特別掲載

STUDIES ON STEREOROENTGENOGRAPHY OF MOTILE ORGANS
Report II. Especially of Gastrointestinal Tract

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運動臓器における立体撮影法の研究
第2報 特に胃腸管について

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(昭和42年4月26日受付)

従来行なわれている管球移動による立体撮影及び我々の試作した2管球同時曝射による同時立体撮影装置を用い，運動臓器，主として今迄報告の見られない消化管の立体撮影を実施し，病巣の立体的観察を試みた．同時に立体映画撮影も試み，各方法について比較検討した．

1．管球移動による立体撮影では，蠕動運動の比較的緩慢な胃噴門部，大腸等に良好な立体観察が得られた．

2．副交感神経節遮断剤等の薬剤で前処置を行なつたものは，より良好な結果が得られ，胃体部，幽門前庭部等でも立体観察の可能な場合も見られた．

3．同時立体撮影では，蠕動運動に影響されず，立体観察は全て良好であつた．

4．同時立体映画撮影では，胃腸管の連続的立体観察が可能であり，食道等において，立体観察はよりすぐれていた．

5．気管支造影，心血管撮影等に同時立体撮影の応用を試みた所，立体観察は良好であつた．

It is impossible to comprehend exactly three dimensional structures and positional relations of various organs of the human body by means of the plane roentgenogram owing to overlapping of shadows and others inevitable in it. Subsequently various attempts have been made since early to view the X-ray image stereoscopically[1)6)14)]. It is necessary for this purpose to take a pair of X-ray pictures of one same organ in the same phase. Stereoroentgenography in the early period was therefore limited to such unmoving objects as bone, foreign substance and others[5)16)24)]. In recent years, however, progress in angiography has stimulated improvement of stereoroentgenography, and made it possible to view three-dimensionally organs in movement[2)4)7)15)]. But up to date no one has succeeded to take a pair of images of an object in perfectly the same phase or perfectly at the same time. Since 1965, we have been engaged in making a model of stereoroentgenography, in which, by simultaneous exposure of two tubes, a pair of images of an object can be recorded on the same film strip[25)]. And with it we have attempted clinical stereoroentgenography of motile organs, especially of the alimentary canal, which had hitherto been

scarcely reported. And we have confirmed that this model can make satisfactory stereoscopical observation useful for clinical diagnosis. We have also attempted simultaneous stereocineroentgenography by making use of this model. Furthermore we have performed stereoroentgenography with the conventional fluoroscopic table by sifting the tube after pretreating the examinee with drug to inhibit the movement of the organ, compared the results with those obtained by our simultaneous method, and found many facts of interest. This paper is designed to report on them.

Apparatus and Method of Roentgenography

1) Stereoroentgenography with the tube shifted. (hereafter referred to as the manual method).

According to the routine procedure of stereoroentgenography, the object to be exposed is fixed, and the tube is first adjusted to the center of the object, and then moved to right and left or up and down for the same distance (about 3 cm) to expose twice.

The apparatus is a generally used fluoroscopic table. But since severe peristalsis produces distortion in the roentgen picture, parasympathetic blocking agent such as Buscopan (Hyoscine-N-Butylbromide) is administered about 15 minute before exposure to inhibit peristalsis. Further to shorten the time for film exchange, spot film is used.

2) Simultaneous stereoroentgenography (hereafter referred to as the simultaneous method)

A model as shown in Phot. 1 was made, with which two X-ray pictures can be taken simultaneously on one film by virtue of enlarging radiography. In this model, two tubes are fixed 20 cm apart from each other with a convergent angle of 11° with the central ray, and are connected with each other. The distance between the tubes and the fluoroscopic table is 80 cm, and that between the table and the screen (film) is 35 cm (Fig. 1).

Phot. 1 Simultaneous stereographic apparatus

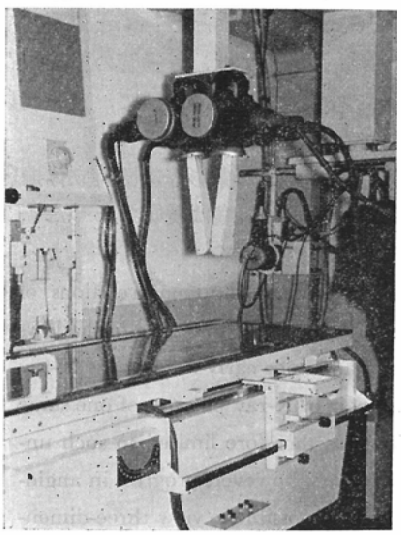
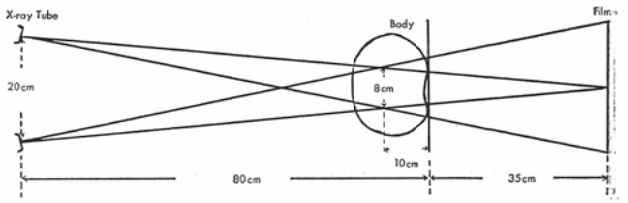


Fig. 1. Schema of simultaneous stereographic apparatus



The model has the following features:

1) It can avoid doubling of the image.

