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A Stereoradiographic Technique and Its Application to the Evaluation of Lung Casts

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Stereoradiographs have been used on occasion for three-dimensional reconstruction and measurement of objects in radiology and radiotherapy. The lack of a good stereoradiographic technique has limited the uses of stereoradiographic exposures. In this paper, the principle of the double-image is outlined and a method of applying this principle to stereoradiographic exposures is developed. A computer program has been developed from geometrical considerations to analyze the stereobronchogram and to calculate the dimensions of the objects in question. The applications of this technique are discussed and its use in evaluating lung casts is described.

Key words: stereoradiograph, principle of double image, airway morphometry, lung casts.

AN ACCURATE DESCRIPTION OF THE ANATOMICAL details of the respiratory airways of man and experimental animals is essential to understand the deposition and ultimate toxicity of inhaled particles, and for physiological research. One approach to obtaining this information is to obtain casts of the airways and make detailed measurements of such anatomical parameters as diameters, lengths, and branching angles, all of which are needed to predict particle deposition¹ and in physiological research. During casting of the lung, however, the effects of either the density of the casting material and/or lack of restraint of the thorax and other organs imposed on the lung may change airway dimensions. This paper describes a stereoradiographic technique

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which can be used to determine dimensions and locations on a stereoradiograph of any three-dimensional object. An example of the use of this method to investigate the artifacts of lung casts is presented.

Principle

The basic element of stereoscopic data reduction is a single point located in three-dimensional space. Two or more points can be connected by line segments to form lines, angles, and branches as shown in Fig. 1. Such geometric forms have analogs in the tracheobronchial tree. If the coordinates of the points are known in three-dimensional space in an arbitrary coordinate system, the length of a line connecting two points $P_1 (x_1, y_1, z_1)$ and $P_2 (x_2, y_2, z_2)$ is

(1)

$$\overline{P_1 P_2} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

Other formulae can be derived to compute other parameters of interest such as branching angles and inclination angles relative to gravity. For example, the branching angle $\angle P_2 P_1 P_3$ (Fig. 1) can be calculated by

$$\angle P_2 P_1 P_3 = \cos^{-1} \frac{\overline{P_1 P_2}^2 + \overline{P_1 P_3}^2 - \overline{P_2 P_3}^2}{2 (\overline{P_1 P_2}) (\overline{P_1 P_3})}$$

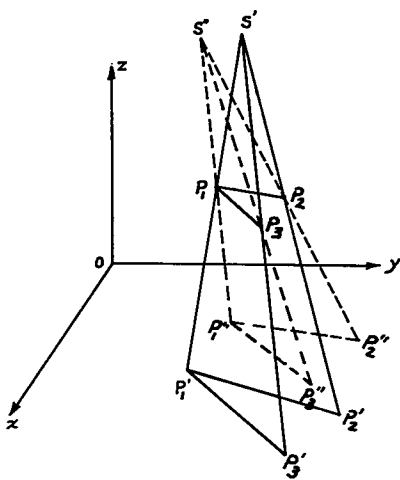


FIG. 1. An object in three-dimensional space with two x-ray sources forming two corresponding images in an xy plane.

if we know the locations of points P_1 , P_2 , P_3 , and segment lengths calculated from equation (1).

The three-dimensional coordinates of each point of interest are calculated from the two-dimensional coordinates of the radiographic film images of the point and from the three-dimensional coordinates of each x-ray source in a common coordinate system. Figure 1 shows an object $P_1 P_2$ in three-dimensional space with its two images $P_1' P_2'$ and $P_1'' P_2''$ corresponding to the two x-ray sources S' and S'' . For an arbitrary point $P(x, y, z)$ lying on the line connecting an x-ray source $S(x_s^i, y_s^i, z_s^i)$, the corresponding point's image $P^i(x_p^i, y_p^i, z_p^i)$ is defined by the following equations

$$\frac{x - x_p^i}{x_s^i - x_p^i} = \frac{y - y_p^i}{y_s^i - y_p^i} = \frac{z - z_p^i}{z_s^i - z_p^i} \quad (2)$$

where the superscript i refers to either ($'$) or ($''$) as appropriate. Equation (2) can be rearranged to give

$$x(z_s^i - z_p^i) + z(x_p^i - x_s^i) = x_p^i z_s^i - x_s^i z_p^i \quad (3)$$

$$y(z_s^i - z_p^i) + z(y_p^i - y_s^i) = y_p^i z_s^i - y_s^i z_p^i \quad (4)$$

Two equations with the three unknown coordinates of the point of interest $P(x, y, z)$ result from each x-ray source used. Therefore, two or more x-ray sources are required to obtain a sufficient number of equations to solve for the position of P . Any three of the resulting equations can be used to compute exact values for the coordinates at point P . Because small errors in hand measurements of the point images and coordinates of the x-ray sources can be expected, a method which uses all equations is preferable. The method selected for solving the overdetermined system (more equations than unknowns) is the least squares method.² This method also allows a means for estimating the error associated with each point's coordinates.

