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ROENTGENOLOGIC EXPLORATION OF THE MUCOSA OF THE GASTRO-INTESTINAL TRACT*

By THE COLE COLLABORATORS

FOREWORD TO AN ADDRESS PRESENTED BY INVITATION TO THE THIRD INTERNATIONAL CONGRESS AT PARIS

MR. PRESIDENT: On behalf of the roentgenologists of America I wish to express the appreciation of my colleagues for the honor you have done our country in assigning to America a consideration of this very important and controversial problem. Realizing as I do that the literature would indicate that very little consideration has been given to this subject by them, this honor is all the more appreciated.

To the American delegates, both my associates and myself wish to express our great appreciation of the honor done us in this assignment.

To the members of the Congress I wish to say that the article here presented is merely a résumé of data that have been assembled in a far more extensive article which will be published serially in RADIOLOGY. The complete data will include the reports of personal communications from many of the foremost American roentgenologists, an extensive study of the foreign literature with translations into English, the assembling of material from the various institutions with which I am associated, and the designing and actual construction of apparatus for applying the localized pressure technic. The assembling of these data and preparation of the illustrations could have been accomplished only by the very hearty and loyal co-operation of those who are directly associated with me. This refers to Robert Earl Pound, M.D., Russell Wright Morse, M.D., Courtenay I. Headland, M.D., William Gregory Cole, M.D., and Ames W. Naslund, M.D., who are herein referred to as The Cole Collaborators, and under which title this complete article will be published.

The honor of presenting this subject would undoubtedly have fallen to the late Preston M. Hickey had he lived, and considering this fact, and the great honor and respect in which Preston M. Hickey was held not only by American roentgenologists but by roentgenologists throughout the world, this complete

*Presented at the Third International Congress of Radiology, Paris, July, 1931, by Lewis Gregory Cole, M.D.

article will be assembled in a bound volume as a memorial to the Dean of American roentgenology, Preston M. Hickey.

The title "Roentgenologic Exploration of the Mucosa of the Gastro-intestinal Tract," which was assigned to us, is an unusual one, probably due to the translation from one language to another, but the term "exploration" is so applicable to the early history of this problem in which the participants were real explorers, that I am more and more pleased with the title as it was assigned.

HISTORY

Reviewing the development of gastro-intestinal roentgenology as presented by Dudley Roberts before the American Gastro-enterological Association in 1928, we find that "Hemmeter must be given credit for first suggesting a way of visualizing the stomach, by means of his intra-gastric bag filled with lead solution. These experiments were not successful but were the first attempts State Normal School, Baltimore, Maryland."[1]

Wolf Becker, in 1896, reported on his experiments with animals, in which experiments he attempted to fill loops of intestine and the stomach with lead solution. These experiments were not successful but were the first attempts at the use of free opaque solutions to make visible the lumen of the hollow viscera.

H. P. Bowditch, Professor of Physiology at Harvard University, in the Fall of 1896, suggested to Walter B. Cannon that the X-rays be used as a means of studying deglutition under normal conditions. This was the beginning of Cannon's famous researches on the motor phenomena of the esophagus, stomach, and intestines. The first public demonstration of movements of the alimentary tract by use of the new method was given in Boston, Dec. 29, 1896. At this time the phenomenon of deglutition as exhibited by the goose when swallowing capsules containing bismuth subnitrate was informally demonstrated by means of the roentgen rays before the American Physiological Society. The first report of the studies of the stomach of the cat was made before the American Physiological Society, May 4, 1897. Cannon was the first to use free bismuth in an opaque meal in animals, and this meal consisted of subnitrate of bismuth mixed with bread which had been softened to a mushy mass by milk, hot water, or thin gravy. Cannon, himself, states that the first *published* account of the use of bismuth subnitrate to make visible the alimentary tract was given by Rumpel, who, on April 20, 1897, published a report of rendering a pathologically dilated esophagus visible by pouring into it 300 c.c. of a 5 per cent suspension of bismuth subnitrate.[2]

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[1]We have in our possession a photographic copy of a letter from W. C. A. Hammell verifying Hemmeter's claims.

[2]We have recently received a personal letter from Dr. W. B. Cannon confirming the accuracy of these statements. He has recorded the early history of his work in an article written in 1913 ("The Early Use of the Roentgen Ray in the Study of the Alimentary Canal," Jour. Am. Med. Assn., Jan. 3, 1914, LXII, 1–3).

Apparently independently and contemporaneously, on June 12, 1897, and July 24, 1897, before La Société de Biologie, Roux and Balthazard presented their first reports of the use of the bismuth opaque meal in the study of the motor function of the stomach. Their full report, published in 1898, included studies of the stomach of frogs, dogs, and man by use of the bismuth opaque meal. Their studies are epochal because these writers were apparently the first to study the *human stomach* by means of an opaque meal, using 15–20 grams of subnitrate of bismuth suspended in 100 grams of water or syrup; and secondly, because they were the first to conceive the value of cinematographic study and devised a single plate-changing apparatus which enabled them to make roentgenograms of the frog's stomach at regular intervals during the progress of the peristaltic wave. Although incomplete, their observations of the gastric motor phenomena in man were exceptionally accurate.

Francis H. Williams, of Boston, deserves far more credit than he has ever received for his early recognition of the value of the roentgen rays in medicine and surgery. Perhaps this is because his extreme reticence has prevented him from claiming it or even accepting it. Williams's book, "Roentgen Rays in Medicine and Surgery," published in 1901, is an early classic. Williams, assisted by Cannon, on Sept. 23, 1899, administered an ounce of bismuth subnitrate in a meal, consisting of a pint of milk into which bread had been broken, to a child ten years of age. Fluoroscopic studies were then made, and twelve tracings made of this and another case at various stages of gastric evacuation and in different postures were recorded in Williams's book in 1901. The findings which are there recorded are remarkably accurate as regards the changes in size, shape, and position of the stomach as the result of respiration, change of posture, and digestion. Williams's Fig. 201 is a reproduction of a tracing which had previously been published in the Transactions of the American Climatological Association, 1898. This was a "cut of a tracing made by means of the fluorescent screen from a girl seven years old, showing the outline of the stomach one hour after a meal of bread and milk containing subnitrate of bismuth."

At the Boston City Hospital, where Williams is an attending physician, he has never allowed the title of "roentgenologist" or "radiologist" to be employed. The appointment is recorded as "physician in charge of the X-ray Department." It has always been his conception that the roentgenologist should primarily be a physician rather than a laboratory worker, and that he should be interested in all phases of medicine rather than limit himself to the making and interpretation of roentgenograms. At the present time the justification of his attitude toward this problem is just becoming recognized. It gives us great pleasure to herewith reproduce an autographed photograph of Dr. Francis H. Williams in recognition of his great wisdom concerning the status of the roentgenological physician.

Einhorn, on April 1, 1899, at the office of Willy Meyer, used the X-ray in a single case to demonstrate a powder blower which he had designed for applying medication to the gastric mucosa.

"In 1898, Holzknecht began using small dose of bismuth in aqueous suspension, especially for the study of the esophagus on a firm basis, but the visualization of the stomach and intestines was not furthered by such meals" (Roberts).

Then for almost half a decade there was a silent era broken only by the contributions of O. Kraus and Lommel. A schematic chart (Fig. 2) helps one to visualize the time relation of the historical events.

Nearly five years later (1904), Rieder, of Munich, with much more publicity and without giving due credit to Roux and Balthazard and no credit to Williams, advocated the use of a meal, the composition of which was almost identical with that previously described and employed by Williams. As a result of Rieder's announcement, this opaque meal of gruel and bismuth became known the world over as "Rieder's meal."

During the following years, 1905–1909, fluoroscopic exploration of the gastro-intestinal tract, with "symptom-complices" as the criterion on which the interpretation of the findings was based, became the vogue, particularly on the Continent. Until 1909, Austria and Germany led the world in this work and among the leaders the names of Holzknecht, Strauss, Rieder, Schwartz, Kreuzfuchs, Groedel, Albers-Schönberg, Haenisch, and Kienböck are outstanding. Many students from all over the world, and particularly from the United States, were attracted to the clinics of Austria and Germany.

An explanation of this popularity of fluoroscopy and symptom-complices is found in the fact that at this time roentgenography of the moving parts was most unsatisfactory. During these years the mechanics of producing X-rays and roentgenograms had not developed sufficiently so that one could obtain satisfactory roentgenograms of the gastro-intestinal tract. Intensifying screens had been employed for the intensification of the photographic effect of the ray in scientific experiments, but these had not yet come into practical use for gastro-intestinal roentgenography. The only two methods of exciting the X-ray tube were by the static machine and by the coil. Neither the static machine nor the coil, however, was powerful enough to make satisfactory roentgenograms in a sufficiently short period of time to avoid blurring incident to the movement of the gastric peristalsis. The slower movement of the colon rendered roentgenography more practical in this region than in the stomach or small intestine. At one time from fifteen to twenty minutes were required to make an exposure of the abdomen as for a kidney stone. By 1903–04, as a result of gradual improvements in apparatus, the time of exposure had been reduced to fifteen or twenty seconds so that roentgenograms could be made of the kidney stone while its motion due to respiration was stopped. Sufficiently rapid exposure to avoid the motion of gastric peristalsis, however, continued to be impossible. Roentgenograms of the stomach were so blurred that they were of little or no diagnostic value. Both methods of exciting the tube, however, were sufficiently strong to enable one to observe fluoroscopically the size, shape, and position of the stomach, as well as some of the grosser lesions of the stomach, when present.

In the United States the resurrection and further development of gastro-intestinal roentgenology dates from 1905. In that year, Hulst, who had visited Rieder in Munich, informally presented roentgenograms of the gastro-intestinal tract at the annual meeting of the American Roentgen Ray Society in Baltimore. The following year, as his presidential address before the American Roentgen Ray Society, he presented an illustrated comprehensive paper on the roentgenographic method of examination of the gastro-intestinal tract which was so complete that it furnished a new impetus to the method Williams had suggested seven years previously. In this paper Hulst accords credit to Williams for giving one ounce of bismuth in emulsion as early as 1897, and it may be this fact to which Williams refers (p. 359 of his book).

The Advent of the Transformer and Screen.—At the same meeting (American Roentgen Ray Society, 1906) at which Hulst resurrected gastro-intestinal roentgenology, Snook first presented the electrical facts upon which he developed and made practical the transformer which superseded the static machine and coil. Snook developed the transformer in 1907, and this, with the improvement and application of the intensifying screen, enabled exposures to be made in a fraction of a second—thus the blur, due to movement of the stomach, was eliminated.

Prior to the advent of the transformer and intensifying screen, bismuth was suspended in a thick gruel which prevented it from filling the crevices between the rugæ. When roentgenograms that showed greater detail became available, bismuth was suspended in buttermilk, which allowed the mixture to seep into the spaces between the mucosal folds in a manner that it could not do when suspended in thick gruel. Then, for the first time, routine plates were made which showed the rugæ of the stomach. With this technic it was possible to observe any growth that protruded sufficiently deeply into the stomach to cause an irregularity of the contour, which was then termed a "filling defect." It was possible also to note spasm of local regions of the stomach or pressure from without, likewise causing a similar "filling defect." In a filling defect due to spasm (Fig. 3) the rugæ were observed within the deformed area; however, in a filling defect caused by a growth protruding into the lumen of the stomach (Fig. 4), the rugæ were singularly absent. Thus, as far back as 1908–09, the first of the four fundamental findings that will later be described, namely, alteration in contour, and the fourth of these findings, the pattern of the mucosa, were already considered of paramount importance in the diagnosis and differential diagnosis of gastric cancer. There then ensued a long and bitter controversy concerning the relative value of symptom-complices observed fluoroscopically and morphology observed roentgenographically as criteria for the interpretation of roentgenological findings into gastro-intestinal diagnosis.

The main contention on the part of those who objected to morphology observed roentgenographically as the proper criterion for diagnosis was that various roentgenograms of the same stomach differ so much in their appearance that a conclusion could not be drawn from the evidence on a single plate. The proponents of the morphologic basis of X-ray diagnosis proceeded to obviate this difficulty by making a series of plates in as rapid succession as possible. As a result, the factor of change in contour that before had been regarded as a disadvantage, proved in reality to be of great assistance. Subsequently this pliability of the gastric wall became the corner stone on which to build roentgenologic gastric diagnosis, and the making of a series of plates in rapid succession was promptly adopted by some observers as a routine procedure and was called "serial roentgenography."

In 1909, Kaestle, Rieder, and Rosenthal attempted to make roentgenocinematographic films of the stomach under the term "bio-roentgenography." They assembled roentgenograms of a normal individual and reproduced these cinematographically to illustrate the normal motor phenomena of the stomach. Through the courtesy of George E. Brewer and William G. Lyle, who was then private physician to E. H. Harriman, the author had the opportunity to observe this roentgenocinematographic demonstration of Kaestle, Rieder, and Rosenthal. This procedure was applied to the study of the motor phenomena of the stomach. Subsequently I was able to find only one cinematographic film which was a reproduction of serial roentgenograms made by their method. With few exceptions, particularly Meyer of Berlin, this method was not accepted on the Continent as a practical method of roentgenological diagnosis of gastro-intestinal lesions.

In 1909 the author began making from ten to twelve plates of the stomach in each of three postures, the erect posture, the prone posture, and the prone oblique posture in which the patient lies on the right side, as a routine procedure for the study of the stomach in every gastro-intestinal examination. To this method he applied the term "serial roentgenography." Because of the frequent intentional and unintentional misinterpretation and misuse of this term, it is best to define here what is meant by "serial roentgenography" as applied to the stomach. Serial roentgenography is a series of eight or more roentgenograms made of the filled stomach in one posture of the individual, these roentgenograms to be made at intervals of from four to ten seconds, so that in this series all of the phases of the gastric motor phenomenon will be depicted. In order to be of value such a series of roentgenograms must be made with the individual in two different postures, the erect and prone, and in two directions, the postero-anterior and oblique. Serial roentgenograms (Figs. 5 and 6) are of limited value unless they are observed on an illumination box of sufficient size so that they may all be observed at once and compared one with another.

During this time the symptom-complex method was used almost exclusively on the Continent. In America, however, during the period of intense development of the direct method there were many minor skirmishes between advocates of the two methods. The real battle occurred in Chicago at the meeting of the Mississippi Valley Medical Association in 1912. Skinner was the advocate of the Continental method. Selby, also favoring the Continental method, was roentgenologist at the Mayo Clinic at the time, and, acting under instruction, stated that, while the X-ray was useful in examining bones and lesions of the kidney and chest, it was valueless fluoroscopically and otherwise as a method of diagnosis of gastro-intestinal lesions. Your essayist presented a series of roentgenograms in support of his contention on behalf of the direct method. These roentgenograms illustrated characteristic deformities of the lumen of the gut that are caused by certain pathologic lesions, particularly cancers, gastric ulcers, postpyloric ulcers and gall-bladder adhesions, calling attention to the points of differentiation among them. This brought the two methods into direct controversy, which raged for a number of years. Carman, who succeeded Selby as roentgenologist at the Mayo Clinic, rather elaborately described a group of what he called "roentgenologic signs" as a basis for the diagnosis of gastro-intestinal lesions. These roentgenologic signs represented the principles included in the symptom-complices, but, in addition, included the direct detection of some of the grosser pathologic lesions by fluoroscopic examination. He was the last influential advocate in the United States of the symptom-complex method of diagnosis.

Among the earlier supporters of the direct method of examination, Arial George gave the essayist more support than any other person, particularly in the diagnosis of postpyloric ulcer, and this subject became the storm center of a cyclonic controversy in Boston in 1913.