2) It can confine the cone of ray to keep the emission of scattered ray to the minimum.

3) It can absorb scattered ray in the air.

4) It can prevent disacord between the two tubes.

5) It can select adequate magnification to obtain clear image and to prevent overcharge of the tubes.

This model is not provided with any diaphragm, but nevertheless distribution of scattered ray (Fig. 2) is as low as below 10% on the surface of the film, so that satisfactory X-ray pictures can be obtained without any difficulty. The range of view varies depending on distances between the tube, the object of exposure and the film.(Table 1). However, on the basis of investigations on conditions of exposure, electric capacity of the tube, magnification and blurring of the image, the maximum width of the object of exposure practically usable was determined as 8 cm (with height of 12 cm). In this case, the magnification is 1.64 times at 10 cm from the fluoroscopic table (Fig. 3), and the resolving capacity is as high as 50 lines/cm.

Fig. 2. Scattered dose distribution
(Automatic isodose plotter TPA-251)

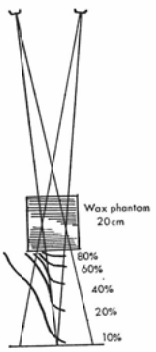


Fig. 3. Magnification

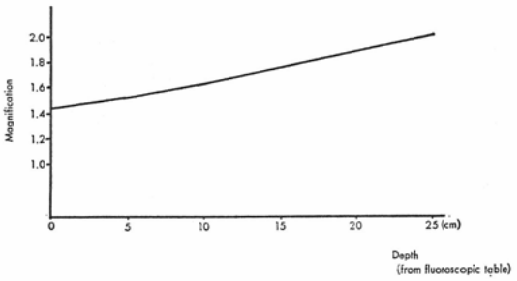


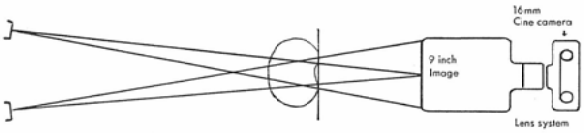
Table 1. Maximum fiield

Tube·····Body	Body·····Film	Magnification	Maximum field
70cm	30cm	1.43	6cm (×12cm)
70	40	1.57	7 〃
70	45	1.64	8 〃
70	60	1.86	9 〃
70	70	2.0	10 〃

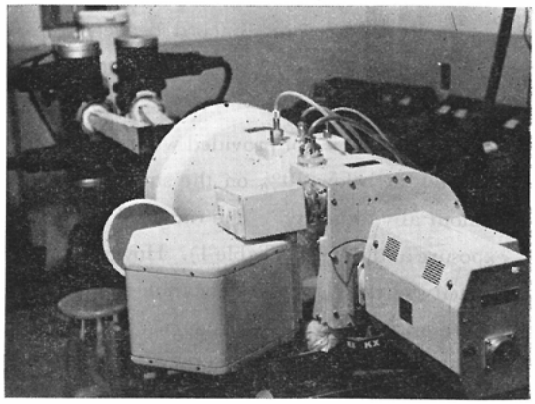
In exposure, the image is exactly located, and to compensate the small range of view, spot roentgenography is made after preliminary fluoroscopic observation. Unlike the manual method, it is not especially necessary to pretreat the examinee with drug for the prevention of organ movement, though the pretreatment can make the image clearer.

The exposure is made with tube voltage of 65–80 kvp, and tube current of 150 mA. Time of exposure is 0.05 sec. for the esophagus, and 0.1–0.15 sec. for the gastrointestinal canal.

Fig. 4. Schema of simultaneous stereocinematographic apparatus



Phot. 2 Simultaneous stereocinematographic apparatus



3) Simultaneous stereocineroentgenography (hereafter referred to to as the cinematographic method)

The above described apparatus is used. And at the site of the fluorescent screen, a 9-inch image intensifier and the optical system are set, and with a 16-mm cinecamera the image is recorded (Fig. 4, Phot. 2). When the image intensifier is of below 9-inches, the X-ray image is unsatisfactory owing to small range of view and insufficient amount of ray. The resolving capacity is 20 lines/cm, lower than in the above described stereoroentgenography. Tube current of 25 mA is sufficient for exposure. The method is the same as above described. After locating the site of exposure, consecutive recording is made.

Method of observation. On stereoscopic viewing,various attempts have been made[3)9)11)18)]. The simplest method is stereoscopic viewing with naked eyes in which two lines of vision are crossed in front of the two films(convergent viewing). This is, however, difficult for some individuals. Objective viewing can be made easily by any one by means of stereoscope, which makes use of a reflector, and stereoscopic bioculars, which makes use of the prism. For the object of viewing the image most correctly and in most natural state, it is necessary that the film should be observed exactly in that direction which is perfectly in conformity with the line connecting the tube and the object of exposure.

Another method is also tentatively used. It consists in preparation of two slides of different color (blue and red) and their observation with a spectacles of the same two colors. But it is necessary to use a filter in the preparation of the slides, and further to project the slides on a screen for the observation. The procedure is thus troublsome, and the sharpness of the image is also lowered. To improve this defect, the image is photographed directly on color film using blue and red intensifying screen. For the moment, the X-ray image is unsatisfactory in contrast owing to low sensitivity of color film, and consequently stereoscopic effect is not sufficient. This method, however, is considered recommendable if color film of high sensitivity is available.