In practice, the coordinates of an x-ray source relative to an arbitrary origin in the plane of the film are difficult to measure directly and precisely. To overcome this difficulty, the x-ray source coordinates were found indirectly by using at least two locator points above the film plane with known coordinates

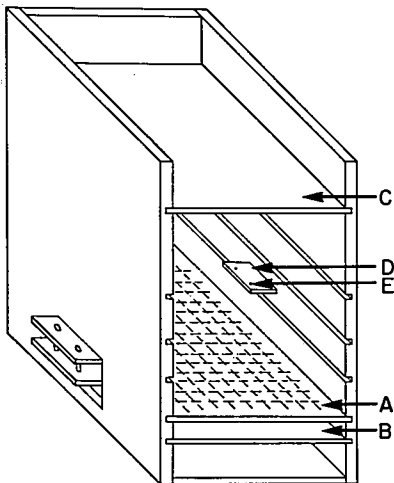


FIG. 2. Schematic diagram of a stereoradiographic positioning and filmholding device (for rodents or small objects).

TABLE 1. Comparison of Physically Measured Values on Test Specimen with Computed Values Based on Stereo Radiograph

	Line Segments Length (cm)					Inclination To Gravity					Angles Between Segments			
	1-2	2-3	3-4	4-5	5-6	1-2	2-3	3-4	4-5	5-6	∠123	∠234	∠345	∠456
Hand measurement	3.35	1.78	5.13	4.52	5.38	90°	90°	33°	25°	85°	56°	123°	56°	117°
Stereo x-ray	3.35	1.80	5.08	4.42	5.38	89.57°	89.74°	32.70°	22.5°	83.35°	54.2°	122.30°	55.1°	117.10°

Metal Wire
(two dimension representation
of actual three dimensional
shape)

relative to a reference origin in the film plane. From their images on the film and their true coordinates, equations (3) and (4) are solved to find the x-ray source location. Four locator points are used, resulting in eight equations for three unknown coordinates (x, y, z) of the source. The eight equations form an over-determined linear system which is solved by the least-squares method.

Method and Experiment With Test Wire

A schematic diagram of a stereoradiographic positioning and filmholding device is shown in Figure 2. The object is positioned on the top of plate A or C. The bottom side of plate A contains a rectangular metal wire grid pattern so that the film, when placed on plate B in contact with plate A, is directly beneath the grid which forms a coordinate system on the film. The movable plate C is used for positioning the object at variable heights from the film to give higher magnification of the images if desired. Two x-ray source locator plates, D, each with two embedded metal locator points, E, are fixed to the two side walls. The locations of these four locator points are known precisely relative to an origin in the grid (xy) plane. A portable x-ray source is placed above the film at a distance of about 81 cm. In making a stereoradiograph, the x-ray source is moved horizontally about 10 to 25 cm for the second exposure.

Based on the geometric principles previously outlined, a computer program for stereographic data reduction was tested using radiographs of a metal object with a known configuration. The

object was placed on the top of plate A, the stereoradiograph was made, and the projected dimensions of the two images on the film were found by hand measurement under 10-power comparator. These data were then processed with the computer program to provide computed lengths and angles of the object. These values showed excellent agreement with the known dimensions of the object (Table 1).