At the time that the serial method was being established it was noted that the mucosal pattern was of great significance, especially in the diagnosis of organic lesions and the differential diagnosis of malignant lesions from spasm. With the roentgenographic technic it was observed that any growth which protruded into the stomach caused an irregularity of contour known as a "filling defect." Spasm of local regions of the stomach or pressure from without caused a similar defect. In a filling defect due to spasm or pressure, the rugæ were observed within the deformed area; however, in a filling defect caused by a growth protruding into the lumen of the stomach, the rugæ were singularly absent. Thus, as early as 1909 the first of the four fundamental findings (Fig. 4), alteration in contour, as well as the fourth fundamental finding, the pattern of the mucosa (Fig. 3), became of paramount importance in the diagnosis and differential diagnosis of gastric cancer.

A special technic was, therefore, developed to accentuate the mucosal patterns. This special technic consisted of sedimentation of bismuth from a thin watery suspension onto the anterior or posterior gastric wall. Details of this technic will be described later. However, at this time we are submitting illustrations to show that the characteristics of the mucosal pattern were even then considered of significance. The roentgenogram illustrated in Figure 7 was made on October 13, 1910, and represents the essayist's first attempt to demonstrate the pattern of the gastric mucosa by a special technic. The roentgenograms illustrated compare favorably with the more modern methods of observing the mucosal pattern.

For a time both the serial method and the special mucosal technic were used on the same patient in order to determine which would be the more satisfactory to adopt for the routine procedure. The serial method with a moderately filled stomach, although far more extensive and, therefore, more expensive, seemed to us to be of much greater value than the special mucosal technic, and was, therefore, adopted as our routine method of examination. The special mucosal technic was used only as an adjunct in certain specific cases. Serial roentgenography was also applied to the mucosal technic (Fig. 8).

At this time the spirit of the pioneer was rampant and we moved from one field of exploration to another with such rapidity that we could not "get organized." These were grand and glorious days to which all subsequent exploration seems tame. Now as I review the evidence that we then assembled, it seems as though there is little that has been added in the last two decades. In proof of this we are largely illustrating this communication with roentgenograms made during this early period.

History of Roentgenological Methods for Study of the Mucosa.—A thorough comprehension of modern technic as employed by various investigators of the gastro-intestinal mucosa is essential to an understanding and interpretation of their findings. Åkerlund, 1921, rediscovered the direct method and published an extensive monograph on duodenal ulcer in which he discussed at length the deformities of the "duodenal bulb" incident to ulcer. He directed particular attention to the correlation of the morphological changes observed in the roentgenograms and the anatomic-pathologic changes observed in specimens obtained by operation and autopsy. This work created or marked the beginning of a new era in roentgenology of the gastro-intestinal tract *as practised by roentgenologists on the Continent.* Symptom-complices were forgotten. The direct roentgenological detection of morphologic changes in the wall of the gut became the fashion. This revived on the Continent the same old controversy concerning the relative value of symptom-complices and direct morphology which had been definitely settled in the United States a decade earlier.

Åkerlund mentioned the "method of the thin layer," explaining that by exerting external pressure upon the duodenal bulb all but a thin layer of the opaque contents may be forced out of the cap, bringing to view the markings of the mucosa and ulcer craters which otherwise would be obscured. Baastrup and Rendich, in 1923, published papers dealing with special methods for demonstrating the pattern of mucosal folds in the stomach. These ideas were greeted as a new departure. Many observers became "mucosa conscious." Yet, whenever a certain idea or method becomes the center of interest, it is always wise to look back over the literature to see what is new and what is a revival of someone's previous work.

In the following section we shall present chronologically the history of certain technical methods of roentgenologic examination of the gastro-intestinal tract. The general story of the usual methods has been presented in the previous chapter, so, at this time, more detail will be devoted to the technical methods of study of the mucosa.

Rieder, 1904, noticed after a bismuth enema had been injected, and after the patient had been standing for a few minutes, that the bismuth would precipitate out of solution into the dependent part of the haustral divisions of the colon, and that this outlined the haustral divisions much more clearly than would the solution originally injected. This was illustrated by him at that time.

Holzknecht and Brauner, 1906, used a watery suspension of bismuth subnitrate in the preliminary part of the fluoroscopic study of the stomach (10 gms. bismuth subnitrate in 50 gms. water, to which is added a tablespoon of milk sugar). Palpation of the stomach in the erect posture made possible the visualization of the mucosal folds. After this procedure, and while the stomach still contained the bismuth suspension, they distended the stomach with gas by having the patient ingest an effervescent mixture of from 4 to 5 gms. of tartaric acid and from 5 to 7 gms. of natrium bicarbonate. The usual opaque meal consisted of 400 gms. of milk gruel and 35 gms. of bismuth subnitrate.

Independently, F. M. Groedel and Erich Meyer, in 1908, recommended the substitution of bismuth subcarbonate for bismuth subnitrate. Due to impurities frequently present in the bismuth subnitrate there was the danger of poisoning from the use of this salt.

The essayist, in 1909, with intent to show the mucosal folds, used the principle of sedimentation of bismuth subnitrate from a watery suspension as a special technic for the demonstration of the mucosal pattern on the anterior and posterior walls of the stomach (Figs. 7 and 8).

Bachem and Gunther, 1910, introduced the use of barium sulphate. Cannon used or suggested the use of barium sulphate as early as 1904.

The mixture of opaque salts with gruel formed a stiff meal which did not readily fill the folds of the mucosa of the stomach. For this reason, after about 1908, in the United States, the opaque salts were mixed with buttermilk. This formed a non-sedimenting suspension of fluid consistency.

Stiller, 1910, criticized the use of the bismuth gruel opaque meal, claiming that its use produced an abnormal condition of the stomach due to the high specific gravity of the meal and the astringent influence of bismuth upon the stomach. For several years there was considerable controversy on this subject.

von Elischer, 1911, working to settle this controversy, sought to study the stomach with a contrast substance, of the smallest amount necessary to make the stomach completely visible, and one which would do away with the high specific gravity and possible chemical irritation of the bismuth meal. He used a thick fluid emulsion mass composed of 75 gms. of "Zirkonoxyd" and from 30 to 40 c.c. of mucilage of acacia. Of this emulsion, from 30 to 40 c.c., which has a weight of from 50 to 60 gms., was injected into the stomach through a tube. The patient was then placed prone in different positions for from five to ten minutes so as to get an equal distribution on the mucous membrane of the stomach. von Elischer found that the emulsion distributes itself over the entire inner surface and fills the folds of the mucous membrane. He considered that this method showed the shape of a gastric tumor more accurately than the usual opaque meal. He also used inflation of the stomach with air in combination with the contrast emulsion.

Forssell, 1913, states: "The relief of the mucous membrane can appear inside of the flatness of the roentgen picture in case a less opaque content is used, or if the content is distributed in a thin layer (von Elischer's method)." Åkerlund, 1921, working in association with Forssell, applied the method of the thin layer to the roentgenologic diagnosis of lesions of the duodenal bulb by using external pressure to displace from the bulb all except a thin layer of the opaque content.

This same method was immediately adopted by Eisler and Lenk, 1921, who used small amounts of barium solution, together with pressure from without, regulated under fluoroscopic control, for the study of the inner surface (mucosal folds) of the stomach.

Baastrup, in a paper read in June, 1923, suggested two methods for obtaining films of the mucous membrane of the stomach. The first method was inflation of the stomach with air saturated with barium powder (similar to a method advanced by Laurell for the examination of the colon). The method was difficult to employ and was soon abandoned. This was similar to the blower demonstrated by Einhorn in 1899. The second method is based upon the physiologic studies of rats' stomachs and the studies on humans of Kaufmann and Kienböck (1911), by which it has been shown that the food latest partaken of gets inside of the food first ingested. "The patient, while still fasting, is given, first, half a tablespoonful of barium sulphate stirred up with water to a smooth, rather thick emulsion; then, shortly afterwards, about seven ounces of smooth rice-flour porridge, of rather thick consistency and flavored with a little powdered cinnamon or sugar, but without any thin fluid."

Rendich, 1923, used a thick emulsion very similar in nature to that previously described by von Elischer. Mucilage of acacia 50 per cent (powdered gum arabic to an equal volume of water) was employed, to which an equal quantity (by volume) of bismuth subcarbonate is added. Honey was also substituted for the mucilage of acacia but did not prove as satisfactory. This emulsion was administered to the patient while he was in the partially recumbent position (10° incline). In this communication Rendich does not make any mention of the previous work which had been done, particularly of the work of von Elischer, which he practically duplicated, and does not mention that while studying in the Army Training School he became fully conversant with your essayist's method of sedimentation of bismuth from thin watery solutions onto the anterior and posterior walls of the stomach.

Pribram and Kleiber (1927), Hilpert (1928), and Vallebona (1926) have revived the combined use of a barium suspension and air distention. The work of Pribram and Kleiber has been limited to the duodenum, while that of Hilpert and Vallebona has had to do with both the stomach and duodenal bulb. Small amounts of barium suspension are ingested and distributed between the rugæ by manual pressure and then the stomach is distended by air injected through a small tube (Pribram and Kleiber, Hilpert), or by chemical means (Vallebona). This method has the disadvantage of diminishing the prominence of the mucosal relief by the distention of the stomach and duodenum.

Trautner and Hoecker, 1927, introduced into the stomach a tube, the end of which was covered with a thin rubber bladder. The bladder was moderately distended with air, and then a small barium meal was given which would settle between the bladder and the gastric wall.

Certain phases of the work of three observers, Åkerlund, Berg, and Chaoul, demand special attention. Åkerlund and Berg use, as a contrast mixture, barium and water in the proportion of three parts of barium to four parts of water. Chaoul uses a mixture of barium, tragacanth, and water. With all three of these observers the element of pressure is the main part of the procedure in securing the distribution of the opaque medium and in acquiring the optimal demonstration of the mucosal pattern.

Åkerlund originally maintained that the method of applying pressure should be as simple as possible. He used the Forssell fluoroscope, designed for both fluoroscopy and roentgenography. The screen of this fluoroscope is so arranged that it may be pressed against the patient and locked in position with the maintenance of any desired degree of pressure. For localized pressure, Åkerlund inserted between the screen and the patient pads of hard cotton, wool, cork or other non-opaque material. Subsequently, he has developed two other methods of pressure. The first is a cone which may be attached to the back of the fluoroscopic screen, into the end of which cone is mounted an inflatable rubber bag. The finer degrees of pressure are obtained by inflation of this rubber bag. The second method is a larger tube to which has been adapted a skillfully designed carrier containing a rotary Bucky diaphragm, and cassette holder. The desired amount of pressure is first secured by fluoroscopic observation, and then the carrier of the Potter-Bucky grid and cassette is substituted for the fluoroscopic screen. The carrier must be withdrawn and reloaded for each exposure, which renders rapid, frequent exposures impossible.

Berg also uses a fluoroscope designed for both fluoroscopy and roentgenography. Pressure is obtained by a tube mounted on the back of the fluoroscopic screen. His apparatus is so arranged that at the moment he sees a fluoroscopic image which he wishes to record, almost instantaneously a cassette is dropped into place, the transformer setting is changed for roentgenography, and the exposure is completed.

Chaoul exerts pressure through a rubber bag strapped in position by means of a leather belt and under fluoroscopic control. Serial roentgenograms are made with the patient in the prone position on a roentgenographic and indirect fluoroscopic table similar to the Cole table. Chaoul uses the fluoroscope only for localization and for the control of the pressure exerted by the inflated rubber bag.

Colon.—The universal method for roentgenographic examination of the colon has been to fill the colon completely with an opaque clyster. This was originally used by Rieder (1904). With some modifications in the composition of the opaque solution this method has remained the routine procedure. Laurell (1921) and A. W. Fischer (1923) suggested the combined use of an opaque suspension and air injection. Laurell injected the colon with air while it was filled with a barium meal. Fischer administered a barium enema, then had the patient evacuate the enema, after which a small amount of the opaque suspension remained in the colon. He would then inject air into the colon. Some of the opaque suspension would remain as a coating on the wall of the colon and its shadow would be sharply defined from the shadow of the air distending the colon. This procedure, of course, would show the mucosal surface with the lumen of the colon distended and, therefore, with a minimum folding of the mucosa.

The more common procedure has been to study the colon after evacuation of the opaque enema, at which time the mucosal folds are most prominent, due to contraction of the colon, and are well outlined by the thin layer of opaque mixture which remains in the contracted areas of the colon after evacuation. This method has been used extensively by Knothe, Berg, Fischer, and Pansdorf, as well as by Frick, Blühbaum, and Kalkbrenner, and has been routinely used by your essayist since 1915.

In the following sections we present a résumé of our own technical methods and certain principles of procedure which have been found helpful. These are discussed under four headings:

(1) Apparatus—Technic of Serial Roentgenography.

(2) Preparation of the Patient.

(3) Choice and Administration of the Opaque Medium, and Roentgenographic Projection and Posture of the Patient.

(4) Application of the X-rays.

(1) APPARATUS—TECHNIC OF SERIAL ROENTGENOGRAPHY

Considering the numerous exposures which are necessary for serial roentgenography, it is essential for economic reasons that the roentgenograms should be as small as is practical to show the region being examined. Extremely small films of the cap and valve are not satisfactory except as complementary evidence used in conjunction with larger films of the entire stomach. To show the entire stomach we have used as small as $6\frac{1}{2} \times 8\frac{1}{2}$ films but prefer 8×10 films for this purpose. We prefer single films for each exposure, rather than multiple exposures on a large film. Multiple exposures on large films are used by some roentgenologists to simplify developing. When this is done the large film should be cut later into single exposures so that the roentgenograms may be matched over each other.

In order to use small films some sort of apparatus which enables one to center the stomach under fluoroscopic control is essential. The reflecting fluoroscope with the mirror set at a 45-degree angle is the best and safest device, especially for the prone posture. The 45-degree angle of the mirror is very essential. Our gradual development of this apparatus in the early days of gastro-intestinal roentgenography and the fact that in some simple form at least it was available in all the institutions with which I was associated, prevented me from recognizing how difficult it was to practise serial roentgenography without such an apparatus. However, when my office was burned in 1924, we were compelled to practise serial roentgenography for a time without such an apparatus, and for the first time I appreciated the difficulties of those who attempt to do serial roentgenography without a convenient method for centering the stomach and changing the films or cassettes.

Why manufacturers are unwilling to build the simple device which we have employed for so many years without making some change of their own that renders it impractical, and why roentgenologists shy from the application of the 45-degree mirror visualization of the fluoroscopic screen with some simple film-changing device, and why they attempt numerous complicated impractical substitutes similar to that recently described by Grier at the meeting of the American Roentgen Ray Society, is one of the mental quirks that it is difficult for me to understand.

The serial table which we use in my private office (Fig. 9) was built as an emergency table just after the fire in 1924 and we have used it ever since. It is so simple that it may be built by any carpenter and, therefore, it does not elicit the interest of the manufacturers of X-ray equipment. It is a box 40 inches high, 36 inches wide, and 7 feet long, placed against a partition which may be a permanent wall or a portable partition which separates the table from an operating booth. Figure 10 shows the details of construction.

Any standard cassettes may be used in a lighted booth. Only one set of screens is necessary if the booth is dark, otherwise, 6 or 8 cassettes with 12 or 16 screens are necessary. The same principle is used for the erect position, with the patient standing at the foot of the table.

A more elaborate serial table has been designed and constructed by one of us (C. I. H.) that may be used without a booth, but it requires cassettes unless it is operated in a darkened room (Fig. 11).

A very simple device consisting of a box about 20 by 24 inches and 10 inches deep, with one side open and a bakelite panel in the top, with a mirror to reflect the image of the fluoroscopic screen, and a horizontal shelf to apply the cassettes to the under surface of the patient, is the simplest of all (Fig. 12). With a wooden leaf at each end which folds back on the top, this box can be placed on any table, and when not in use the leaf at each end folds back on the top of the box and it may be placed on the floor and used as a convenient stool or step. This device was first used at General Hospital No. 1 and was dubbed the "Baby Grand."

The value of serial films is very greatly diminished unless one has illuminating facilities so that all the films can be observed and studied at once, and, therefore, an illuminating box 40 inches high and at least 8 feet long is essential.

