

Branch Point	ADDRESS (P COUNT)	COMMAND	CODE	REMARKS
0	000	8	010	
	001	0	000	
	002	7	007	
	003	.	012	
	004	5	005	
	005	2	002	
	006	↓( )	025	
	007	0	000	
	010	+	060	
	011	HALT	401	
	012	↓( )	025	
	013	7	007	
	014	=	020	
	015	1/X	054	
	016	×	070	
	017	1	001	
1	020	6	006	
	021	0	000	
	022	9	011	
	023	↓( )	025	
	024	1	001	
	025	×	070	
	026	↑( )	031	
	027	7	007	
	030	[illegible]	076	
	031	↑( )	031	
	032	7	007	
	033	=	020	
	034	R→°	046	
	035	↓( )	025	
	036	2	002	
	037	SIN/COS	040	

MONROE

THE CALCULATOR COMPANY
A DIVISION OF LITTON INDUSTRIES

1498-S

Programmed by ________

Fig. 5 Program

PROGRAM

NO.________ PAGE ____ OF ____

DATE ________ MODEL ________

Branch Point	ADDRESS (P COUNT)	COMMAND	CODE	E	A	M	0	1	2	3	4	5	6	7	8	9
				REMARKS												
2	040	2ND FUNC	036													
	041	↓( )	025													
	042	3	003													
	043	↑( )	031													
	044	1	001													
	045	∠	076													
	046	HALT	401													
	047	=	021													
	050	R→°	046													
	051	↓( )	025													
	052	4	004													
	053	SIN/COS	040													
	054	÷	072													
	055	2ND FUNC	036													
	056	↓( )	025													
	057	5	005													
3	060	=	020													
	061	↓( )	025													
	062	6	006													
	063	↑( )	036													
	064	2	002													
	065	—	062													
	066	↑	031													
	067	4	004													
	070	=	020													
	071	SIN/COS	040													
	072	1/X	054													
	073	×	070													
	074	HALT	401													
	075	×	060													
	076	↑( )	031													
	077	3	003													

Programmed by ________

Fig. 5 Program

PROGRAM

NO. ______ PAGE ___ OF ___

DATE ______ MODEL ______

Branch Point	ADDRESS (P COUNT)	COMMAND	CODE	REMARKS
4	1 0 0	×	0 7 0	TO EXECUTE THE PROGRAM:
	1 0 1	1( )	0 3 1	
	1 0 2	5	0 0 5	RELEASE SWITCH "LOAD"
	1 0 3	=	0 2 0	
	1 0 4	HALT	4 0 1	MAKE SURE THAT THE "STEP"
	1 0 5	×	0 7 0	SWITCH IS RELEASED
	1 0 6	1( )	0 3 1	
	1 0 7	6	0 0 6	THEN:
	1 1 0	CHGSGN	0 1 3	DEPRESS RESUME
	1 1 1	+	0 5 0	ENTER "a"
	1 1 2	HALT	4 0 1	DEPRESS RESUME
	1 1 3	=	0 2 0	ENTER "b"
	1 1 4	×	0 7 0	DEPRESS RESUME
	1 1 5	HALT	4 0 1	ENTER "c"
	1 1 6	÷	0 7 2	DEPRESS RESUME
	1 1 7	HALT	4 0 1	READ Z
5	1 2 0	=	0 2 0	DEPRESS RESUME
	1 2 1	HALT	4 0 1	ENTER "b"
	1 2 2	To (0)	7 4 0	DEPRESS RESUME
	END 3	OF PROGRAM		READ X
	4			ENTER "d"
	5			DEPRESS RESUME
	6			ENTER "b"
	7			DEPRESS RESUME
	0			READ Y
	1			
	2			DEPRESS RESUME AND THE
	3			PROGRAM COMES BACK TO
	4			ITS STARTING POINT, READY
	5			TO REPEAT THE OPERATION.
	6			
	7			