There is stereocomparameter devised by Takahashi (1954)[22)] for stereoroentgenographical measurement of the depth of the focus. But this is not yet used generally. We have preliminarily photographed a scale on film with the above described apparatus, and the depth is measured by placing this film on the stereoroentgenogram of the focus. Further to make the measurement as exact as possible, distances on the two films are determined for theoretical computation[10)23)].

Observation with naked eyes or with the stereoscope is sufficiently useful for practical clinical purpose,

but it inevitably has defect of being subjective. In view of this attempt is now being successfully made by Tobe (1966)[26] to transform the stereoroentgenogram into a three-dimensional object.

Results of application of the apparatus

1) Stereoroentgenography of the alimentary canal.

Stereoscopic viewing of the esophagus is perfectly impossible by the manual method which requires twice exposures, since barium passes through it almost instantaneously so that remarkable distortion is produced in the image. By the simultaneous method, stereoscopic viewing is possible to some degree, but it can sometimes produce blurring of the image owing to the movement during the exposure. To the object of kinetic recording the esophagus and the gastric region, simultaneous cineroentgenography is fitted, but in this case the image has less contrast than that by plain roentgenography owing to the use of the image intensifier. There is also difficulty in the way of viewing. The fittest to the observation of the esophagus is the simultaneous stereocineroentgenography.

The manual method is usable for stereoscopic viewing of the cardia and the fornical part, where the peristalsis is relatively slow, if the examinee is pretreated with hyoscine-N-butylbromide. But when the peristalsis is rapid in these parts, stereoscopic viewing is only partially possible. Further the image is sometimes influenced by heart beat. On account of this, the simultaneous method is preferable also for observation of these parts. In this case, the pretreatment is of course unnecessary. It is also fitted to stereoscopic viewing of the direction of reliefs and condition of the mucous wall in the cardia.

Stereoscopic viewing of the corpus, pylorus, and duodenum is considerably difficult by the manual method owing to peristalsis. It is impssible in many occasions even after pretreatment with the drug. There are, however, cases from which good images are obtained by the manual method. In the simultaneous method, the difficulty arising from the movement of the object is already solved to a greater extent. But with regard to good contrast, many are still to be desired. It is necessary in fluoroscopy to secure thorough sticking of barium to the organ. In virtue of the enlarging radiography, changes in the gastric mucosa can be grasped in details by this method. On the other hand, however, clumping of barium, when present, enlarges blurring of the image, making it unclear. In the case of gastrectomized patients, the cinematographic method often gives better results, since barium passes more rapid after the operation and further since it is more difficult in them to control the amount of air.

Of the small intestine, in which peristalsis is considerably rapid, and in which loops are multiple, neither the manual method nor the simultaneous stereoroentgenography is successful in giving satisfactory stereoscopic view, because it is difficult to obtain a pair of images from this organ. When the duodenum and the upper part of the jejunum, where loops are less, are observed, stereoscopic viewing is possible. Especially the cinematographic method, which gives kinetic and continuous view, is fitted for their observation. However, conditions of exposure, such as tube voltage and tube current, still raise some difficulty in this technique.

The double contrast photographing is relatively easy of the large intestine which performs relatively slow peristalsis, and consequently its stereoscopic viewing is also easy. And the manual method can be used for it with satisfactory result if the examinee is pretreated. Since extensive observation must be made in this region, it is necessary, and also possible when one is skillful, to resort to the manual method without divided use of film. In the simultaneous method, the image of the large intestine is clear, since

the movement of the organ exerts scarcely any effect, and further since the conditions of the exposure are good.

In this way, stereoroentgenography is very effective in observing the esophagus, direction of gastric reliefs, state of tumorous elevation of mucosa, position of the intestinal canal, especially its tortuosity and depths, natures of adhesion and diverticula, and in distinguishing overlapping shadows.

2) Observation of other organs

Stereoscopic viewing of the bronchus is possible to a certain degree by means of the manual method, when the object is the bifurcation and the part of greater lumen. It is, however, impossible with finer one or when the heart beat exerts strong influence on the bronchus. Stereovision is satisfactory by the simultaneous method, which is not affected by movement of the organ. By stereobronchography, details can be seen with good three-dimensional effect since not only satisfactory contrast is provided by contrast medium but also shadow is intensified by the stereoscopic method. In the cinematographic method, it is not necessary to arrest respiration, and in addition stereoscopic effect is increased by kinetic recording.

In the stereoroentgenography of the cardiovascular system, in which the contrast medium passes instantaneously, the manual method is not applicable. As to the procedure, it is important to decide when to inject the contrast medium. For this reason the photography must be made in connection with the apparatus synchronized with cardiac currents. But different from the conventional stereoroentgenogram, which must be observed from various view points, the film of the simultaneous cinestereoroentgenography presents before the observer's eye the three-dimensional image which neither requires nor permits any subjectve speculation. Moreover, the cinematographic method, which is capable of consecutive recording, enable us to perform observation in various phases.

