examination of the small intestine by means of duodenal intubation

J.L.SELLINK M.D.

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I
INTRODUCTION

Our knowledge of the diseases of the small intestine has increased greatly since the second world war. The advances made in the auxiliary sciences, in particular biochemistry and histology, are mainly responsible and have led to their increased importance in this field.

It is unfortunate that although radiology also contributed new understanding, it has not been able to match the progress of the other sciences. In spite of the advancements made in, for instance, vascular examination, radiology has experienced a relative decrease in its importance to the differential diagnosis of the diseases of the small intestine. The main reason for this is that radiology can only offer an extremely modest contribution to the differentiation between the many diseases with the malabsorption syndrome. In a number of cases, radiological differential diagnosis is in principle not possible because there are only histological and biochemical abnormalities of the mucous membrane of the small intestine without macroscopic abnormalities. There remain however many diseases with malabsorption for which a morphological examination can be highly valuable. This applies for:

1. diseases with gross anatomical abnormalities:
   anastomoses, fistulae, blind loops;
   strictures, adhesions;
   diverticula.
2. diseases with local, usually rather gross mucosal abnormalities:
   leukemia, Hodgkin's disease, lymphosarcoma;
   intra-mural bleeding;
   local edema due to venous congestion (e.g. thrombosis) or lymphatic obstruction (irradiation treatment).
3. diseases with more general mucosal abnormalities:
   edema due to: lymphangiectasis,
   allergic reactions,
   protein-losing enteropathy;
   amyloidosis, Whipple's disease, scleroderma.

For some of these diseases, the radiologist is the only one who can provide the correct diagnosis. However, with the conventional methods of examination still in use, he often cannot even make a differential diagnosis and must suffice with the report that malabsorption probably exists. This opinion is based on the observation of flocculation (p. 20) as well as the eventual disintegration into segment clumps (p. 24) of the barium meal in the small intestine. This conclusion incidentally is seldom important since the referring specialist is usually already aware of the malabsorption syndrome on the basis of other evidence. As soon as flocculation occurs, every morphological evaluation of the small intestine becomes impossible, because there is no longer any relationship between the boundaries of the contrast spots and those of the intestinal mucous membrane (fig. 3). The flocculation is usually irreversible and the flocculi continue to grow in size until segments are formed. In addition, when the rate of transit of the contrast fluid through the small intestine is slow, this clump formation is further promoted in the distal ileum by the absorption of fluids from the intestine. In the colon, segmentation (p. 27) of the barium column is the natural end of every normal passage through the small intestine. When various methods of examination as well as the results obtained with diverse brands of contrast media are observed, it then becomes apparent that the development of flocculation is also highly dependent upon both of these factors. As a result, one radiologist will observe flocculation frequently and the other only when there is a serious malabsorption. The highly illogical situation then arises that a radiologist can only interpret the small bowel examination of a colleague to a limited degree. Even if there are signs of a pronounced and relatively early flocculation on the x-ray film of a patient with a known malabsorption, he will not be able to express his opinion about the severity of this malabsorption. It is therefore obvious that in the roentgenologic findings an observed flocculation and segmentation must be reported such that faulty conclusions will not be drawn. In fact, this means that each radiologist builds up experience exclusively for himself based on the use of one specific contrast medium for one specific method of examination; this experience cannot be transferred to someone else. Should he change one or both of these aspects, then he has lost his experience in this respect and he must start again.

The radiological diagnosis of tumors in the small intestine is almost as difficult as the differentiation between diseases with the malabsorption syndrome. In 1938 this caused insurmountable difficulties (33) in cases without any obstruction and even today the radiologist seldom finds a tumor in the small intestine of a patient with limited clinical symptoms.

According to various articles, 1.5 to 6.5 per cent of the total number of tumors in the digestive tract are localized in the small intestine (146, 33). Although there are more malignant tumors in the stomach and more benign tumors in the colon, in the small intestine both types appear with approximately the same frequency (77). It is fortunate that most of the tumors are located in the duodenum and in the distal part of the ileum because in fact these two areas are the most accessible for unimpeded radiological examination. The fact that many tumors in the remaining parts of the small intestine are never diagnosed is however usually due to the technical execution of the examination and not the flocculation of the contrast medium. An additional drawback is that many radiologists do not take enough exposures of the small intestine and during the examination, the films are studied insufficiently or not at all. Although it is normal to take many spot films during fluoroscopy of the stomach and colon, this is usually not done for the much longer small intestine.