Example—Evaluation of lung casts. With the precision and validity of the stereoscopic method and computational technique established, experiments were performed involving the casting of rodent lungs to evaluate the lung casts. The experiments were performed to visualize the changes in airway geometry during lung casting, using an *in situ* lung casting technique.⁵ A powdered tantalum technique was used to obtain a good outline of the airways.⁴

The animal subject was anesthetized with sodium pentobarbital and a tracheostomy was performed. An endotracheal tube was tied into the trachea. A measured amount of tantalum powder (about 2.5 μ m mean particle diameter) was introduced through the trachea using repeated pulses of air to disperse the Ta powder into the lung. This insufflation was repeated until a good bronchogram was obtained. The animal was placed in the stereoradiographic positioning and filmholding device and was prepared for lung casting by a saline replacement *in situ*⁵ with some modifications for bronchography. Two stereoradiograph pairs were taken, one after CO₂ washout (prior to saline infusion) and the other upon completion of injecting the casting material. During the filling process, additional stereobronchograms or monobronchograms were taken at pre-

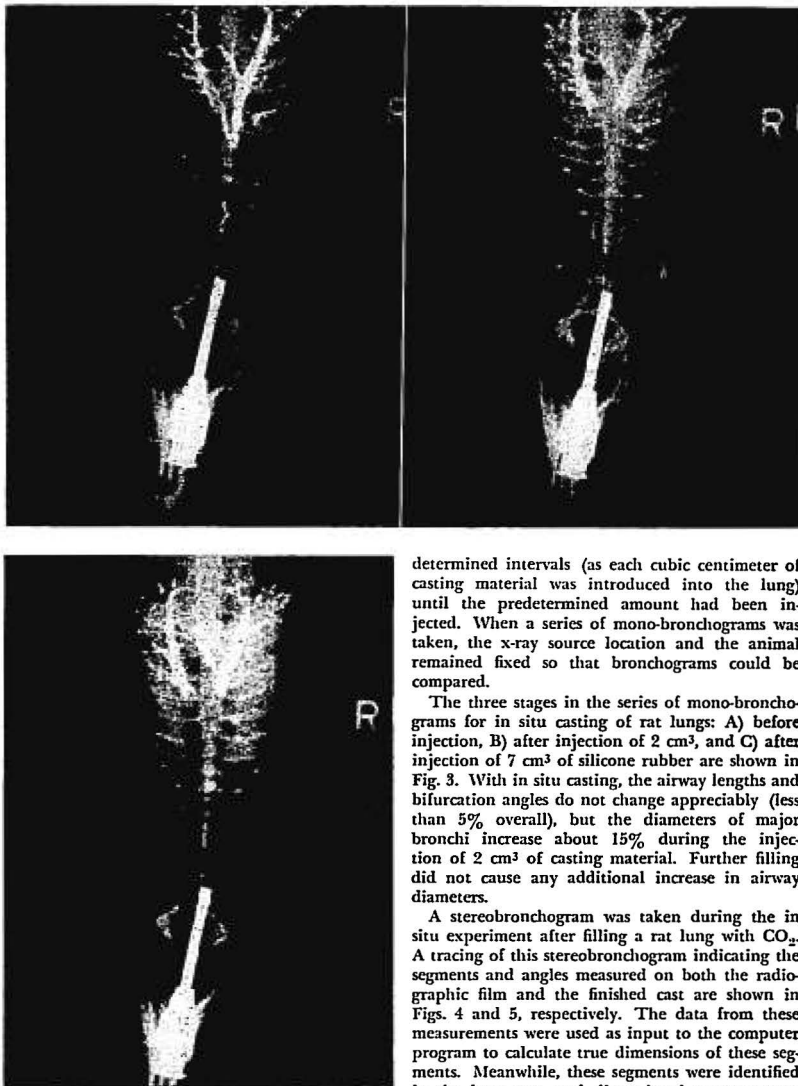


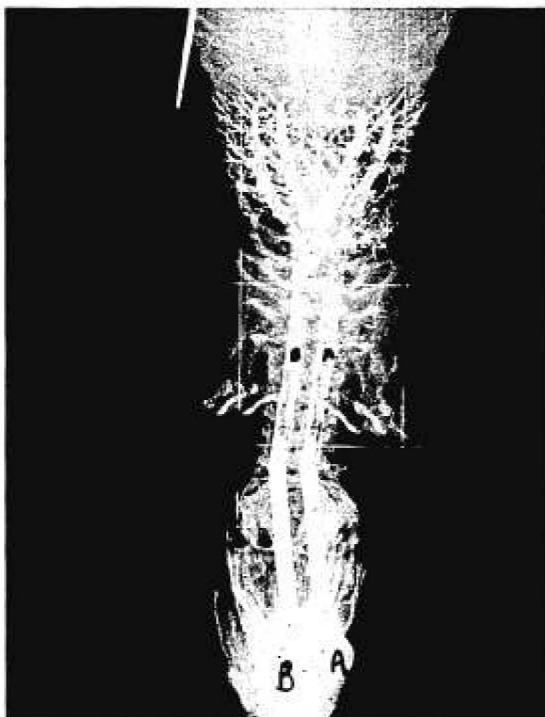
FIG. 3. Series of bronchograms during lung casting. A (top left) before injection, B (top right) after injection of 2 cm³, and C (bottom) after injection of 7 cm³ of silicone rubber.

determined intervals (as each cubic centimeter of casting material was introduced into the lung) until the predetermined amount had been injected. When a series of mono-bronchograms was taken, the x-ray source location and the animal remained fixed so that bronchograms could be compared.