A much more elaborate roentgenocinematographic apparatus has been installed in the Joseph Purcell Memorial Laboratory at the Fifth Avenue Hospital, through the generosity of his wife, Anna Purcell. True moving pictures of the stomach and intestine may be made with this apparatus on a roll film 10 inches wide. This film is perforated at the edge and may be moved 10 inches between each exposure. By use of a gear shift, similar in size and construction to an automobile gear shift, several different speeds may be used. Exposures may be made at the rate of 4 per second, 3 per second, 2 per second, 1 per second, or 1 every two seconds, or single exposures at any time interval desired. This apparatus may be used either in the horizontal position for the prone or supine postures, or in the vertical position for the erect posture. It is shown in Figures 13 and 14. The large film may be reduced to the standard 31 mm. (Fig. 15) or the sub-standard 16 mm. film and projected either from a standard or sub-standard motion picture projector, showing not only the motion of the stomach but that of the small intestine, and the relation of rapidity of motion of one to the other. [This film was demonstrated at the Third International Congress of Radiology in Paris, July, 1931.]

(2) PREPARATION OF THE PATIENT

For an examination of the esophagus, stomach, and small intestine, the patient should be in an over-night fasting condition, without catharsis. Even with this precaution and in cases without obstruction, small amounts of food residue are not infrequently found to be present in the stomach. In such cases a longer period of starvation may be necessary. After gastric lavage or after expulsion of the test meal, small quantities of the lavage fluid and of the test meal remain in the stomach and blur the outline of the barium shadow. This is particularly important in the study of the surface of the mucosa by the "thin layer technic." Food remnants, mucus, and air bubbles all produce a confusing mottling of the shadow which may completely destroy all the finer detail. For an examination of the colon or small intestine by colon clyster, the patient should have a thorough catharsis, preferably by castor oil (from 1 to 2 ounces). The cathartic should be given twenty-four hours before the examination is to be made. Waiting twenty-four hours after the giving of the cathartic allows the spastic effect of the cathartic to subside and does away with troublesome spasm during the giving of the enema. Fasting is not essential.

In the colon, as in the stomach, the presence of food remnants (feces) produces a mottling of the contrast shadow which destroys the fine detail and often simulates in appearance certain pathologic findings. We do not believe that the colon can be satisfactorily evacuated by the aid of cleansing enemas. Not only does this method fail to evacuate all of the fecal material, but there is, also, a retention of part of the cleansing solution—which is just as disturbing as the original contents of the colon.

(3) CHOICE AND ADMINISTRATION OF THE OPAQUE MEDIUM AND ROENTGENOGRAPHIC PROJECTION AND POSTURE OF THE PATIENT

As the opaque substance we use, routinely, chemically pure barium sulphate for examination of all parts of the gastro-intestinal tract. We use the single opaque meal, following the progress of this meal through the entire gastro-intestinal tract. This serves to establish the emptying time of the stomach, identifies all parts of the intestinal tract, and indicates the progress of the ingested meal through the small intestine and colon. *If there is any suspicion of an obstructive lesion in the colon, the study of the colon by means of the barium enema should precede the barium meal.*

Esophagus.—For an examination of the esophagus we use a thick paste of barium and water, so thick that the patient cannot swallow it without mixing it with saliva. This thick paste will pass down the esophagus slowly and some of it will remain in the esophagus for a considerable period of time, even with the patient erect. Fluoroscopic and roentgenographic examination may be made in either the erect or supine posture. For the usual roentgenographic examination and to obtain a greater filling of the esophagus it is best to administer the paste to the patient while he is in the horizontal position. For a study of the peristalsis in the esophagus Palugyay elevates the pelvis above the level of the shoulders so that the opaque paste must be forced up an inclined plane.

The esophagus must be studied in the antero-posterior and both oblique projections, exactly as one would step around a tree in order to study its outline.

The demonstration of the mucosal surface by a thin layer depends upon the retention of the opaque substance between the folds of the mucosa or its adherence to the surface of the mucosa. This is difficult to control. We believe this can be best accomplished by originally giving a very small amount

—a level teaspoonful—of the thick paste. This will usually be sufficient to leave a thin coating of barium on and between the folds of the mucosa.

The Barium Meal.—The contour of the stomach, we find, is best shown after a full barium meal—8 oz. by weight of barium to 5 oz. of water—is administered. This amount—7-oz. volume—is less than that employed by most observers but is all that is necessary. Over-distention of the stomach is undesirable as it not only gives a less satisfactory visualization of the stomach and cap, but, also, causes the stomach to obscure an unnecessary amount of upper intestine. This amount of barium insures that the margin of the gastric shadow will be very sharp.

To establish the contours of the various surfaces of the stomach, roentgenograms should be made in the postero-anterior projection and both the right and left oblique projections. For the right, or first, oblique projection, the right side of the patient is against the film; for the left, or second oblique projection, the left side of the patient is against the film.

Roentgenograms made in the postero-anterior projection should be made with the patient both erect and prone, as the profile of the postero-anterior projection is not the same in the erect and prone postures.

The oblique projections may be made with the patient either erect or prone. We believe that the erect posture is preferable, as the anterior and posterior surfaces of the stomach are brought more into profile with the patient erect. In the prone-oblique posture there is a rotation and a lateral shift in position of the stomach.

The roentgenographic examination of the stomach in the erect position should be made as soon after ingestion of the barium meal as the cap and duodenum begin to fill. One of the chief sources of failure to obtain good roentgenograms in the erect posture is that the making of the roentgenograms is delayed by fluoroscopic examination until the gastric muscle has lost its tone and is unable to hold the barium in a column. Early lack of tone and peristalsis may be stimulated by external irritation, either a slap with the hand or a dash of cold water.

When an individual assumes the supine position most of the gastric contents flow back into the fornix of the stomach. This position is very useful when one wishes to study the upper part of the stomach in a dilated state.

The Small Intestine.—The same moderately thick mixture of barium sulphate and water (8:5) serves as the best medium for a roentgenographic visualization of the small intestine. The following conditions must be fulfilled to secure roentgenographic visualization of the small intestine:

1. The opaque medium must be of such composition and consistency that it will pass out of the stomach at a fairly rapid and uniform rate of speed.
2. The medium must be of sufficient consistency to pass evenly—and, preferably, very slowly—through the small intestine.
3. Roentgenographic examinations must be made at intervals which will show the various parts of the small intestines when they are best filled.

Examinations are made routinely at one-half, two, four, and six hours after ingestion of the barium meal, but may be made at more frequent intervals if necessary.

It is *absolutely* essential, if one is to obtain the best roentgenograms of the small intestine, that there be no nutrient value in the menstruum in which the barium is suspended. This eliminates buttermilk, malted milk, and, also, flavoring extracts. Sustained fasting is essential.

Roentgenographic examination of the small intestine is made only with the patient in the prone position. Comparative roentgenograms were made in both the prone and erect postures and it has been found that: (1) The position of the small intestine varied but little in the two postures; (2) the loops of the small intestine were more discretely shown in the prone position; (3) there was no appreciable distortion of the small intestine in the prone position.

It must be remembered, however, that the preceding remarks regarding the position in which the small intestine is studied apply to the use of the barium meal. When one is examining the abdomen to determine whether or not there is an abnormal dilatation of any of the loops of the small intestine by gas due to obstruction, the erect posture is very helpful, in that it allows one to visualize fluid levels in the gas-filled intestine.

Pansdorf varies this procedure slightly in that he does not give the barium meal at one time, but in fractions, the patient taking one swallow every ten or fifteen minutes. This diminishes the bulk of the opaque mixture in the intestinal coils and does not serve as well to demonstrate their caliber.

The *colon* as outlined by the barium meal is examined daily, the roentgenograms revealing the progress of the barium meal through this region.

Visualization of the Mucosal Pattern of the Stomach.—The visualization of the mucosal pattern depends fundamentally upon a satisfactory distribution of an opaque suspension in the furrows between the mucosal folds. There are two methods: (1) The use of a moderate amount of a thin suspension of an opaque salt, through which can be seen the shadow due to displacement of the opaque suspension by the folds of the mucosa, and (2) the methods of the "thin layer."

In roentgenograms made with the first method the folds are shown as less opaque linear shadows within the flat whiteness of the gastric shadow. This method has the disadvantage that the shadow of the opaque suspension as a whole lacks sharpness because of the small content of opaque material.

The method of the "thin layer" may be applied in several ways. The bulk of a full or small sized barium meal may, by external pressure, be displaced from a local region of the stomach or cap, leaving only a thin layer which does not conceal the shadows of the thicker layers of opaque substance which are present in the furrows between the mucosal folds.

The more common and satisfactory procedure is to give only a small amount of the barium-and-water mixture (8:5), a sufficient amount to fill the furrows but not enough to cover the folds. If too little of the barium mixture is used, some of the furrows may not be filled. If too much is employed, the mountain peaks of the mucosal folds may be so flooded by the mixture as to be completely obscured in the roentgenogram.

The greatest difficulty with this method is to secure a satisfactory distribution of the small amount of barium mixture in the stomach. Special methods for the distribution of the barium have been devised to show the rugæ most clearly and to emphasize the mucosal pattern.

When a small amount of the barium mixture is administered, it passes along the lesser curvature in such a manner that this region has been termed the gastric pathway, and trickles into the by-ways of the crinkled rugæ along the greater curvature. Eventually the remainder of the paste is deposited in the antrum: some, perhaps, passes into the cap. This method of distribution depends upon the normal gastric motor phenomenon. Most observers have the patient assume various postures so that the mixture may flow into the furrows with the aid of gravity. Some observers, with more or less success, have attempted to assist Nature by spreading or smearing the barium paste over the surface of the mucosa by using deep manual massage of the abdominal wall, either with or without fluoroscopic control.

Distribution of the Opaque Salt by Sedimentation.—This method was originally employed by the author when he attempted to develop the special mucosal technic previously mentioned. This is accomplished by administering through a drinking tube to a patient in the prone posture, on a flat table, about 1 gram of bismuth subnitrate or bismuth subcarbonate in 4 oz. of water. This amount of solution moderately distends the stomach. In from fifteen to twenty minutes the bismuth settles or gravitates onto the furrows between the mucosal folds of the anterior gastric wall. If the correct amount of bismuth has been used, it just fills the furrows between the rugæ and the results illustrated in Figures 7 and 8 are obtained. If too large an amount of bismuth is used in 4 oz. of water, the furrows are more than filled and the mucosal folds are covered, so that the results are unsatisfactory. A modification of this method is to fill the stomach more completely with a watery solution of 1 gram of bismuth to 8 oz. (120 c.c.) of water. With this larger amount of water, the mucosal folds are smoothed out so that the bismuth settles onto a relatively smooth surface. Then, as the water is drawn off by means of a small tube, the stomach diminishes in size, the mucosa is thrown into folds, and the bismuth becomes incarcerated within the furrows between the folds. We have found that the sedimentation of the bismuth is accelerated if the required amount of dry bismuth is placed on the tongue and then washed down with the 4 or 8 oz. of water.

A preliminary washing out of the stomach with an alkaline solution, in order to dissolve the mucus, makes this method even more satisfactory. The mucosa of the posterior gastric wall may be likewise demonstrated by placing the patient in the supine posture.

The Barium Clyster.—The solution which we use is a suspension of barium sulphate in mucilage of acacia and water: 10 ounces by weight of barium sulphate, 7 ounces of mucilage of acacia, and 32 ounces of water. This solution should be warmed to body temperature before injection. The injection is made by gravity through a rubber enema tube to the end of which is attached a funnel. The rapidity and pressure of the injection is controlled by the height of the funnel above the patient's body. The use of the funnel allows one to see at all times whether or not the suspension is going in rapidly, or slowly, or not at all. Back-flow of the suspension into the funnel is due to temporary contraction or spasm of the colon. The suspension should be injected slowly and at a low pressure. If this is done, one rarely fails to fill the normal colon completely. The injection is followed under fluoroscopic control and should be stopped as soon as the cecum is filled. Over-distention of the colon is a disadvantage.

When the colon is completely filled, a roentgenogram is made with the patient in the prone position, the ray being projected in the postero-anterior direction. As in other parts of the intestinal tract, we are dealing with a tube which must be viewed from several angles to bring its several contours into profile. This is particularly true of the colon because of the usual overlapping of the transverse colon and the ascending and descending colon at the hepatic and splenic flexures, respectively. Therefore, roentgenograms should be made in both the right and left prone-oblique positions, with sufficient rotation of the patient's body to make visible, in turn, these two flexures of the colon. This procedure is an excellent protection against the very real possibility of overlooking a lesion due to overlapping of the different parts of the colon.

After these roentgenograms have been made, the colon should be evacuated, either by the patient or by drainage through the enema tube. The study of the colon after evacuation is just as important as the study of the filled colon. It is essential to know whether or not there is an unusual retention of any division of the colon, particularly proximal to the hepatic flexure. In addition, a thin layer of the barium mixture remains on the mucosa of the colon and gives an excellent demonstration of the mucosal pattern of the contracted colon. The studies by Knothe, Berg, and Frick, Blühbaum and Kalkbrenner of the mucosa of the colon have all utilized this slight retention of the opaque mixture after evacuation.

A. W. Fischer (1923) recommends the combined use of an opaque mixture and air injection. He uses the usual opaque mixture. After evacuation, he studies the mucosal pattern of the contracted colon, and then injects air into the colon. A thin layer of opaque mixture adheres to the surface of the mucosa and when the colon is distended with air, one obtains, at times, an excellent visualization of the mucosal surface. The results are difficult to control and duplicate.

(4) APPLICATION OF THE X-RAYS

Roentgenograms may include an entire region, such as stomach, cap, and duodenum, or they may be limited to small localized areas three or four inches in diameter. Films of an entire region may be made with or without a grid. Those made with a grid are more brilliant, but because of the increased length of time required for exposure, and other unsatisfactory grid characteristics, they are less diagnostic than the roentgenograms made without the grid and with the use of a cone of just sufficient size to include the stomach, cap, and duodenum. A thorough consideration of this subject would in itself require a book. We shall, therefore, mention only the salient principles.

Secondary radiation is the bane of the roentgenologist's existence—particularly true in regard to the gastro-intestinal tract. Five factors have been employed to prevent the development of secondary rays or to obviate their detrimental effect: (1) The gas tube, (2) the cone, (3) compression, (4) the grid, and (5) the close apposition of the film to the opaque medium.

The gas tube generates fewer secondary rays per cubic space radiated than any other tube because of the fact that the indirect rays generated in the gas tube are of very low penetration and are easily eliminated by the cone.

The cone is one of the oldest and is perhaps the most important device for obviating secondary radiation. It utilizes the principle of diminishing the surface area of the region that is being exposed. The smaller the cone, the smaller the surface area (or cubic space) radiated, consequently, the less the secondary radiation, the more brilliant the roentgenogram.

Compression is used to diminish the thickness of the part being exposed. When combined with the cone it diminishes to a minimum size the cubic space exposed to the X-ray. The smaller the cubic space radiated, the less is the secondary radiation. Compression also diminishes the time required for exposure. Compression may be applied either between the tube and the patient's back, or to the patient's abdomen, as will be described later.

The grid tends to eliminate secondary radiation. The larger the area that is exposed to radiation, the more valuable is the grid. Conversely, the smaller the area, the less valuable is the grid. The grid has its advantages and its disadvantages. It increases the time of the exposure twofold or threefold, thus allowing the motion due to peristalsis to become a detrimental factor. It increases also the distance of the film from the patient, causing distortion.

Close apposition of the film to the region under observation not only lessens the amount of secondary radiation, but is an application of the following law of optics, "the nearer an object is to a screen or film, the clearer and more distinct is its shadow."