In this way, the stereoroentgenography, especially the simultaneous method, can be applied with great advantage not only to the alimentary canal but also to the angiography, which has recently made rapid advance. Table 2 summarized the application of the various methods.

Table 2. Indications of different methods

Method	Indication
Manual	Examination of cardiac area, upper part of gastric body, and large intestine
Simultaneous	Examination ot esophagus, stomach, duodenum, upper part of jejunum, large intestine, and bronchography and angiography
Cinematographic	Examination of esophagus, and bronchography and angiography

Case Report

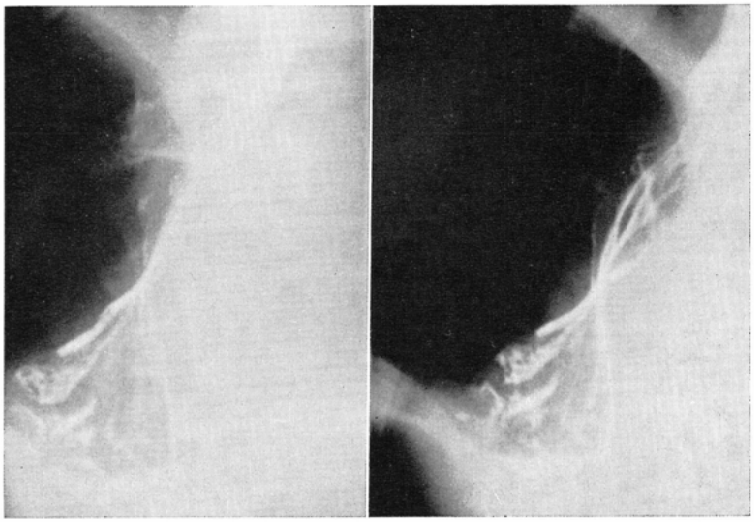
Below are described various cases to which were applied the different stereoroentgenographies.

1) The cardia (by the simultaneous method)

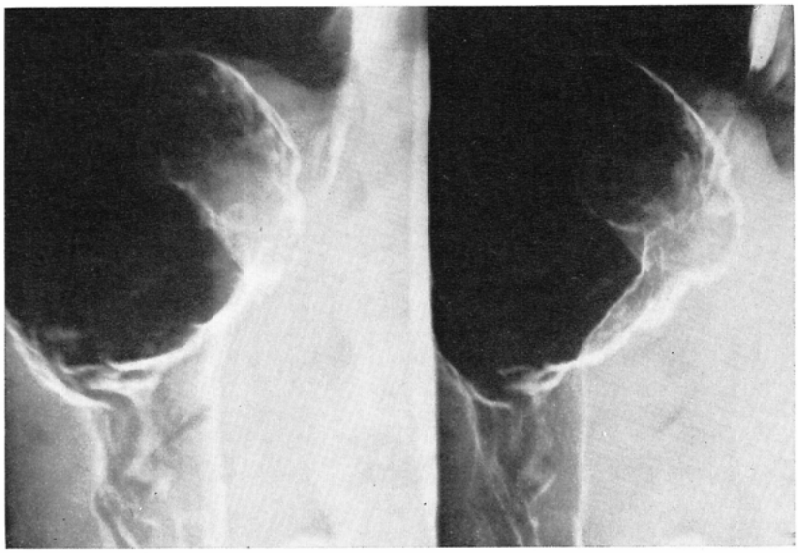
Fluoroscopy of the stomach showed compact reliefs in the cardia. But the simultaneous method revealed that they were in effect discrete ones. Only in appearance they seemed compact, because in the plain roentgenography they were seen overlapping. (Phot. 3)

2) Cancer in the cardia (by the simultaneous method)

Phot. 3. The cardia (by the simultaneous method)



Phot. 4. Cancer in the cardia (by the simultaneous method)



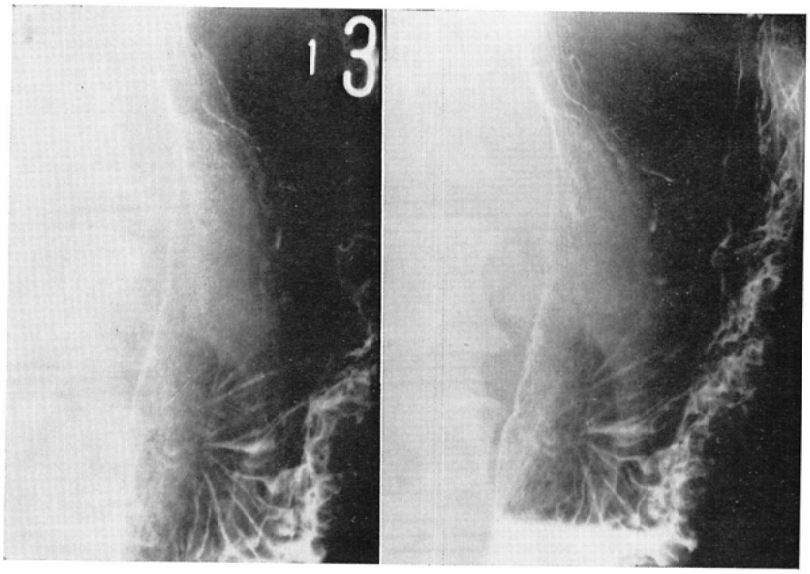
As a shadow indicative of tumor was observed inside the cardia, its position, extension and size were ascertained by the simultaneous method. And the presence of a tumor, extending from the posterior to the anterior wall of the cardia, and having irregular rugged surface with a depression in the center, was confirmed stereoscopically. (Phot. 4)