The three stages in the series of mono-bronchograms for in situ casting of rat lungs: A) before injection, B) after injection of 2 cm³, and C) after injection of 7 cm³ of silicone rubber are shown in Fig. 3. With in situ casting, the airway lengths and bifurcation angles do not change appreciably (less than 5% overall), but the diameters of major bronchi increase about 15% during the injection of 2 cm³ of casting material. Further filling did not cause any additional increase in airway diameters.

A stereobronchogram was taken during the in situ experiment after filling a rat lung with CO₂. A tracing of this stereobronchogram indicating the segments and angles measured on both the radiographic film and the finished cast are shown in Figs. 4 and 5, respectively. The data from these measurements were used as input to the computer program to calculate true dimensions of these segments. Meanwhile, these segments were identified in the lung cast, and direct hand measurements were made using a seven-power hand-held comparator. Considering the uncertainty involved in identifying the corresponding points between the

FIG. 4. Stereo bronchogram of a rat before injection of casting material.



finished cast and the stereoradiograph pairs, results of the dimensions of the airways before casting (calculated from the stereobronchogram) and after casting (from the cast) (Table 2) agree favorably with those seen in the monobronchogram

series. Two segments measured and calculated from the stereobronchogram after injection of casting material are also included in Table 2. Since the casting material moved the tantalum powder down during injection, most of the points identified

TABLE 2. Airway Size Changes Before and After Casting of the Rat Lung

	Segment Diameter (cm)			Line Segment Length (cm)					Angle Between Segments (Degrees)		
	d ₂₋₃	d ₄₋₅	d ₆₋₁₃	L ₁₋₄	L ₁₀₋₁₂	L ₁₀₋₁₁	L ₆₋₇	L ₇₋₁₄	∠8-7-9	∠11-10-12	∠14-7-8
Stereo x-ray before casting	0.23	0.25	0.30	3.43	0.46	0.51	0.74	0.69	46.9	55.1	54.6
Hand measurement from cast, mean*	0.26	0.29	0.34	3.10	0.53	0.53	0.75	0.58	29.6	50.4	61.5
Stereo x-ray after casting	0.25	-	-	3.58							

* Mean of five individual measurements.

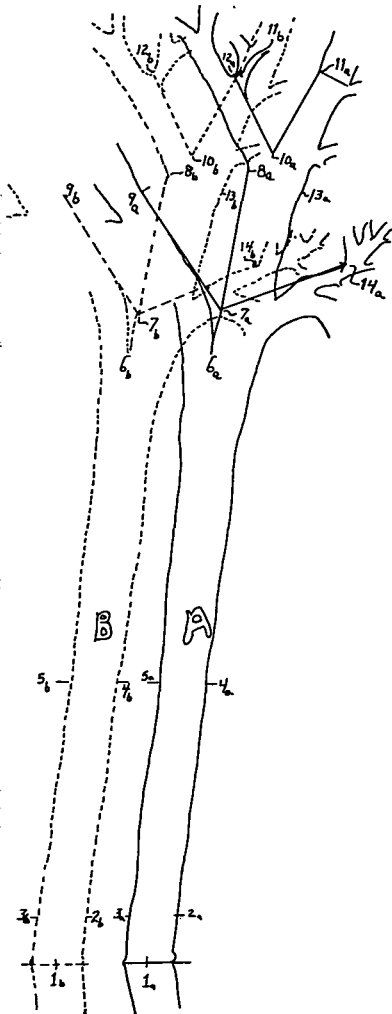


FIG. 5. Trace of the stereo bronchogram in Figure 4 with indications of segments and angles measured.

in Fig. 5 are very difficult to identify in this stereo-bronchogram. Data of the in situ experiment with rabbit are shown in Table 3 with Figure 6 showing