One or more of these principles to minimize the effect of secondary radiation are applied by the various observers, especially by those who have constructed their own apparatus. The ingenious apparatus designed by Åkerlund utilizes two of these five principles for obviating the detrimental effects of secondary rays. His device employs compression in the following manner. Between the fluoroscope or film and the patient he causes pressure to be exerted on the abdomen, which is soft and compressible, rather than on the patient's back, where the ribs and spine render it practically incompressible. This procedure is not new. To it, however, Åkerlund added a revolving grid located in the end of the cylinder that is pressed against the patient. For the perfection of this he deserves great credit. By the use of this apparatus, one diminishes the detrimental effects of the secondary rays that are generated in a relatively large region. However, the revolving grid that increases the brilliancy of the roentgenogram, as does any other grid, likewise adds to the time of exposure and likewise adds the disagreeable grid characteristics, while its large size prevents local application of pressure. Some of the prominent observers who previously used this apparatus, realizing that the smaller the area of observation, the less valuable the grid, discontinued its use. This method, although employing two of the five methods of diminishing the detrimental effects of secondary radiation, namely, compression and the grid, does not utilize the other three, that is, the tube, the cone, and the close apposition of the film to the opaque medium.

Berg employs a method similar to Åkerlund's, but without the revolving grid. Of the five methods of diminishing the detrimental effects of secondary rays, Berg depends chiefly on compression applied to the abdomen by a cylinder or cone mounted on the back of the fluoroscopic screen. In doing this he has exaggerated *reversely* the fifth principle by placing the film away from the patient. Berg, with this apparatus under fluoroscopic control, is able to exert any desired pressure on the stomach or cap, displacing the bulk of the barium mixture and leaving only that which is caught in the furrows between the mucosal folds. He is enabled thus to make a thorough fluoroscopic exploration of the gastric mucosa. When any interesting area is observed fluoroscopically a film is substituted for the screen and a radiographic record is made. In this procedure only one method of obviating the detrimental effects of secondary rays is employed, namely, compression. By this method Berg gets a gross elimination of the widely scattered secondary rays, and he speaks of the Bucky effect of the cylinder. A close scrutiny of the illustrations appearing in Berg's book indicates that his most brilliant roentgenographs are those in which his special compression apparatus has not been used.

It should be noted that in both Åkerlund's and Berg's compression cylinders the fluoroscopic screen or film is inserted at the end of the cylinder and is at a very considerable distance from the patient; therefore, the screen and film are not in close apposition to the region being examined. In Åkerlund's device the film is separated from the patient by the thickness of the grid and the housing over the grid. The fifth principle—close apposition of the fluoroscopic screen or film to the part being examined—which is perhaps the most important of the five principles for eliminating secondary radiation, is employed by neither Åkerlund nor Berg, and the detrimental effects are exaggerated by both of their methods.

Bearing in mind the five factors enumerated as aids to the diminution of the detrimental effects of secondary radiation, one of us (C. I. H.), at the essayist's suggestion, has designed and constructed a device for examining fluoroscopically and roentgenographically small localized areas of the gastro-intestinal tract, particularly the stomach and cap (Figs. 16 and 17). The principles employed in this apparatus are as follows:

(1) An X-ray tube is used that generates fewer secondary rays in the patient than any other tube, namely, the gas tube.

(2) A cone is used which has the smallest diameter that will cover a 3¼ × 4 inch film at a 24-inch distance.

(3) Compression is exerted on the soft, compressible abdomen by a rectangular piston which has rounded corners. No compression is exerted by the small cone attached to the tube holder.

(4) No grid is used.

(5) The device is so arranged that the intensifying screens and fluoroscopic screen are located at the end of the piston which is pressed into the abdomen. Thus, with pressure, the film and screens are embedded well within the normal contour of the abdomen and in close contact to the opaque medium.

With this device we not only see the exact image which we desire to radiograph prior to the rapid insertion of the film, but we also see the actual fluoroscopic image recorded on the film.

An old-fashioned gas tube is employed because this is the only tube in which indirect rays are not generated on the back of the target. The elimination of indirect rays from the back of the target diminishes the quantity and penetration of the secondary rays generated in the patient. The gas tube is the only tube used for roentgenographic work in the institutions with which I am associated, except in connection with portable and dental apparatus.

The second principle involved in our device for eliminating secondary radiation is the limitation to a minimum size of the surface area exposed to the rays. This principle is accomplished by employing the oldest of all methods for obviating secondary radiation, namely, a cone of such small diameter that it barely covers a 3¼ × 4 inch film at a 24-inch distance.

The third principle, namely compression, is applied to the soft parts of the abdomen which are compressible, and in this manner the distance between the film and the posterior surface of the patient is reduced to a minimum. Secondary rays are developed in proportion to the cubic space that is radiated; therefore, with a cone of minimum size and with the desired maximum amount of compression, the cubic space radiated is reduced to a minimum. Thus the quantity of secondary rays generated is reduced to a minimum.

The fourth principle, namely the grid, is not used because, as we have stated previously, the grid is chiefly of value when large areas are to be roentgenographed. By using this apparatus only a very small area is exposed and so the grid would be of little or no value, and actually detrimental.

The fifth principle, that is, close apposition of the film or screen to the part being examined, is employed, bringing about not only a diminution of the secondary rays generated between the stomach and the film, but also a more brilliant and clear-cut image in accordance with the optical law, "the nearer the film to the object, the sharper the shadow."

Pressure.—As regards the roentgenological examination of the gastro-intestinal tract, compression and pressure are entirely different; at least, we shall so regard them. Compression is applied to diminish the thickness of the part and so reduce its secondary rays. Pressure is employed to displace the bulk of the opaque medium (barium) from the lumen of the gut and to accentuate the mucosal pattern. Pressure is usually applied to small areas as by Åkerlund and Berg, although Chaoul applies pressure to larger areas by means of a large, inflatable, flat rubber bag which is strapped to the abdomen. We use both, as is shown in our illustrations. Pressure as applied by Åkerlund and by Berg is usually under fluoroscopic control, that is, the operator personally views the region fluoroscopically. When he sees some finding which is of interest he substitutes a film for the screen and makes a small roentgenograph for a permanent record. While he is making this roentgenograph he can personally orient himself and determine the exact region that is being examined. However, if the small films, especially those of the stomach, were to be observed without a knowledge of the exact region in which they were made, as observed fluoroscopically, it would be difficult to identify the region.

Pressure gives a different set of findings for a criterion on which to base radiographic diagnosis, and undoubtedly it allows a more comprehensive study of the mucosal folds and the surface of the mucosa. In our own experience and by an intensive study of the illustrations submitted by others, we find that there are very few instances in which the diagnosis of an organic lesion has been established by pressure in cases in which it has not been established by radiographs made without pressure.

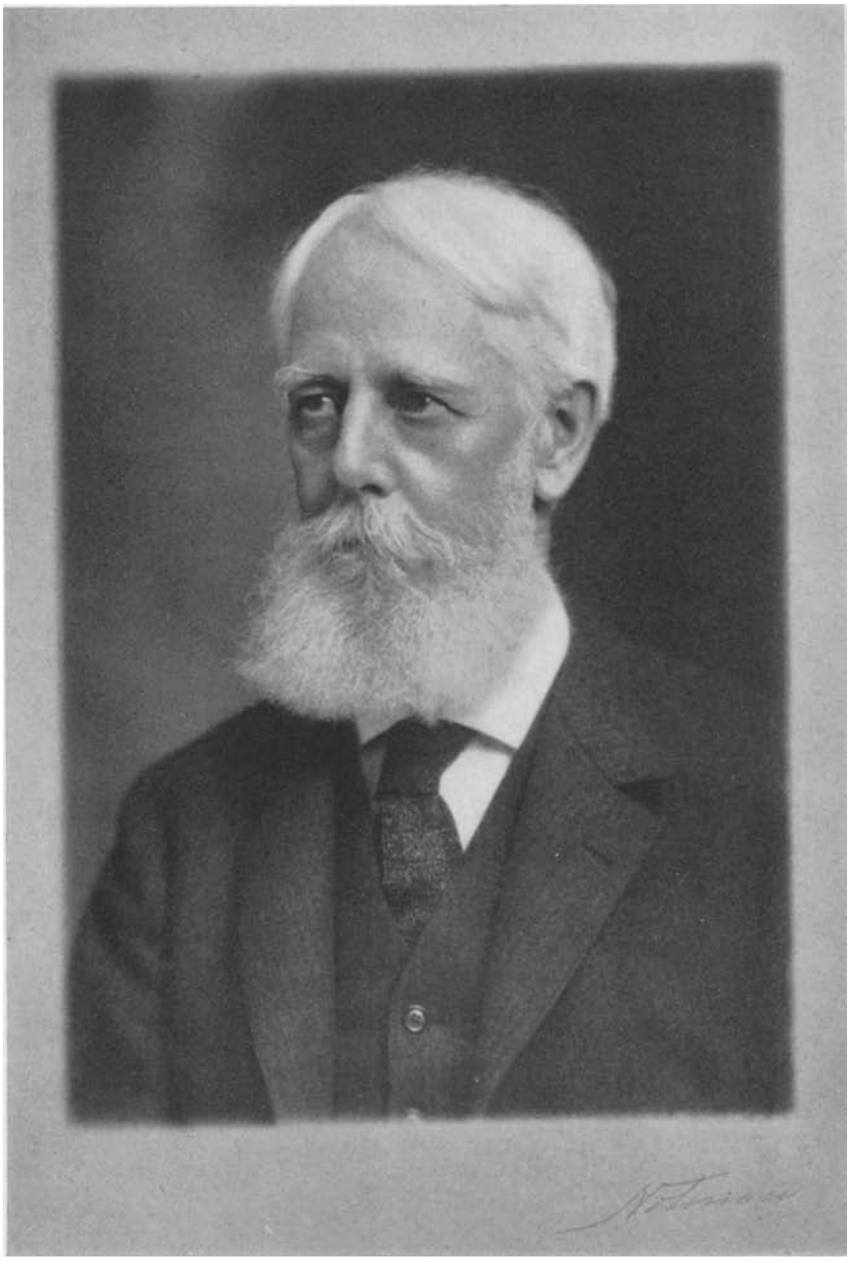
The manner in which the rugæ of the stomach diverge as they approach certain types of carcinomatous growths or the manner in which they converge toward the crater of an ulcer at a certain late stage in its process of repair, are findings of scientific interest. They do not, however, alter the diagnosis as established by the routine method without pressure. It must be remembered that visualization of rugæ and application of pressure are not synonymous. Indeed, it is often more difficult to determine the size and shape of the crater of an ulcer when the barium is displaced by pressure than it is when the crater is filled by moderate distention of the stomach without pressure.

External pressure—whether achieved with Åkerlund's rotary grid, the cylinder used by Berg, a rubber bag strapped to the abdomen as recommended by Chaoul, or with our own apparatus constructed by Headland—has both its advantages and disadvantages as a method of showing or exaggerating the pattern of the mucosal folds. It is a moot question whether or not it should be used. Some observers depend very largely on gradation or dosage of external pressure to displace the bulk of a small opaque meal from a local region so that the mucosal pattern of local regions may be observed fluoroscopically or roentgenographically. Small roentgenographs made with various devices show more contrast than roentgenographs of full size, but with the grid interposed or with the film at the end of the cylinder away from the patient, detail is diminished and distortion results. Even when one is able to obtain small roentgenographs with great brilliancy and without loss of detail, there is still much question in my mind as to whether the findings aid or hinder in the diagnosis of gastro-intestinal lesions. Although numerous articles have been illustrated by brilliant, localized roentgenographs, very few observers have recorded any systematic comparison of these small local films obtained by pressure, with routine roentgenographic examinations, serial or otherwise.

We have run quite a large series of cases, making twelve small roentgenographs of the cap with varying degrees of pressure (Figs. 18 and 19), in addition to the routine serial roentgenographic examination. By comparing the findings of the cap, as observed by both methods, we have come to the following conclusions.

Whereas small roentgenographs are much more economical, they are limited to a small region and difficult to orient, except in the cap. The small films of the stomach are almost valueless inasmuch as they cannot be oriented except by comparison with a large film which shows nearly as much detail. The small films furnish brilliant contrasts and are fascinatingly interesting to study, especially with the old-fashioned hand stereoscope to which these $3\frac{1}{4} \times 4$ inch films are so well adapted. Nevertheless, we have yet to find a case in which the small films, made with varying degrees of pressure, have caused us to alter the diagnosis as based on serial films of full size made without pressure. Pressure interferes, in many instances, with the manner in which a normal or pathological cap behaves when it receives a squirt of barium through the pyloric valve, or when its distal two-thirds are evacuated by a broad peristaltic wave. A cap under abnormal external pressure does not act normally in response to the gastric motor phenomenon. Thus external pressure employed to exaggerate the mucosal pattern becomes a two-edged sword with which, I fear, many will cut their fingers!

(To be continued)



Francis H. Williams M.D.

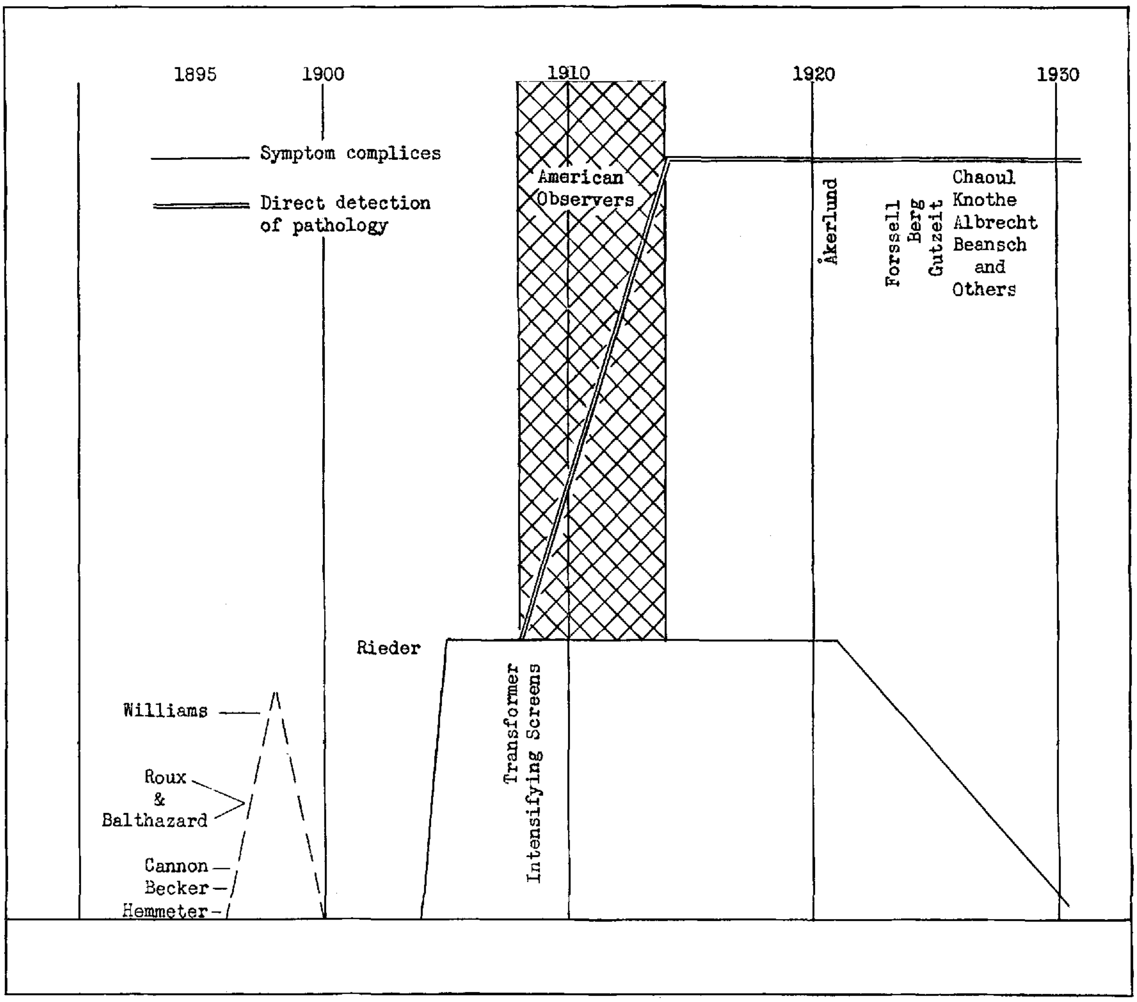


Fig. 2. Chart showing graphically the time relation of periods of advance in the roentgenological diagnosis of lesions of the stomach and cap. During the period between 1896 and 1900 observations were made as to the use of the X-ray and the opaque meal for making visible the stomach. From 1900 to 1904 was a period of silence. Rieder's work in 1904 resurrected the use of the X-rays for study of the gastro-intestinal tract, and for the first time roentgenologic examination was used for diagnosis, the criterion for diagnosis of pathologic lesions being the so-called "symptom complices." Satisfactory roentgenography of the stomach was possible only after the introduction of the transformer and intensifying screens in 1908. Roentgenographic examination of the stomach made possible the direct detection of abnormal morphologic changes in the wall of the gut. The period from 1908 to 1914, indicated by the cross-hatched area on the chart, was the "red letter days" of roentgenographic exploration of the gastro-intestinal tract.