MONROE
THE CALCULATOR COMPANY
A DIVISION OF LITTON INDUSTRIES

1498-S

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Fig. 5 Program

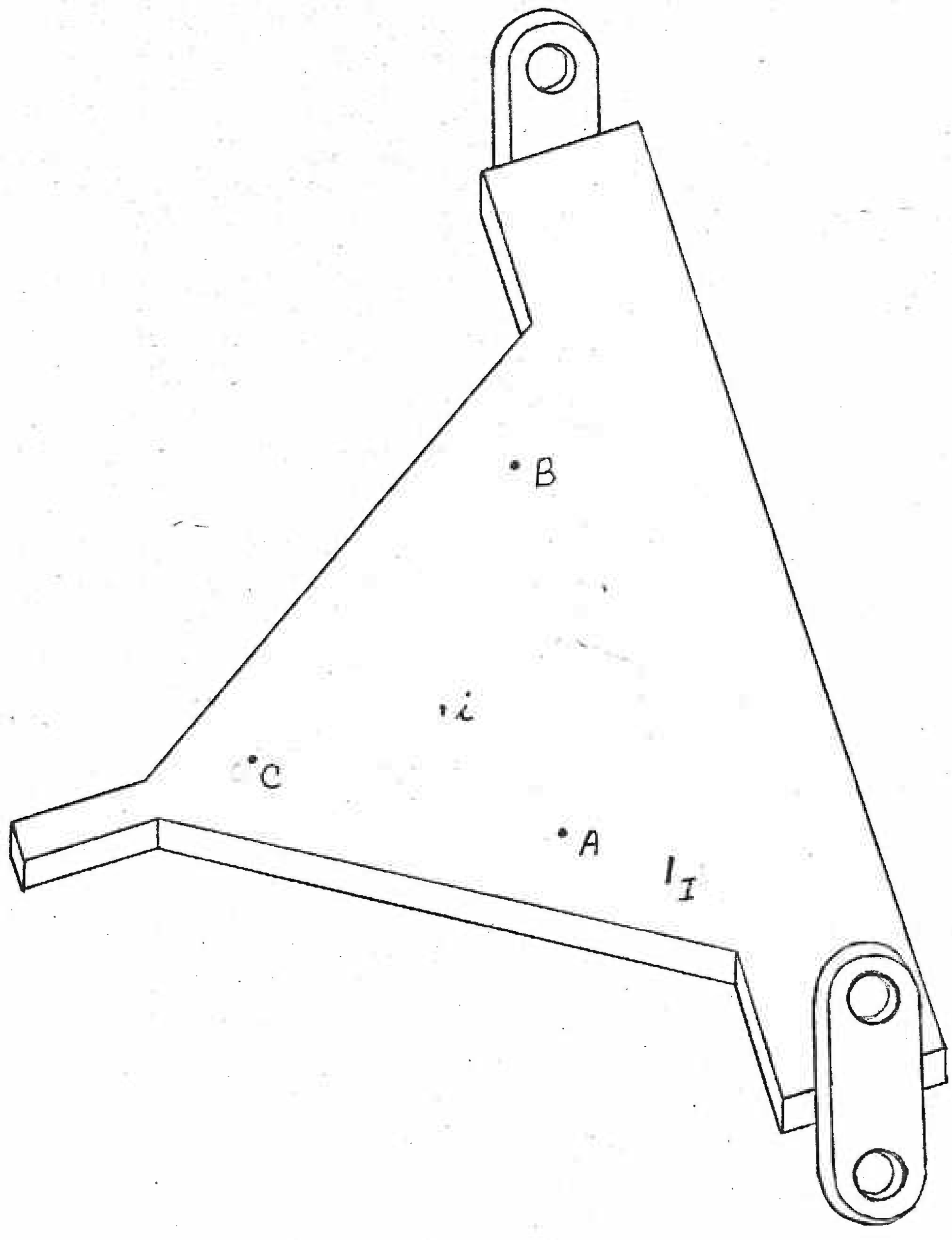

Fig. 6 Plexiglass Phantom with "A" "B" "C" Implants and Marker No. 4 or "i" and Marker No. 5 or "I".