3) Ulcer in the corpus (by the manual method)

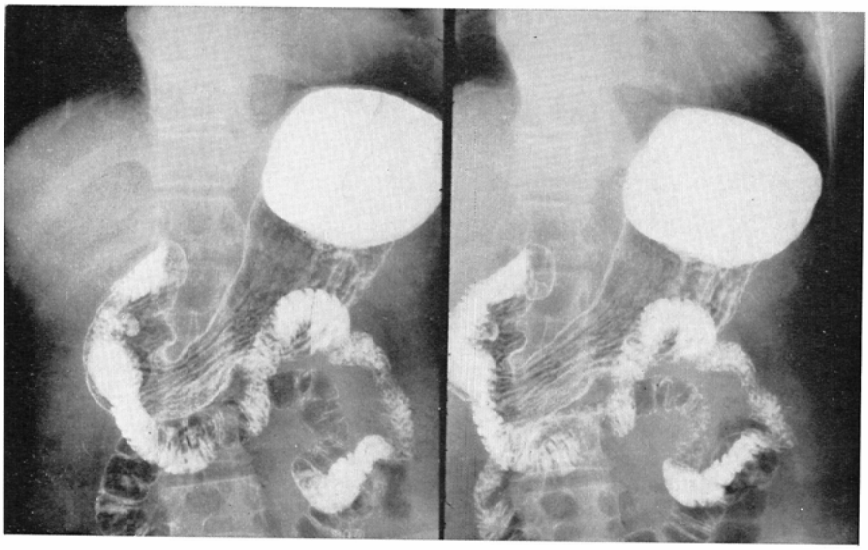
Ulcer was found in the supero-posterior wall of the gastric corpus. Gastric reliefs were concentrated around the ulcer. The posterior wall of this region was pressed from behind. (Phot. 5)

4) Duodenal diverticulum (by the manual method)

Phot. 5. Ulcer in the corpus (by the manual method)



Phot. 6. Duodenal diverticulum (by the manual method)



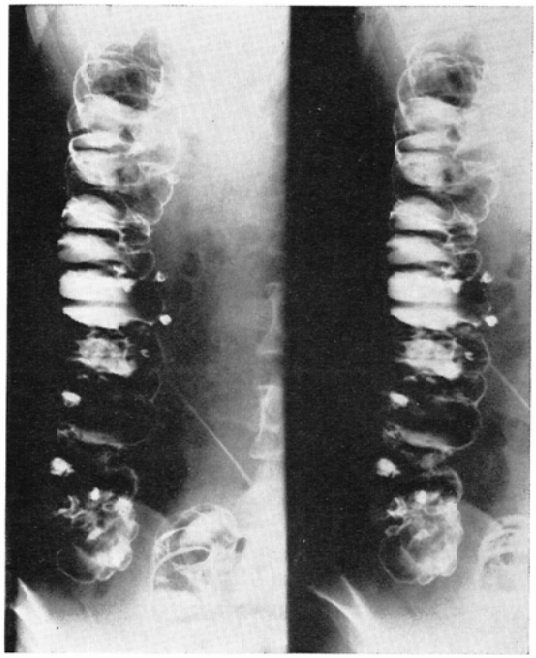
Intero-posterior protrusion of diverticulum, and tortuosity of the duodenum and the jejunum were stereoscopically observed by the manual method. (Phot. 6)

5) Colonic diverticulosis (by the manual method)

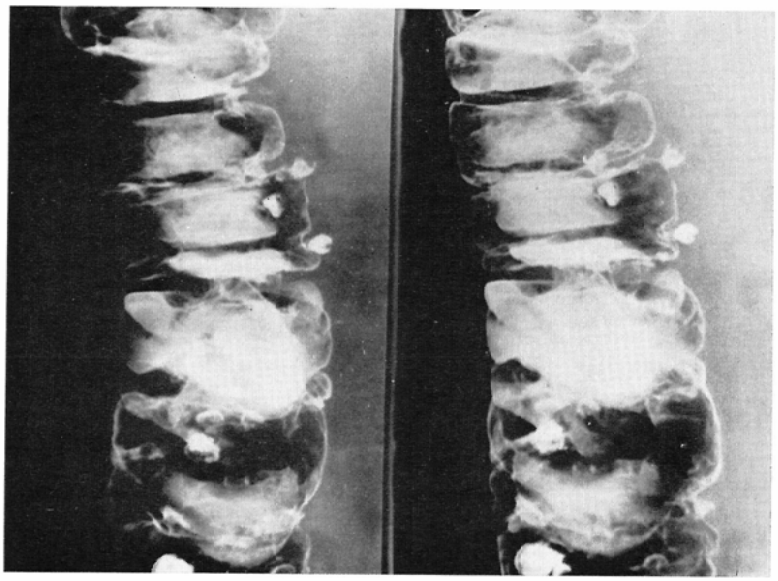
After barium enema, diverticula were discovered fluoroscopically. Detailed observation was performed by the manual method, and diverticula protruding anteriorly, interiorly as well as posteriorly were three-dimensionally. (Phot. 7)