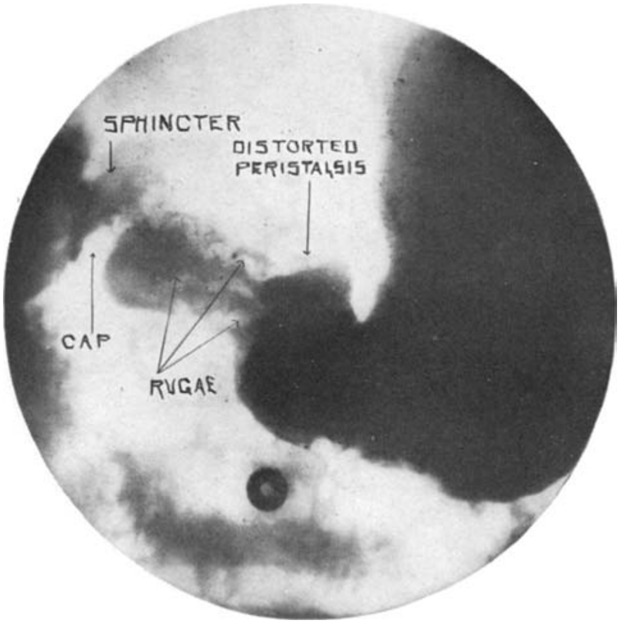


Fig. 3. Spasm of the stomach.

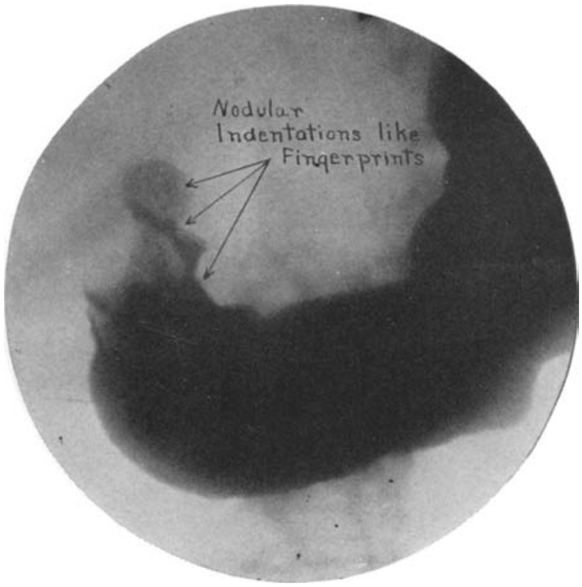


Fig. 4. Cancer of the stomach.

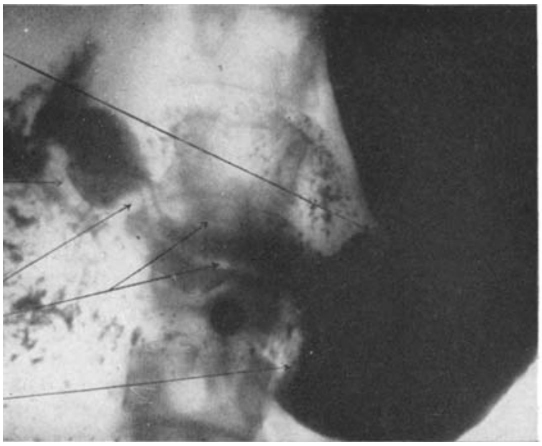


Fig. 3′. Spasm of the stomach.

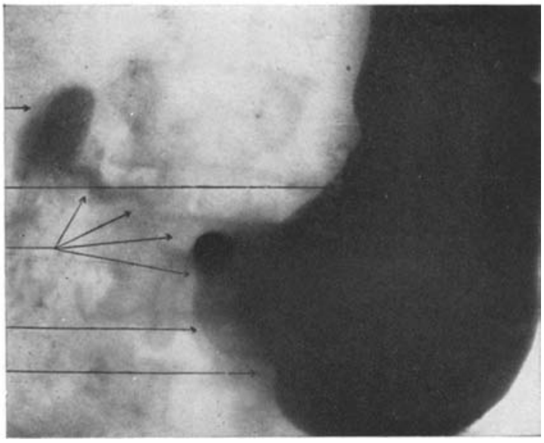
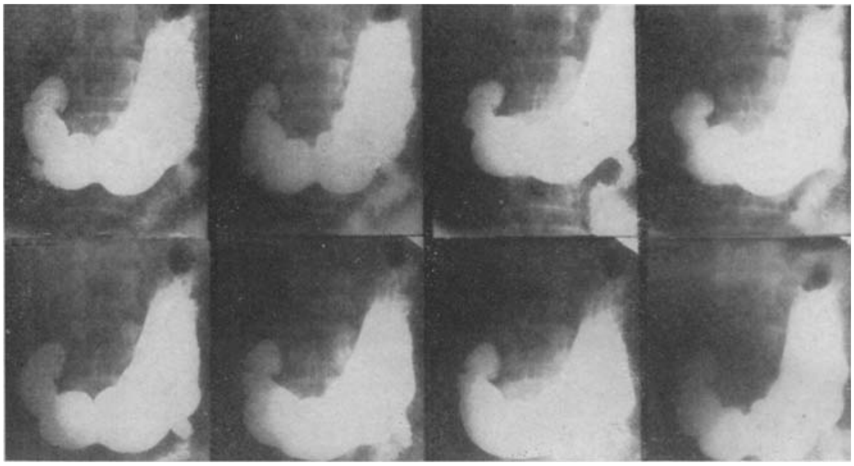
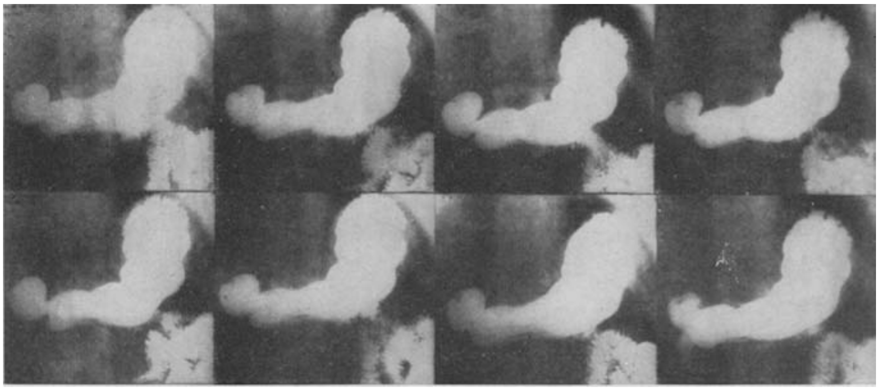


Fig. 4′. Cancer of the stomach.

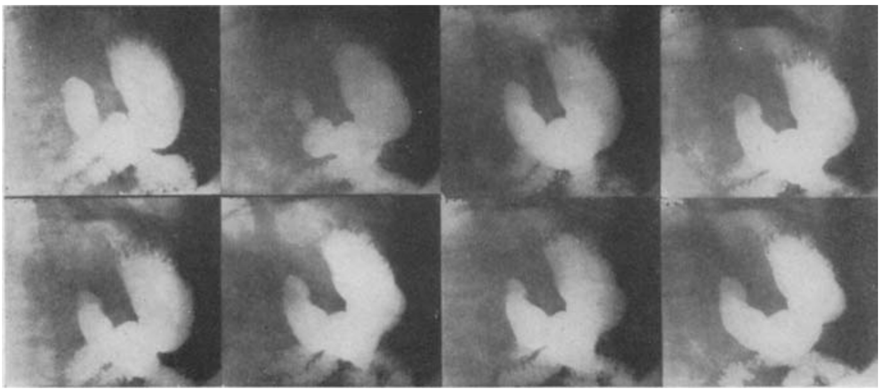
The changes shown in the above roentgenograms were designated as filling defects, due either to spasm as shown in Figures 3 and 3 prime, where the rugæ are observed more distinctly than usual, or to a cancer protruding into the lumen of the stomach as shown in Figures 4 and 4 prime, where the rugæ in the involved area are completely obliterated. These figures illustrated an article originally published in 1912, and these reproductions are made from the same photo-engraved blocks.



Erect



Prone



Prone oblique

Fig. 5. Serial roentgenograms of the stomach in the postero-anterior and right oblique directions with the patient prone, and in the postero-anterior direction with the patient erect.

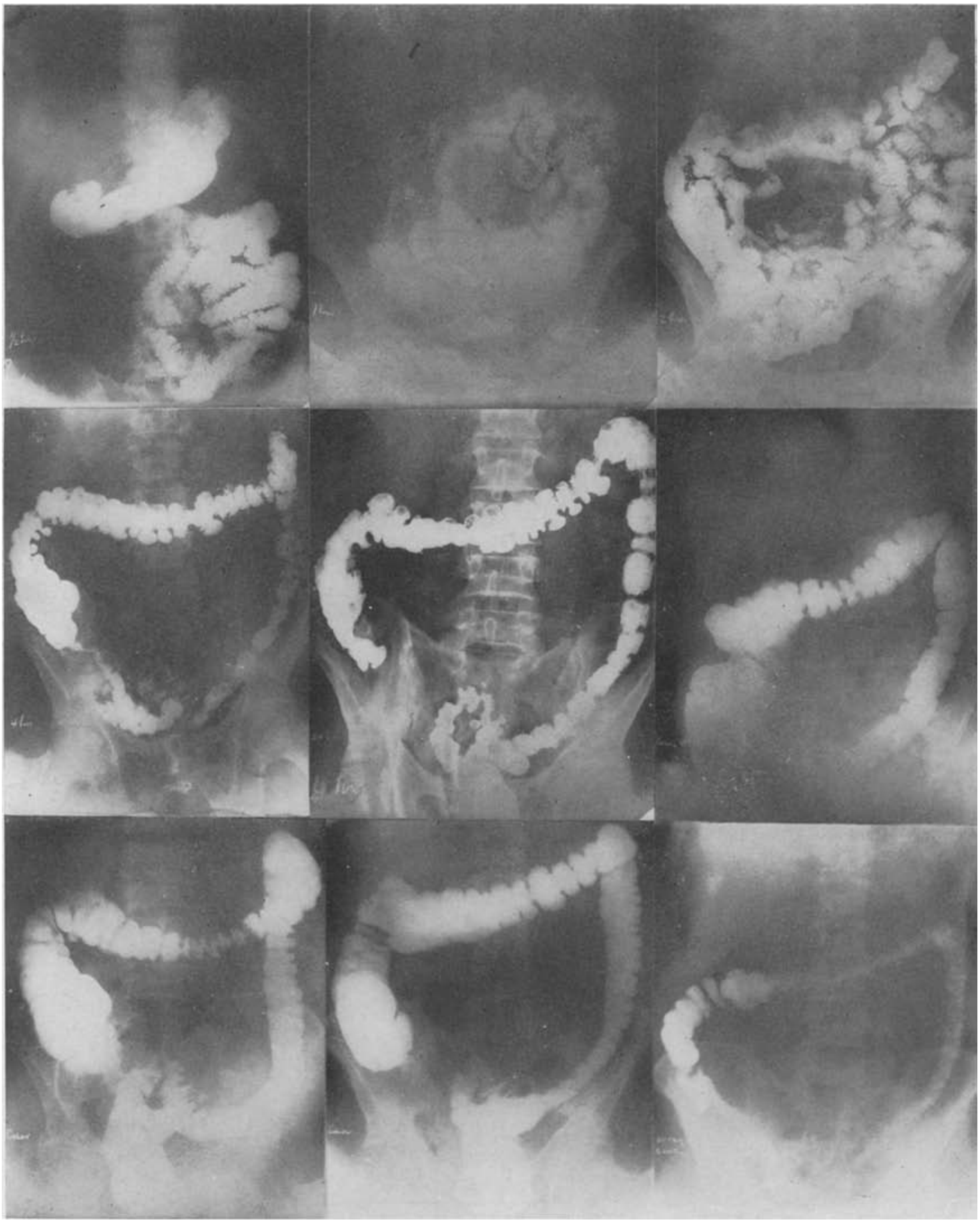


Fig. 6. Roentgenograms showing the passage of the barium meal through the small and large intestine, and examination of the colon after administration of the opaque clysma and after its evacuation indicate, together with Figure 5, what the essayist originally designated as serial roentgenography of the gastro-intestinal tract.

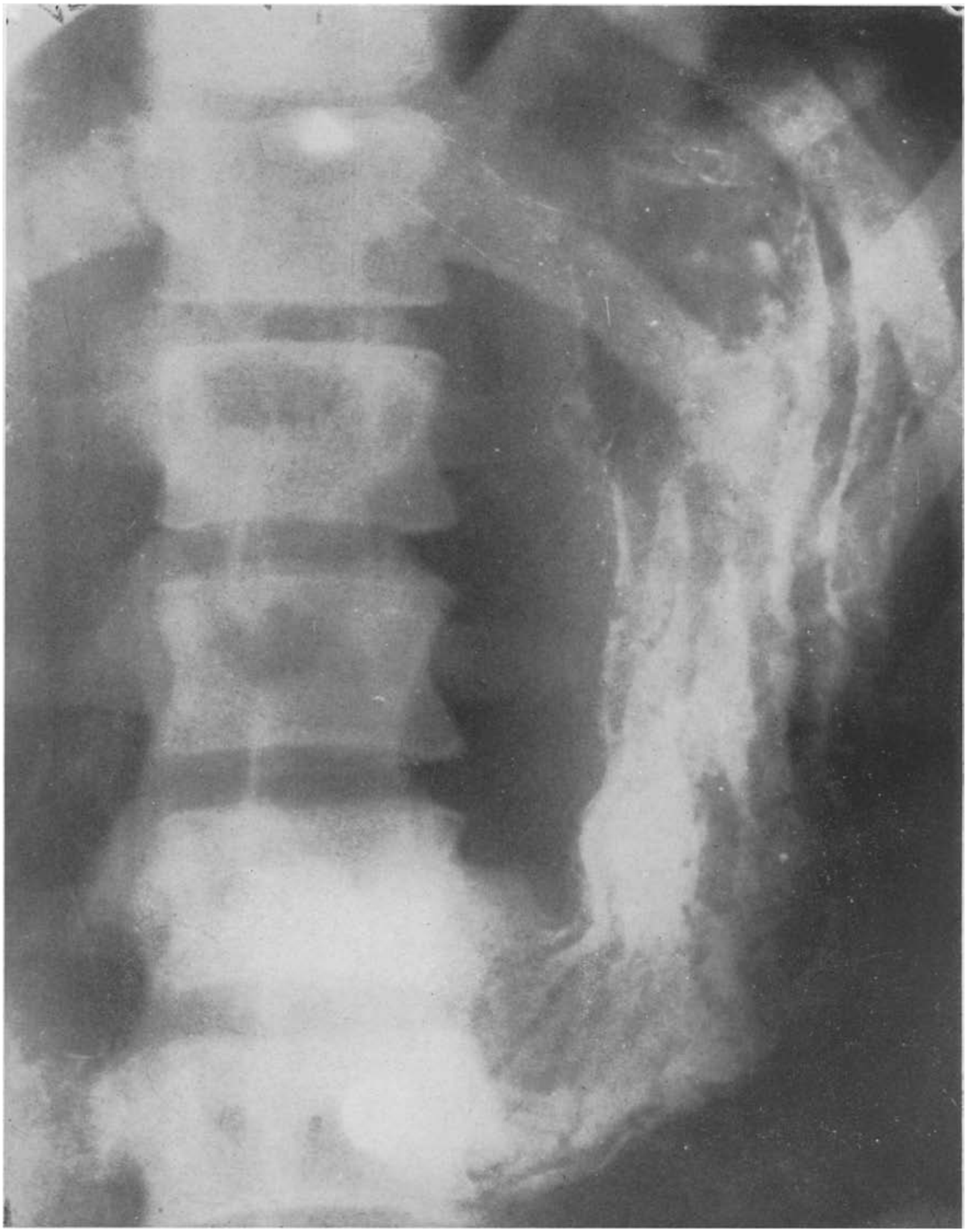


Fig. 7. Patient, Mr. S., Oct. 13, 1910. This roentgenogram was the essayist's first intentional attempt to demonstrate the pattern of the gastric mucosa by a special technic. The patient ingested a suspension of one gram of bismuth subnitrate in four ounces of water, and was placed in the prone posture for twenty minutes, the heavy bismuth settling out of suspension onto the furrows between the mucosal folds of the stomach.