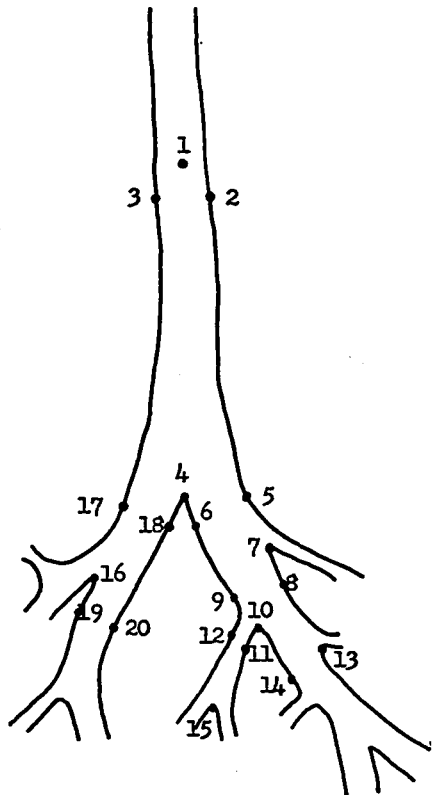


FIG. 6. Sketch of the rabbit airways indicating the points being measured.

the sketch diagram of the points (segments and angles) being measured. These data further confirm that the main artifact is increasing the diameters of the major bronchi.

Discussion

In this paper, the principle of the double image is outlined and a method of applying this principle in stereoradiographic exposures is developed. A test wire experiment is described and the results show the precision and validity of the technique.

TABLE 3. Airway Size Changes Before and After Casting of the Rabbit Lung

	Segment Diameter (cm)						Line Segment Length (cm)				Angle Between Segments (Degrees)				
	d ₂₋₃	d ₄₋₄	d ₆₋₉	d ₁₁₋₁₂	d ₁₃₋₁₄	d ₁₇₋₁₈	d ₁₈₋₂₀	L ₇₋₁₀	L ₁₀₋₁₁	L ₄₋₁₈	L ₁₀₋₁₅	∠4-10-13	∠1-4-7	∠4-7-10	∠4-10-15
Stereo x-ray before casting	0.41	0.43	0.41	0.28	0.30	0.36	0.38	0.74	0.23	1.30	-	137	140	132	-
Hand measure- ment from cast, mean*	0.46	0.43	0.38	0.23	0.36	0.41	0.36	0.71	-	1.19	0.71	158	138	135	125
Stereo x-ray after casting†	0.48	0.38	0.41	-	-	0.43	-	0.79	0.20	1.24	0.79	117	150	110	129

* Mean of two individual measurements.

† 20 cm³ of casting material was injected.

A stereoradiographic technique has been described by Hughes, et al.³ who similarly used equation (2) in describing the use of stereoradiograph pairs for measuring airway length and diameter in situ. Their procedure, however, required three exposures for each measurement and the construction of a special frame for their x-ray source. This inconvenience caused them to use a two-dimensional approximation method in their experimental data handling. The use of x-ray source locator points and a least-squares computing method requires only two exposures, or one simultaneous double exposure, and eliminates this difficulty. In addition, only two measurements from the radiograph are required for determining the location of each point (four measurements for calculating a segment length) rather than the three measurements for point determination in Hughes' method.

The stereoradiograph pair technique can be applied in various ways, such as to locate lung tumors or constricted airway segments and to quantitate the changes in major airways in a

living animal during breathing. In these cases, a pair of comparable x-ray sources has to be used with perfect synchronization in firing time and some modifications in locator points. As an example of the application, lung casts of rodents were evaluated by this technique.

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REFERENCES

1. Beekmans, J. M.: The deposition of aerosols in the respiratory tract. I. Mathematical analysis and comparison with experimental data. *Can. J. Physiol. Pharmacol.* 43:157, 1965.
2. Franklin, J. N.: Matrix Theory. Englewood Cliffs, NJ, Prentice-Hall, 1968; pp. 50-55.
3. Hughes, J. M. B., Hoppin, F. G., and Wilson, A. G.: Use of stereoscopic x-ray pairs for measurements of airway length and diameter in-situ. *Br. J. Radiol.* 45:477, 1972.
4. Nadel, J. A.: New technique for studying structural changes of airways in-vivo using powdered tantalum. In *Airway Dynamics—Physiology and Pharmacology*, A. Bouhuys, Ed. Springfield, IL, Charles C Thomas, 1970, p. 73.
5. Phalen, R. F., Yeh, H. C., Raabe, O. G., and Velasquez, D. J.: Casting the lungs in situ. *Anat. Rec.* 177:255, 1973.