6) Colonic diverticulosis (by the simultaneous method)

Phot. 7. Colonic diverticulosis (by the manual method)



Phot. 8. Colonic diverticulosis (by the simultaneous method)

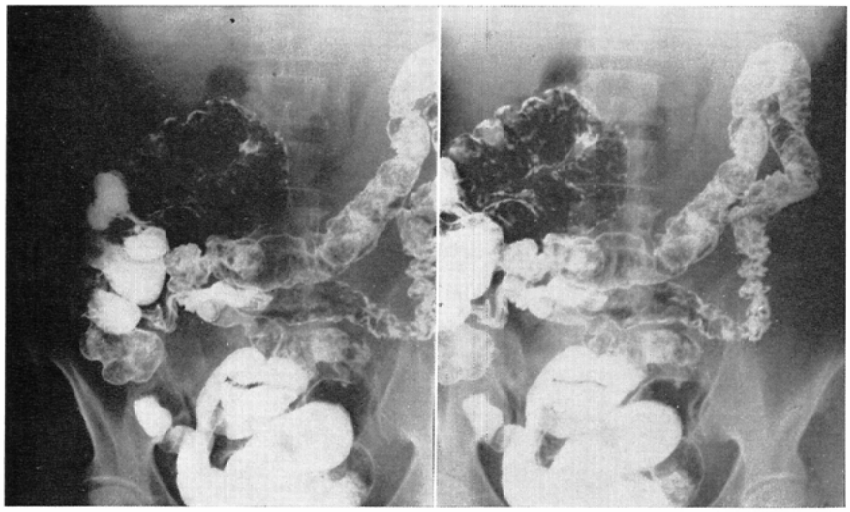


The same case as mentioned above was viewed by the simultaneous method, and better stereovision was obtained. (Phot. 8)

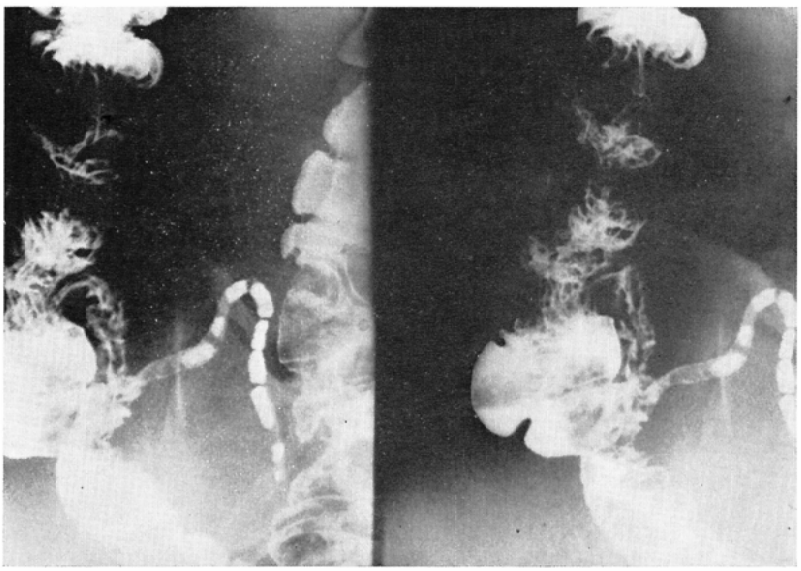
7) Adhesion after excision of abdominal reticulosarcoma (by the manual method).

In a case of ileocecum tumor, adhesion was produced after its excision. The manual method after

Phot. 9. Adhesion after excision of abdominal reticulosarcoma (by the manual method)



Phot. 10. Ileocecum region (by the manual method)



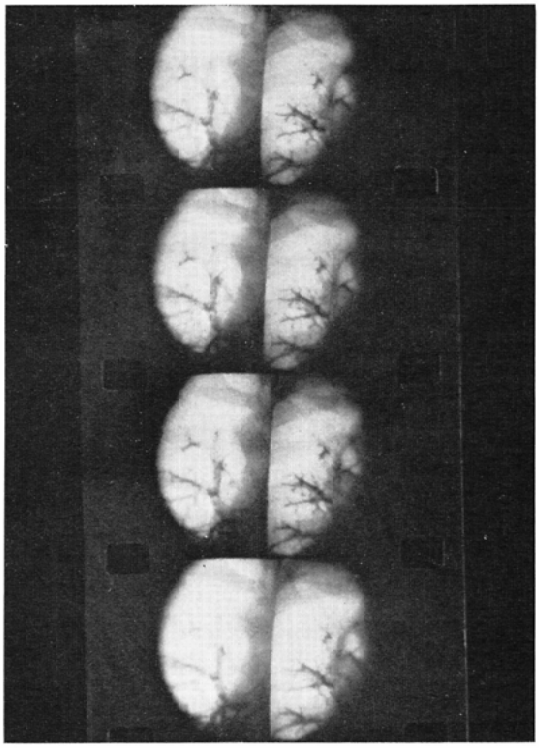
barium enema disclosed that the transverse colon turned antero-inferiorly from the splenic flexure, and that the ascending colon had adhesion a little above the ileocecum region, then extending postero-superiorly to the hepatic flexure. (Phot. 9)