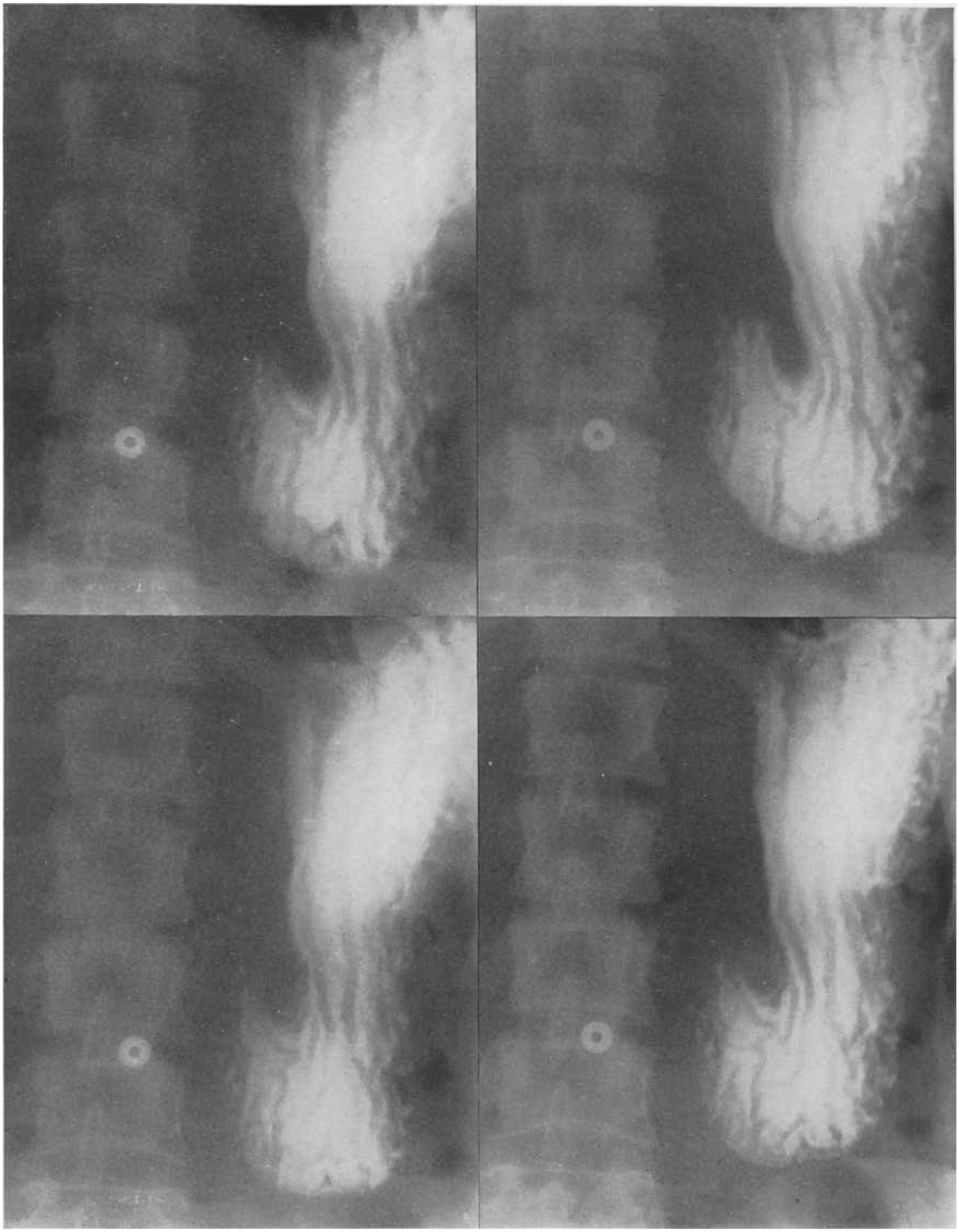


Fig. 8. Serial roentgenography, *i.e.*, multiple roentgenograms of the stomach in combination with the special mucosal technic as illustrated in Figure 7, shows the constancy of position of the mucosal folds except as they are disturbed by the progressive peristaltic contractions.

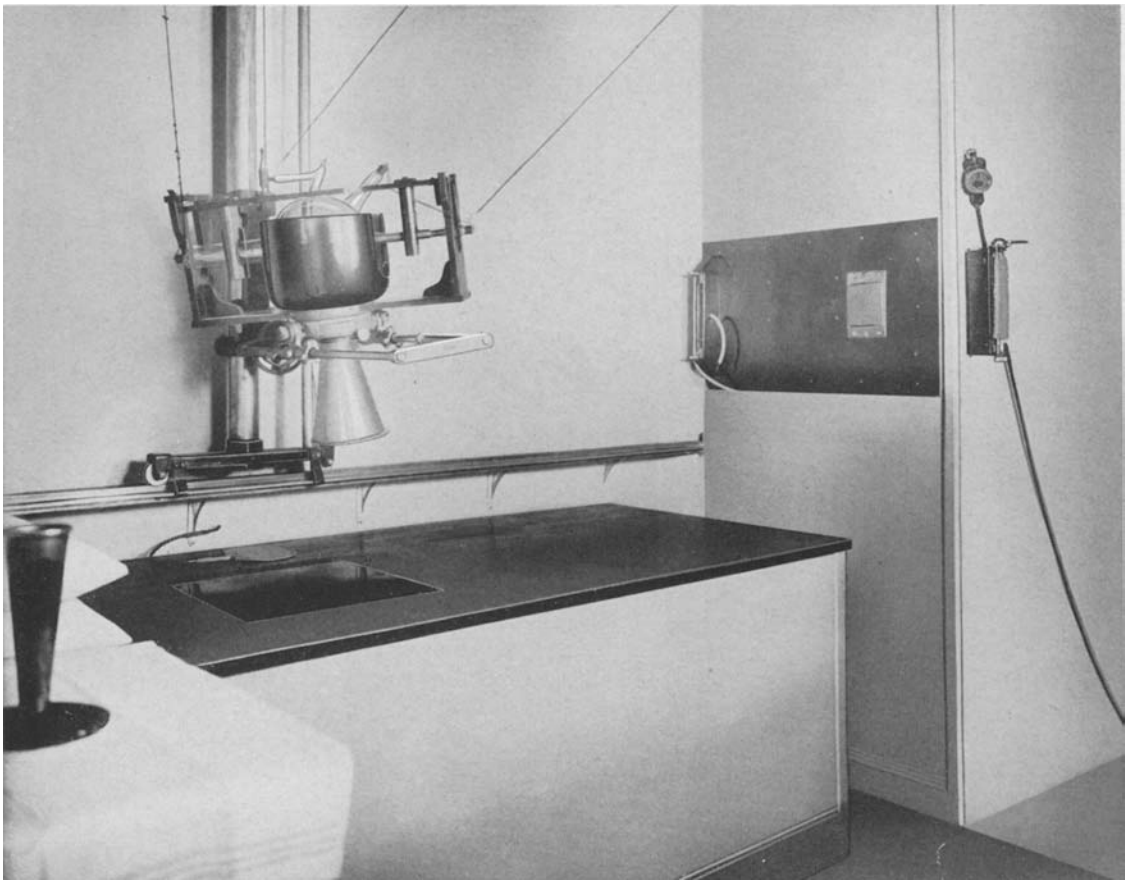


Fig. 9. Serial table; built as an emergency table just after the fire in 1924, since which time it has been in constant use. This table is a box 40 inches high, 36 inches wide, and 7 feet long, built into a wall concealing a dark operating booth. The bakelite panel in the top of the table is the top of the film-changing device shown in detail in the cross-sectional drawing (Figure 10).

The bakelite panel in the wall at the end of the table conceals the film-changing apparatus for making serial roentgenograms of the patient in the erect posture. This film-changing apparatus is a cassette built into the wall, entirely similar to the erect film-changing apparatus shown in the Model Table designed and constructed by Headland (Figure 10). The back of the cassette is made of bakelite, and carries the back intensifying screen in front and a fluoroscopic screen behind. The fluoroscopic screen is covered with lead glass. The patient is held tightly in position by the belt shown in the picture. The holders of the belt are offset from the wall so that the angle of the belt is not acute and will not slip easily. The holder on the right side, which contains the ratchet gear, is mounted on hinges, so that it may be swung back out of the way into the position shown in the photograph.

The compression device designed and constructed by Headland can be seen partially protruding through the bakelite panel in the end wall. The detailed construction of this is shown in Figures 16 and 17. The small cone on the table in the foreground is used when we make the small compression roentgenograms and will just cover a 3¼ x 4 inch film at a 24-inch distance.

The small rubber bag shown lying on the table behind the bakelite panel may be attached to a rubber tube for use with either the prone or erect apparatus. It is used for exerting pressure on relatively large areas of the stomach and colon, and is inflated from the operating booth under fluoroscopic control.

Exposures may be made either from the operating booth or from the room itself, in the latter case by using the hand switch hanging on the wall.

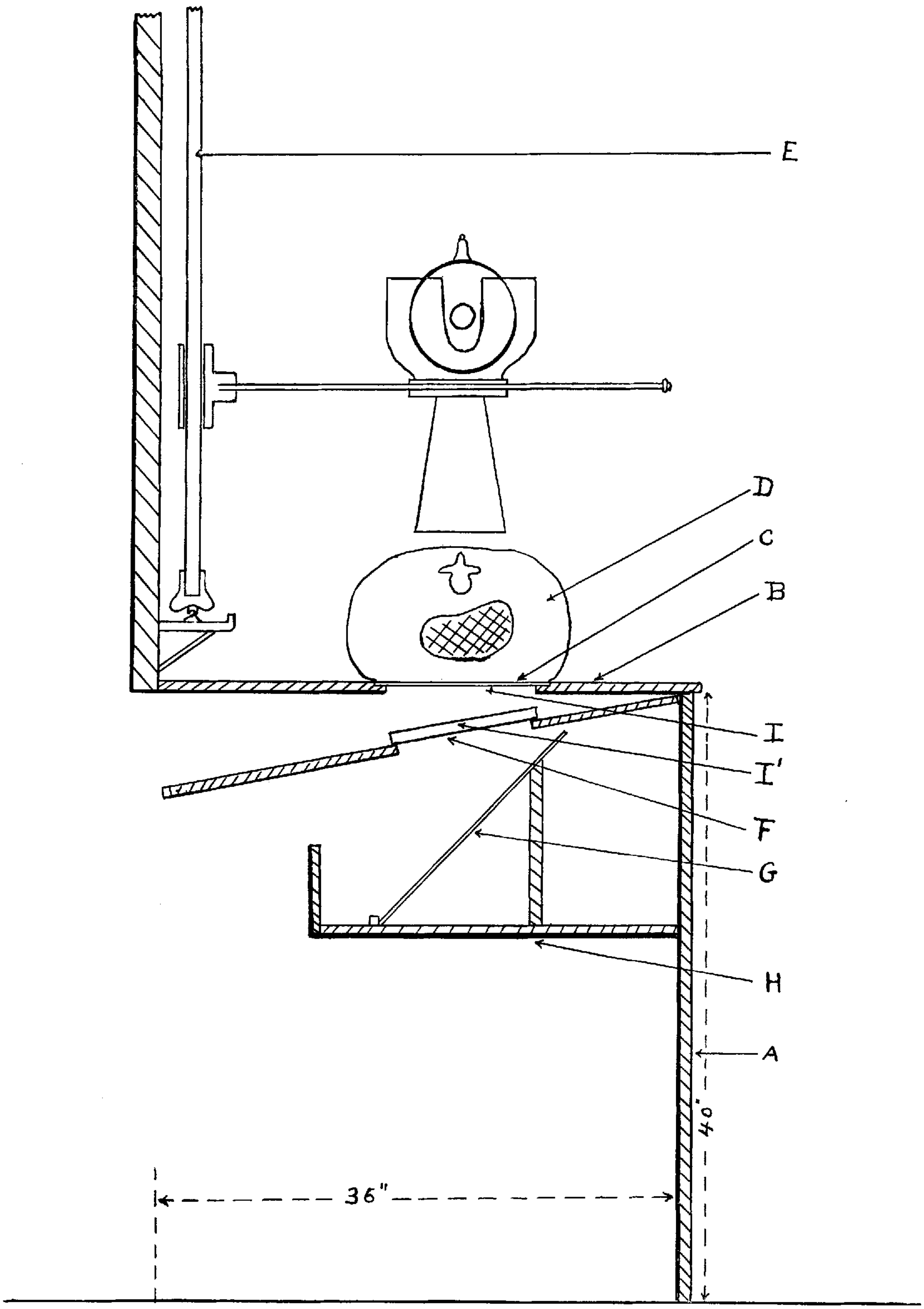


Fig. 10. Cross-sectional drawing of the serial table shown in Figure 9. *A,* a wooden box 40 inches high, 36 inches wide, and 7 feet long. *B,* wooden top of box. *C,* bakelite panel mounted in the top surface of the box. *D,* cross-section of patient in the prone posture. *E,* tube stand mounted on rail on the side wall. This mounting of the tube stand is optional, as one may also use a floor tube stand. *F,* fluoroscopic screen, surface down. *G,* mirror in which to view the fluoroscopic screen. *H,* lead-lined box to prevent secondary rays from hitting operator. *I,* intensifying screen, surface down. *I',* intensifying screen, surface up. *I* and *I'* are for use with naked films when the booth is dark. Any standard cassette may be used in a lighted booth. Only one set of screens is necessary if the booth is dark, otherwise 6 or 8 cassettes with 12 or 16 screens are necessary. The same principle is used for the erect position, with the patient standing at the foot of the table.

The entire table and the exposed wall of the booth is lined with lead, which is indicated by the heavy black line in the drawing.