8) Ileocecum region (by the manual method)

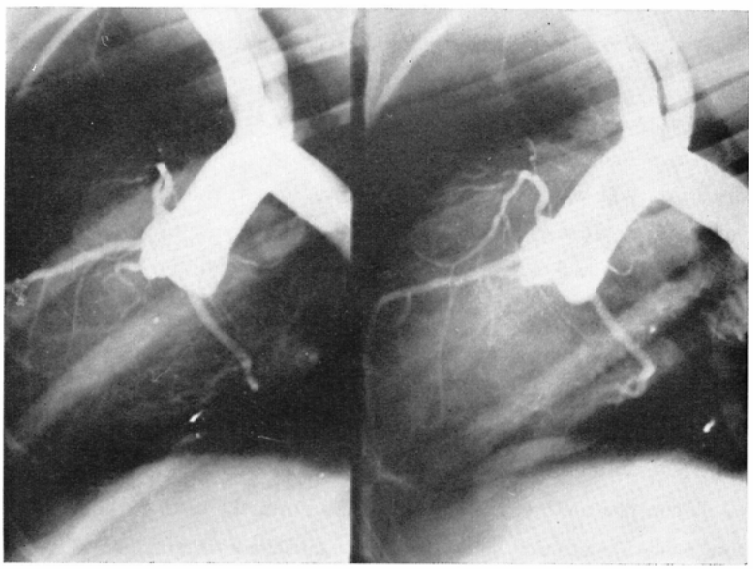
Stereovision of the ileocecum region. The appendix vermiformis protruded anteriorly from the ileocecum, and after making curvature extended posteriorly. The ascending colon ran rather superofrontally. (Phot. 10)

9) Bronchography (by the simultaneous method)

Phot. 11. Bronchography (by the simultaneous method)



Phot. 12. Cardioangiography (by the simultaneous method)



A case after operation of pulmonary cancer.

After the injection of contrast medium into the bronchus, it was recorded cinematographically. The bronchial configuration could be viewed both kineticlly and stereoscopically. (Phot. 11)

10) Cardioangiography (by the simultaneous method)

The simultaneous method was applied to the angiography. A catheter was inserted into the aorta of an adult dog to inject contrast medium, and satisfactory stereovision of bifurcations and extensions of the coronary arteries was obtained. (Phot. 12)

Discussion

Progress in angiography has antiquated the hitherto used stereoroentgenography by tube sift and necessitated the development of a new method which is capable of taking three-dimensional X-ray picture of the motile organ. As the result, Fernstrom's method (1955)[4] making use of a mechanized casette changer and various other devices have been attempted. In all of them, sequent exposure of two tubes are resorted to in order to take two images in a shortest possible time interval. Against this, our method is not sequent but perfectly simultaneous exposure of two tubes, taking two images on the same film strip. In it, have naturally been introduced the enlarging radiography and high voltage method, and consequently problems of scattered ray, visual field and various others have been raised. Below are described how each of them has been dealt with, and how they are compared with those of other methods. Moreover, significance and future of stereoroentgenography are also discussed.

The plane roentgenography has fatal defect that it must be observed the three-dimensional human body only plainly. It is difficult by this method to grasp the position, size, depth, etc of the organ exactly three-dimensionally. Even by the best X-ray picture we may fail to comprehend rightly the overlapping of images. And additional lateral or multidirectional roentgenography is helpless in many occasions in the assessment of the image. In contrast with this, it is easy by stereo-roentgenography to determine, for example, the depth of the focus. It is also easy to compute theoretically the value from the direct measurement on the film[23]. In this way, we may judge the state of the focus to some degree without performing tomography. Or we may perform tomography more effectively by preliminarily knowing the depth of the focus by the above mentioned method. It is also a significant feature of our method that even the biginner can observe the focus intuitively and stereoscopically if it is correctly used.

Our method has thus great advantage in roentgenological observation of the living body, and can be said ideal for X-ray diagnosis.

Now some discussion will be made on the procedure, and at the same time on what points should be improved in the future. It is prerequisite in stereoroentgenography of the gastrointestinal canal to give double contrast media to make distinct the state of the mucosa, and for this purpose it is necessary that barium should stick well to the mucosa. Saito, et al (1966)[18], by using antiacids, parasympathetic blocking agent or digestive enzyme, have succeeded to make distinctly visible not only stomach relief but also gastric area. If this method is applied in stereoroentgenogarphy, it is possible to discern stereoscopically a smallest focus in gastric mucosa as well as early stomach cancer. On the other hand it was found out that in the general fluororoentgenography of the duodenum and others where it is difficult to use effectively the double contrast method or where they can not make distinct the lesional area, the routine dorsoventral exposure in side position sometimes gave satisfactory result Now stereoscopic viewing is

often successfully performed by the manual method with the patient in side position, but the range of its application is naturally restricted owing to the limitation of the manual method. In this case, the simultaneous method is of course usable, if the apparatus are especially arranged for this purpose.