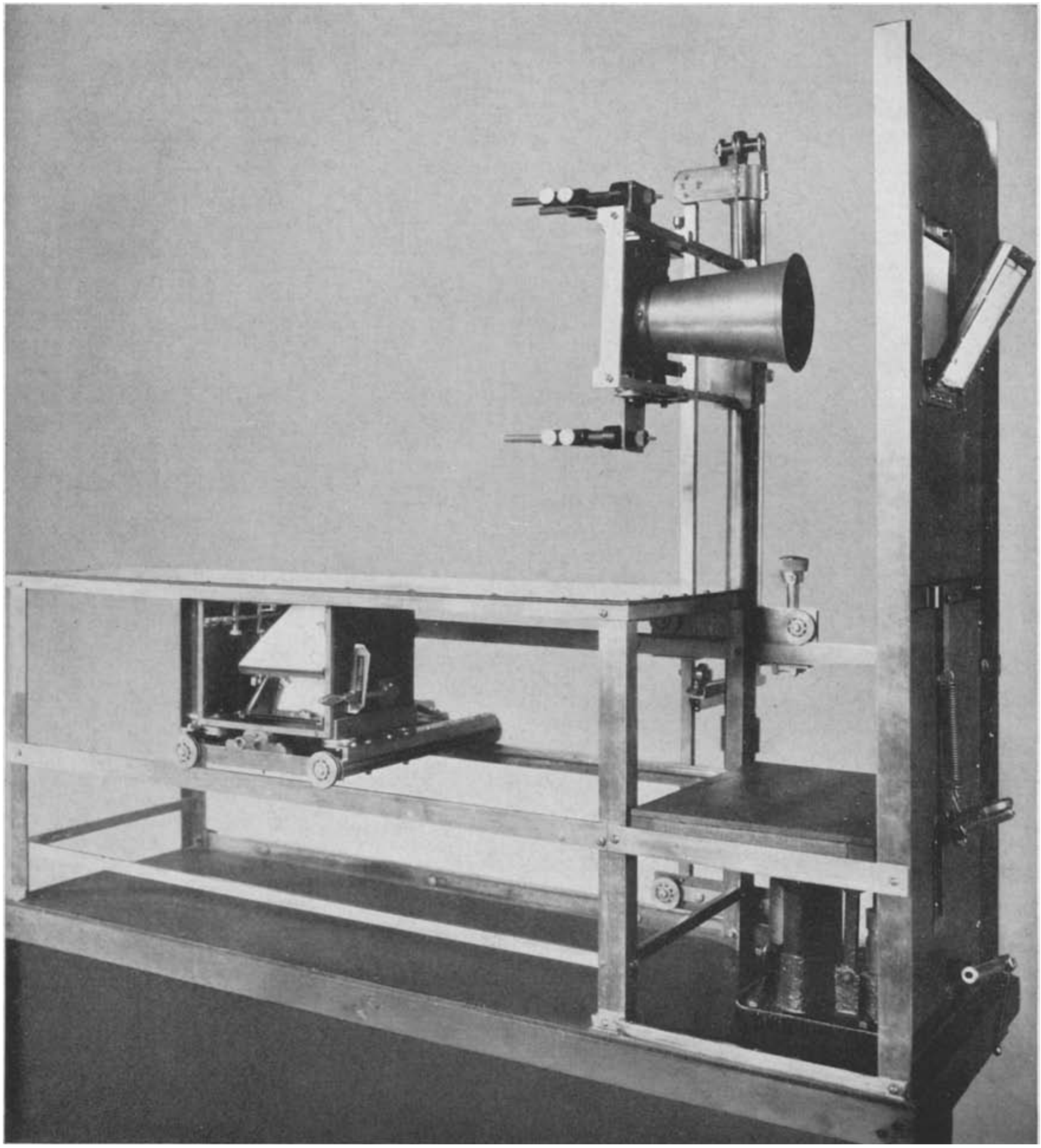


Fig. 11. Model of serial table designed and constructed by C. I. Headland, M.D. This table may be used as it is in a darkened room, or may be mounted as an integral part of the wall of an operator's dark room.

In the prone film-changing apparatus the movable hinged shelf which carries above, the lower intensifying screen, and, below, the fluoroscopic screen, is shown hanging down so that the intensifying screen is visible. Below this is the 45-degree angle mirror, and in the mirror one can see the reflected image of the fluoroscopic screen. This box may be interlocked with the tube stand so that the cone automatically is centered to the intensifying and fluoroscopic screens, when the apparatus is moved either up and down or across the table. Thus, by moving the tube stand and film-changing apparatus as a unit, one can localize and center the stomach without moving the patient.

For roentgenography in the erect posture the patient stands upon the platform at the end of the table, facing the lead-lined vertical panel. The platform is mounted on an hydraulic elevator, and the lowering and raising of the elevator is controlled by the two levers which pass through the vertical panel. The film-changing apparatus mounted in the vertical panel is a cassette, the back of which has been replaced by a bakelite cover on the front of which is mounted the back intensifying screen, and on the back of which is mounted the fluoroscopic screen covered with lead glass.

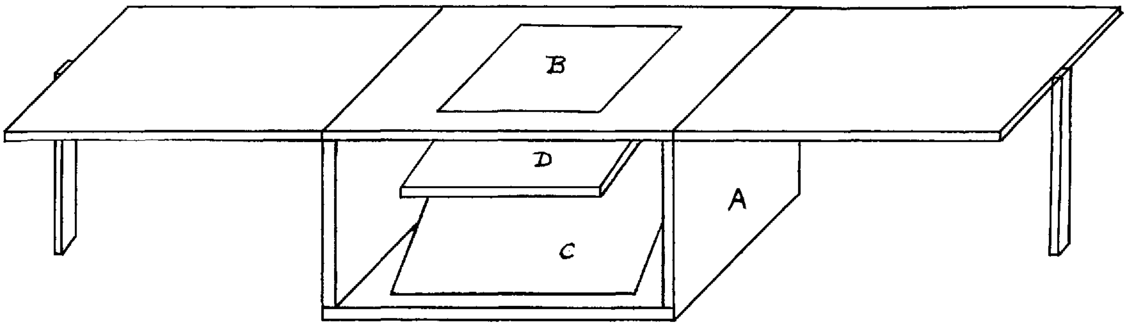


Fig. 12. Diagrammatic drawing of the simplest type of apparatus for serial roentgenography. This was primarily constructed and actually used at Base Hospital No. 1. *A,* a flat wooden box. *B,* a bakelite panel mounted in the top of the box. *C,* a mirror, set at an angle of 45 degrees, to reflect the fluoroscopic image. *D,* a wooden shelf attached by hinges to the back side of the box so that it is movable. A fluoroscopic screen is mounted on the under side of this shelf, the fluorescent surface facing the mirror. Cassettes are slid onto the top of the shelf, so that when the shelf is held up against the top, either by the hand or a locking device, the cassette is pressed firmly against the under surface of the bakelite panel. At both ends of the box are leaves of wood to support the patient's body. These leaves are not quite as long as the box and may be so hinged that when not in use the leaves may be folded back on the top of the box, and the entire apparatus may then be used as a step or stool.

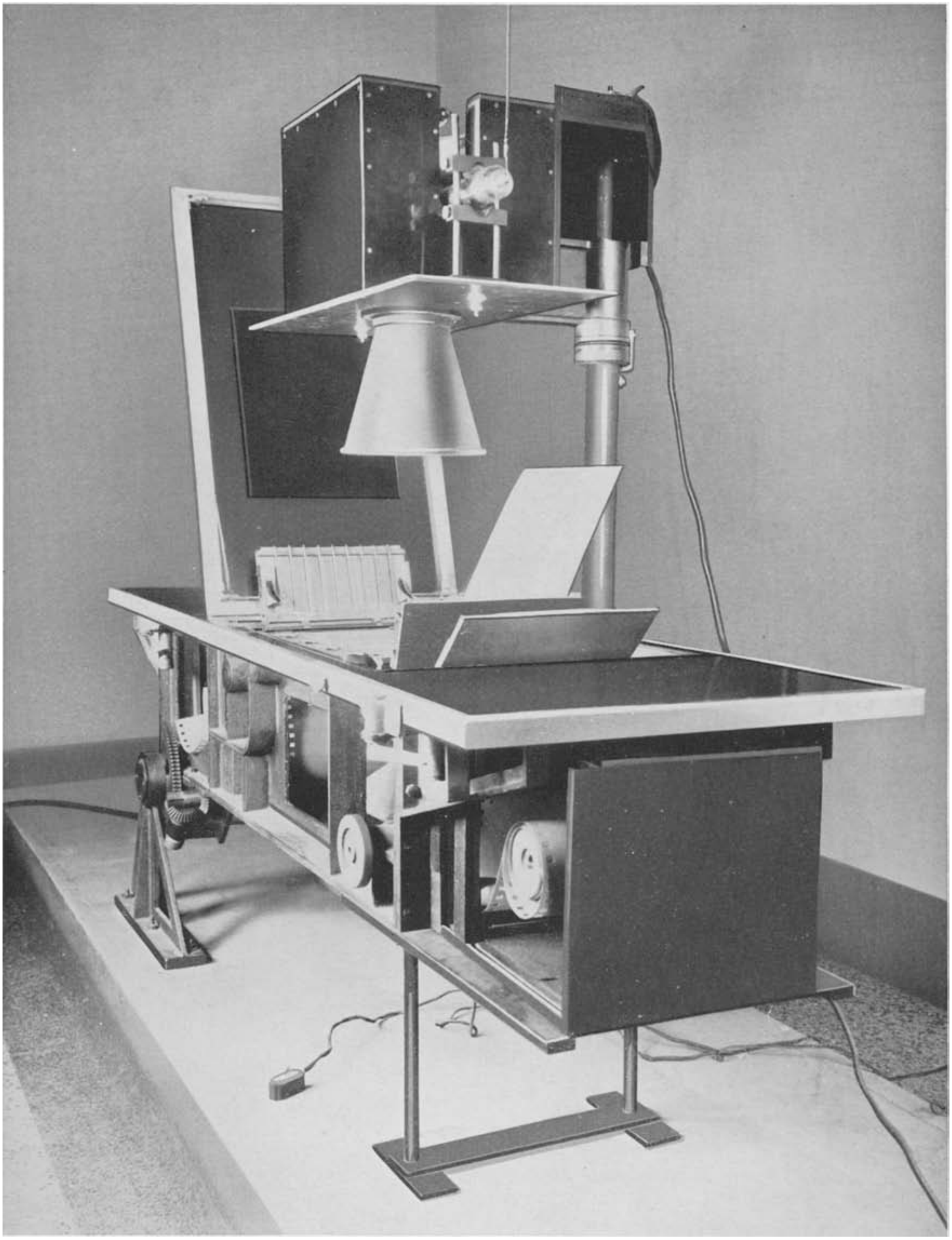


Fig. 13. A roentgenocinematographic apparatus designed to move a perforated film 10 inches wide in exactly the same manner that a standard motion picture camera moves a smaller film. This apparatus is installed in the Joseph Purcell Memorial Laboratory at the Fifth Avenue Hospital, New York City. With this apparatus we are able to make true motion pictures of the stomach and a short run of a roentgenocinematographic film is shown in Figure 15.

The unused film is contained in a magazine and is shown under the near end of the table. After passing around wheels with sprockets the film is threaded between intensifying screens and then through rollers back into another magazine at the far end of the table. In this photograph the apparatus is opened up for threading, and when the doors of the apparatus and the table top are closed it appears as is shown in Figure 14. A worm gear at the far end of the table enables it to be used in either the horizontal or vertical position or at any desired angle. The same reflecting mirror which has been employed on the serial tables, enables one to observe the action of the stomach both prior to the making of the film and during the time that the film is actually being exposed.

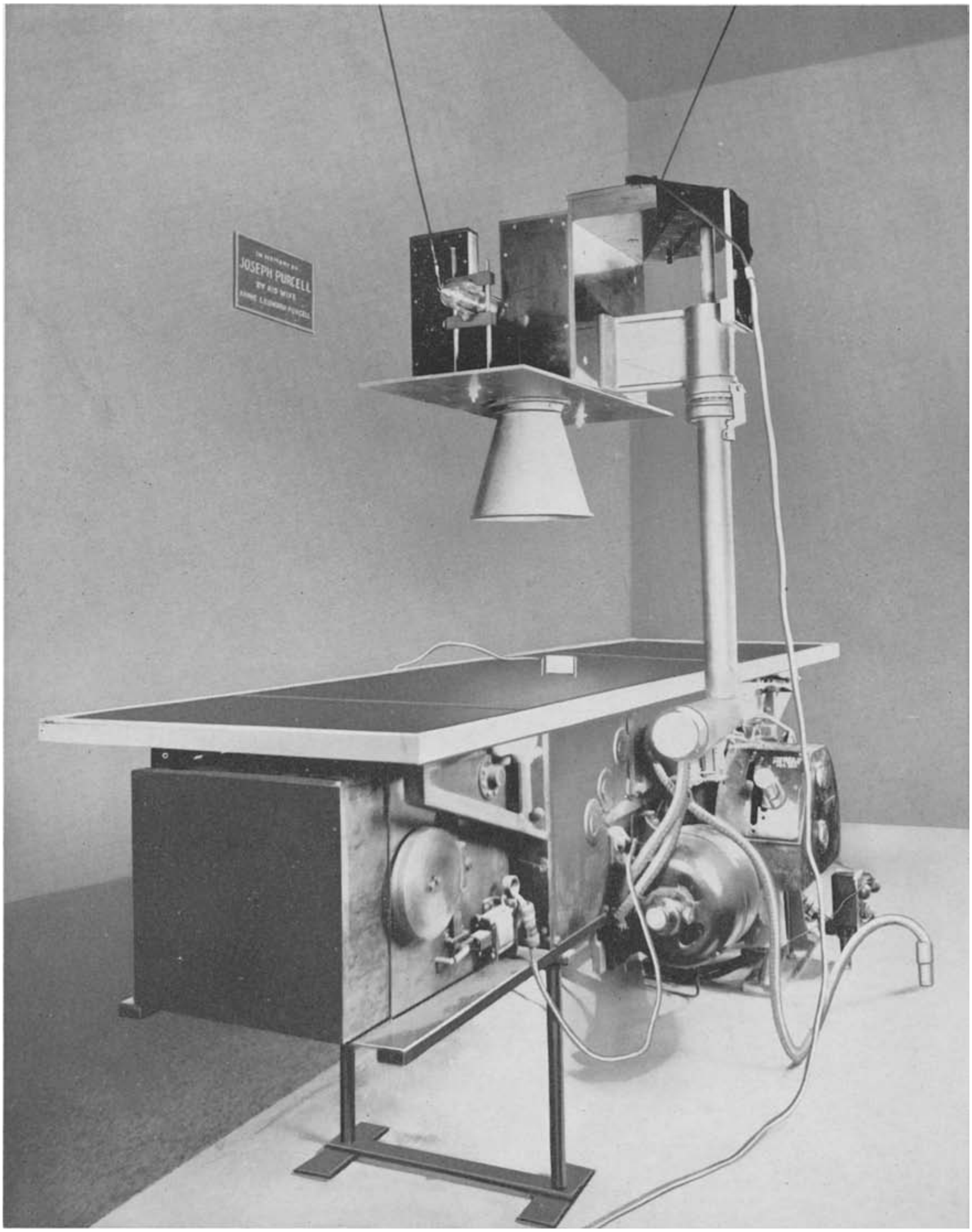


Fig. 14. The roentgenocinematographic apparatus closed and ready for action. The tube is enclosed in a ray-proof box. The timing of the exposures is accomplished by a switch at the top of the tube stand which may be used to break either the secondary or primary current. The motor which drives the mechanical parts is observed in the foreground, and just behind this is a speed-changing device similar in size and shape to a gear shift on an automobile, which enables us to make a continuous roentgenographic film at various rates of speed.