Now some words will be said concerning the procedure of stereoroentgenography. In the manual method rapid operation is necessary, since the object must be exposed successively twice in the same phase. On account of this, Kerekes (1956)[8] and Wise (1960)[27] made use of spot film, and we employed, besides it, drug to inhibit the movement of the organ, with good result. But despite the rapidest possible operation, stereoscopic observation may fail if the rapidity of organ movement exceeds that of the operation. Also the inhibition of organ movement by pretreatment with parasympathetic blocking agent or other has its limit, and so the object of exposure is also limited. If more effective inhibiting drug is found, the manual method can of course be applied more extensively. In order to shorten time of tube-shift, some use two tubes, which are exposed one after other. In this case, special devices for film exchange are made to shorten interval between exposures: Hettler et al (1961)[7] shortened it to 0.1–0.2 sec. by using rollfilm, and Fernstrom et al. (1955)[4] to 0.17 sec. by means of a mechanized casette changer. Their accomplishments clearly demonstrate that stereography can thus be applied sufficiently well to angiography. With our model, however, the interval between two exposures is zero, that is, two images can be recorded simultaneously, so that the movement of the organ causes scarcely any trouble. But in providing two tubes, a special apparatus must be placed. Any further, for the enlarging radiography, it is imperative to use tubes of small focus in order to obtain clear image. In recent years, highpowered tubes of small focus have been developed, and are used in the routine enlarging radiography without any significant disadvantage. When the subject of exposure is obese, the high voltage apparatus can be used. For the prevention of the effect of scattered ray and for improving the sharpness of the image, Santos (1966)[19] placed, between the tube and the object of exposure, a lead box with holes corresponding to the cone of ray. In our model, a lead cone is directly connected to the X-ray tube, and by this means the objective has easily been attained. As for the range of view, there is no problem with the manual method as with the conventional radiography. With our simultaneous method, however, the range is 8 cm$\times$12 cm as above mentioned, since two images must be recorded on the same film strip by the enlarging radiography. But if the spot radiography is made by this method after locating the aimed lesion by fluoroscopic observation, it gives scarcely any practical inconvenience. There is room, also in this case, for enlarging the visual range by elevating the capacity of the apparatus. Nearly the same can be said with the cinematographic method. But because this need many optical parts such as an image intensifier and a camera, its resolving capacity is naturally lowered, and there is also significant difficulty in the method of observation. But at the same time it has fascinating advantage that it can not only record the motile organ both kineticly and stereoscopically, but also make possible the direct stereofluoroscopic observation. Zarnstorff et al (1964)[29] succeeded in stereoradioscopic observation of the coronary artery by recording the left and right-eye images alternately on the same film strip by the help of a circular mirror, and by viewing them through a polarizing filter. Marked improvement has recently been made in the image intensifier so that we can expect bright future of the cinematographic method.

Furthermore, the lately developed subtraction technique (Rockoff et al, 1962[17], Wise et al, 1966[28]) and television[12][20][21] are also expected to make contribution to stereoroentgenography. After all our simultaneous method is considered one of the best, since it has fulfilled the absolute requirement of the

Table 3. Comparison of different methods

Method	Resolving capacity	Viewing method	Stereoscopic effect	Remark
Direct radiography	50 lines/cm	With stereoscope or naked eyes	Good	Manulal method: Visual range large. Manipulation simple. Pretreatment with drug necessary. Application limited. Simultaneous method: Visual range limited (8cm ×12cm). Special devices necessary. Pretreatment unnecessary. Application extensive.
Indirect radiography	33 lines/cm	With stereoscope or naked eyes	Satisfactory	Less effective than the manual method. Film 60mm×60mm
Cinematography, image 5″	15 lines/cm	With naked eyes	Unsatisfactory	Not within the visual range of the simultaneous method. Resolving capacity poor.
Cinematography. image 9″	20 lines/cm	With naked eyes	Satisfactory	16 mm-cinecamera used. Stereofluoroscopy possible. Good kinetic and stereoscopic observation
Television (TV)	25 lines/cm	With naked eyes	Satisfactory	
Video tape recording	?	With naked eyes	?	Repeated observation possible

stereoroentgenography by the capability of taking the two images of an object in the same phase. Table 3 summarizes the above mentioned various methods.

Summary

Stereoroentgenography of the motile organ, especially of the alimentary canal, was performed with our model of simultaneous radiography by simultaneous exposure by two tubes as well as by the conventional method of tube sift. And it was confirmed that by these methods, state of the mucosa, and passage of the alimentary canal could be grasped correctly and three-dimensionally. Particularly the simultaneous method was excellent.

The simultaneous method was also applied to bronchography and angiography. Further, the simultaneous cinestereoroentgenography was attempted with satisfactory result in stereoscopic observation.

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