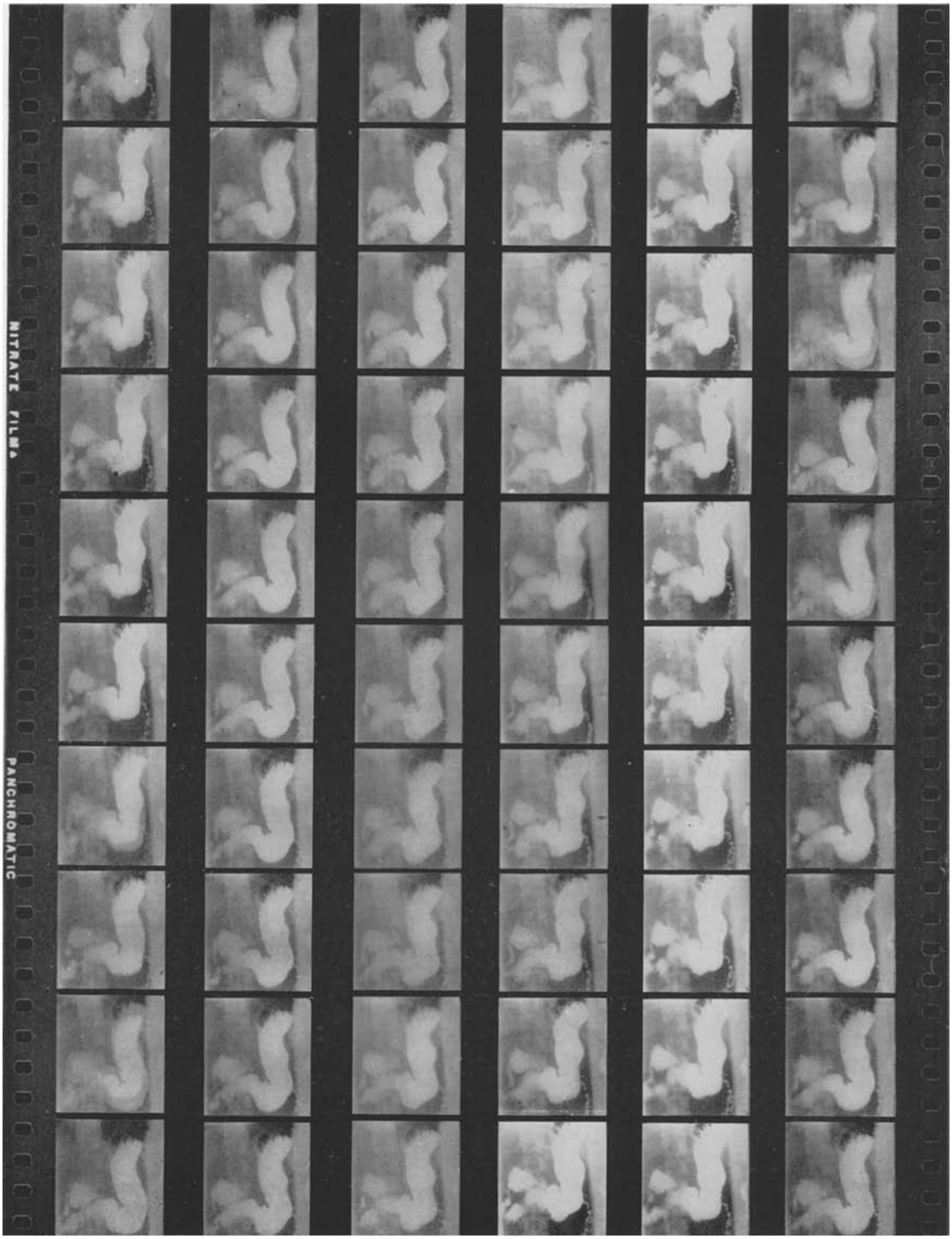


Fig. 15. Shows a short run of roentgenocinematographic film of the stomach made with the apparatus illustrated in Figures 13 and 14.

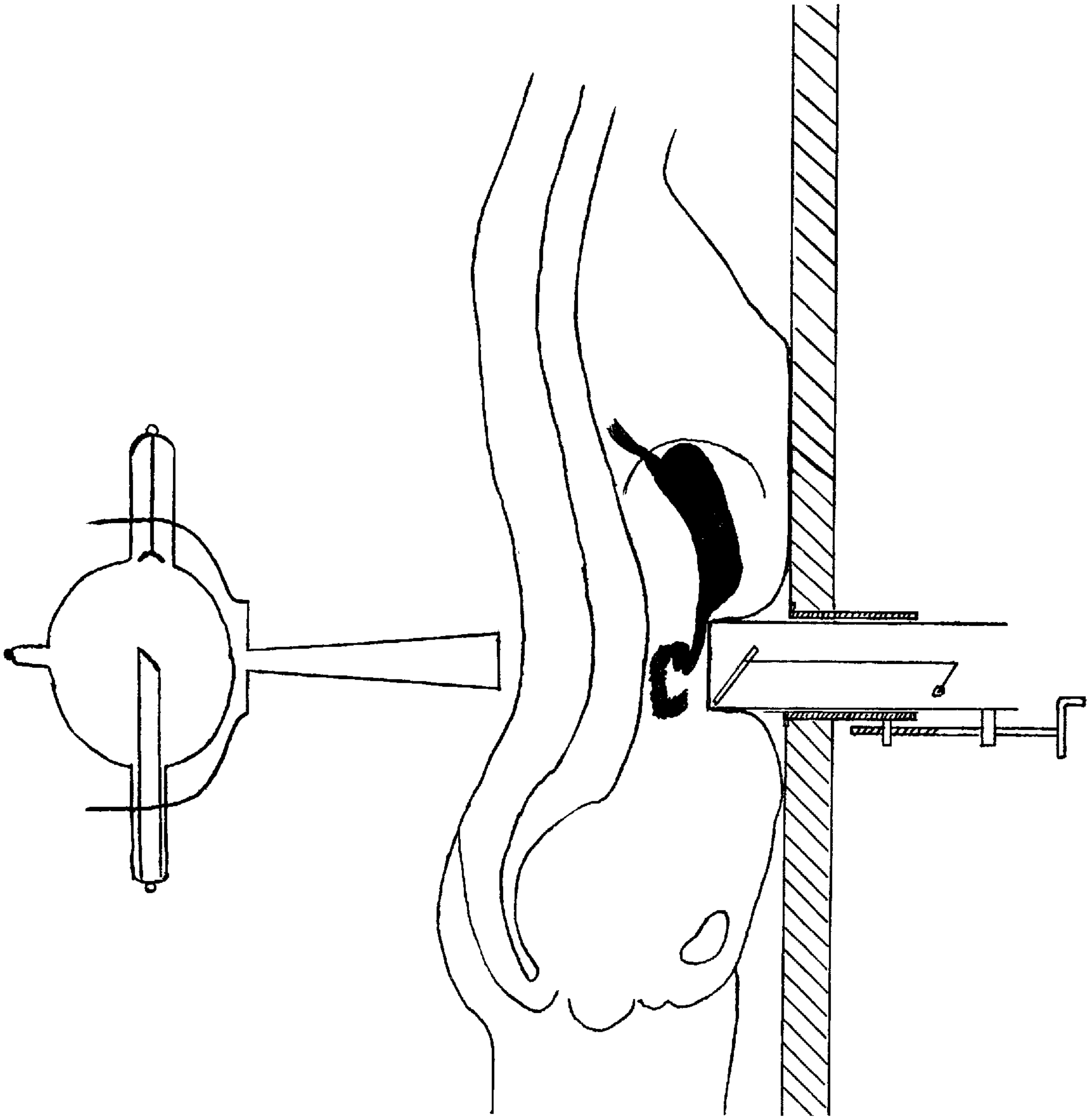


Fig. 16. Diagrammatic drawing showing the method of use of the compression apparatus designed and constructed by C. I. Headland, M.D. The patient is held against the face of the wall by the strap shown in Figure 9. This figure also shows the face of the apparatus protruding through the wall.

Compression is exerted on the soft, compressible abdomen by a rectangular piston which has rounded corners and is faced with a beveled layer of cork (third principle). The piston is pressed into the anterior abdominal wall by means of the screw gear. The intensifying screens and the fluoroscopic screen, mounted inside the front of the piston, are thus buried in the anterior abdominal wall and in extremely close contact with the opaque medium (fifth principle). No grid is used, the film being separated from the abdominal wall by only a thin intensifying screen and a thin layer of bakelite and cork. The gas tube is used which generates fewer secondary rays in the patient than any other tube (first principle). A cone is used which has the smallest diameter that will cover a 3¼ x 4 inch film at a 24-inch distance (second principle). The region to be examined is localized and the degree of compression desired is obtained under fluoroscopic examination. The image recorded in the roentgenogram is observed fluoroscopically at the instant of exposure.

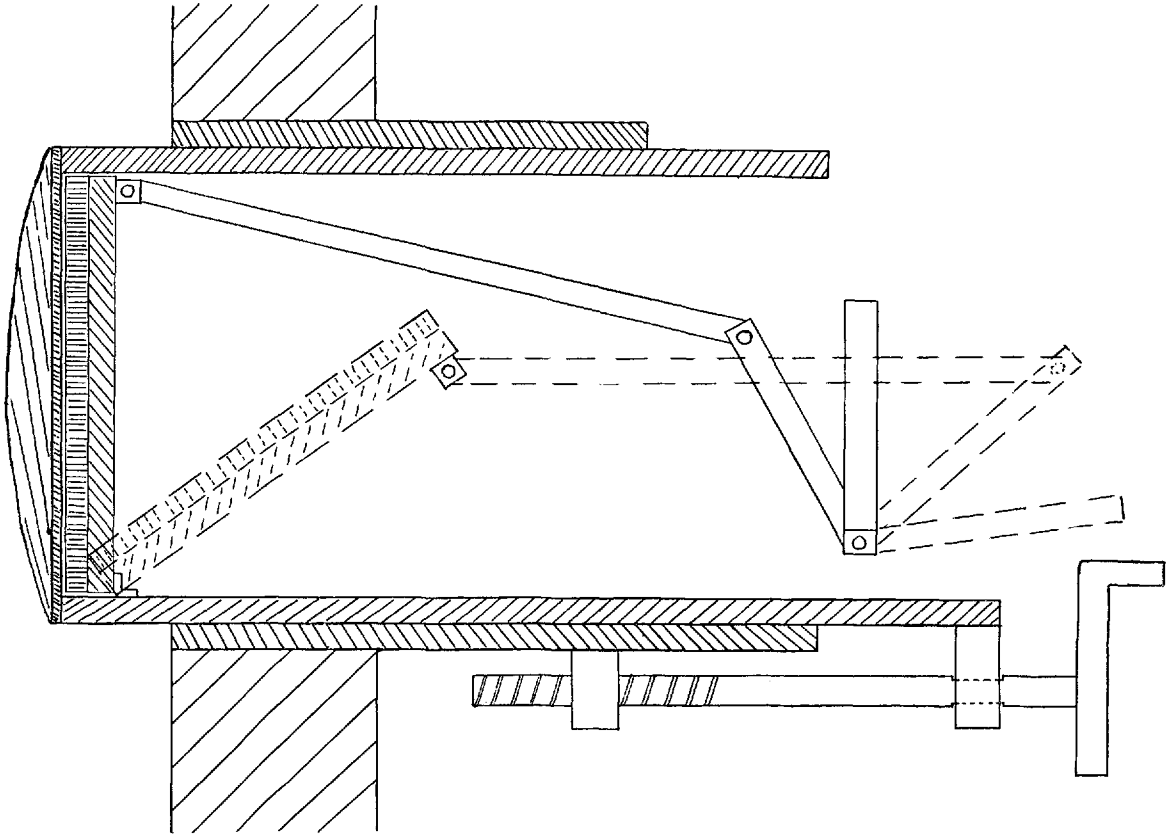


Fig. 17. Diagrammatic cross-sectional drawing showing the plan of construction of the compression device designed by C. I. Headland, M.D. The dotted lines show the position of the movable plate when drawn back for insertion or removal of the film. On this movable plate are mounted the back intensifying screen and the fluoroscopic screen.

Fig. 18. An enlargement of a 3¼ x 4 inch film similar to those shown in actual size in Figure 19. This is presented to show the detail and contrast as reproduced on the photo-engraving directly from the original film. This detail is obtained by using four out of the five fundamental principles for eliminating secondary radiation described in the text, namely, (1) gas tube, (2) small cone, (3) compression, (5) close apposition of the film to the part being examined. The fourth principle, the revolving grid, is not employed.

A, the cap, with criss-cross arrangement of the mucosal folds. *B*, pyloric valve. *C*, pyloric canal. *D*, antrum. *E*, descending duodenum. *F*, duodenojejunal flexure.

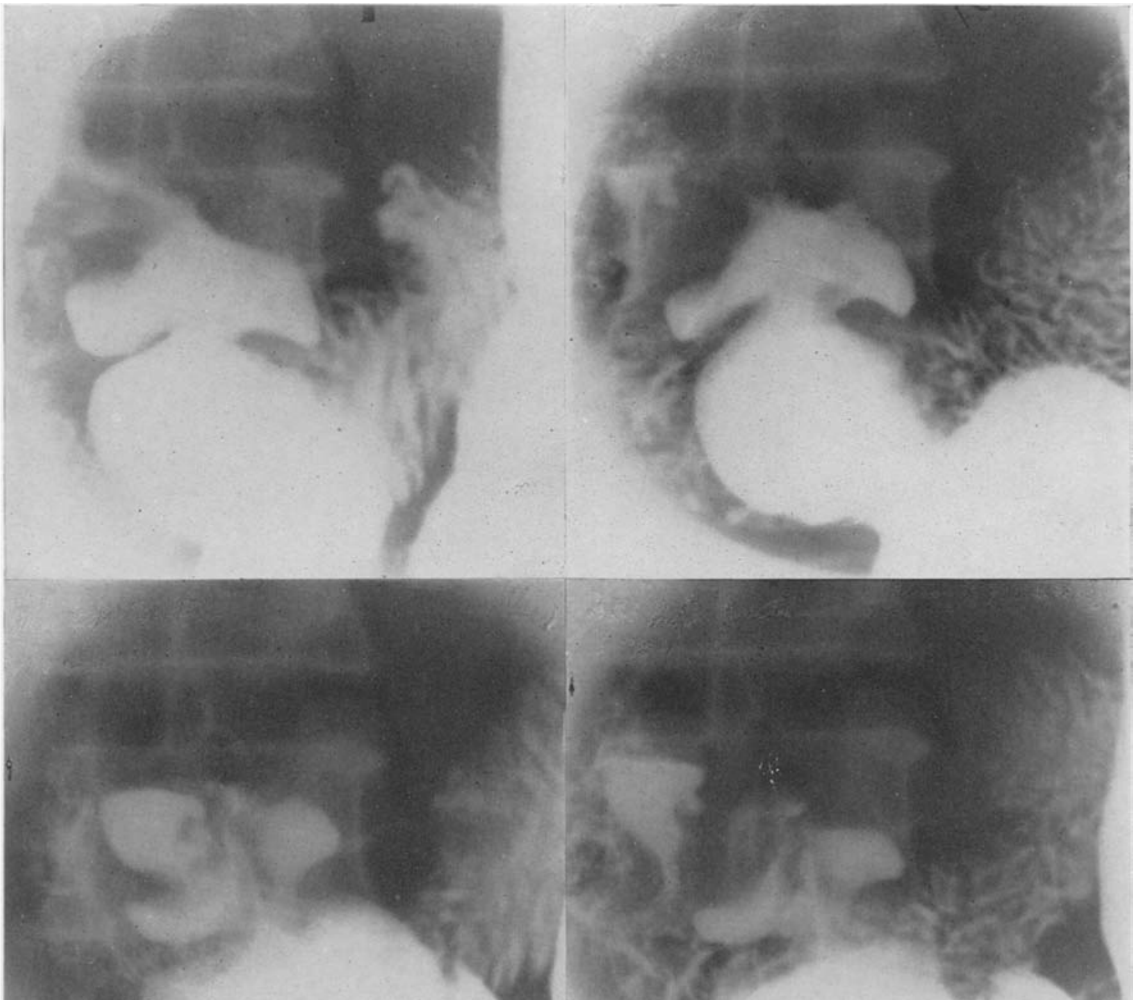


Fig. 19. Roentgenograms showing four stages of graduated pressure on the same cap. These are reproduced in actual size directly from the original films. A small ulcer on the posterior surface of the cap is shown distinctly, but it is not as characteristic as the crater deformity shown in the oblique films of the cap without pressure, which will be illustrated later when describing ulcers of the cap.