The difficulties encountered in locating smaller abnormalities in the mid-portion of the small intestine are demonstrated by the fact that the radiologist seldom finds a Meckel's diverticulum while a study of autopsy material has shown that this occurs in 2 per cent of the deceased.

For as long as the radiological examination of the small intestine has existed, now almost 70 years, the transit time has been included in the roentgenological report. The transit time however appears to be highly dependent upon many factors, including not only the pyloric function but also the quantity, the caloric value, the temperature and the method of administration of the contrast medium.

When RIEDER (180) introduced his standard 'meal' at the beginning of the century, this meal was in general use and recording the transit time was probably useful. This harmony however did not last very long because the method of examination and the use of contrast media later became highly diversified. It is therefore not surprising that the average transit time reported between 1930 and 1950 by prominent radiologists varied between 2 and 5 hours with extreme values of 1 and 8 hours (124). From the above, it is obvious that including these values on x-ray films and in reports is exceedingly unimportant today. It would probably be better to omit them since they can lead to incorrect conclusions.

In principle, the radiologist can also carry out a functional examination of the small intestine; until now however only a few attempts have been made in this direction. The difficulties in this field are still enormous so that realization of this type of examination will require more advanced experimentation. A condition for a functional examination is in any event a contrast meal with caloric value, obtained by adding nutrients. Unfortunately the stability (p. 27) of the contrast media now available is inadequate since all additives with caloric value cause flocculation.

Even in 1958 PYGOTT wrote that a follow-through examination of the small bowel has no value and as a routine study cannot be justified (172). Since then there has been little change; for many radiologists the examination of the small intestine is a stepchild, for others a problem child.

There has long been agreement about the best way to carry out examinations of the upper gastrointestinal tract and the colon, but a good examination technique without disadvantages does not yet seem to exist for the small intestine. A contrast medium which meets all requirements and which is without any doubt the best also does not exist. It is therefore not surprising that the examination of the small intestine has fallen into disrepute and is often not carried out in the best possible manner. In The Netherlands even the cost reimbursement tariff of the health service reflects this situation, because it is by far not enough to cover the actual costs of an adequate roentgenological examination.

AIMS

The aim of this study is to attempt to bring about an improvement in the unsatisfactory results of the radiological examination of the small intestine. These poor results can be blamed on the method of examination or the contrast medium used, or may be even both. In the chapters to follow, an attempt will be made to investigate this problem further by considering all factors involved in the radiological examination of the small intestine.

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II
HISTORY*

Within six months after the discovery of x-rays by WILHELM CONRAD RÖNTGEN in December 1895, WEGELE had localized the human stomach by inserting a tube containing a metal wire. HEMMETER used a tube to introduce lead acetate into the stomach after first testing this procedure on mice. Also in 1896, WALTER CANNON of Boston introduced a mixture of bread and bismuth** into the beak of a goose and using the fluoroscope, studied the mechanism of deglutition. In 1897, he used the same contrast medium to observe the peristaltic movements of the stomach of a cat. In the same year, BOAS and LEVY-DORN published their method for the examination of the human stomach. As contrast medium, they used bismuth nitrate packaged in capsules of gelatin and cellulose. In France, ROUX and BALTHAZARD also studied the human stomach; they used the same contrast medium but made a pap of water and syrup. In Germany fluoroscopic studies of the human esophagus were made using a 5 per cent suspension of bismuth in water. The bismuth nitrate is highly poisonous in large quantities and was quickly replaced by bismuth carbonate. In 1898, RIEDER administered the bismuth in the form of tablets or cookies; HOLZKNECHT made a paste with lactose in 1900 and several years later, a solution of 10 g bismuth with a teaspoon of lactose in 50 ml water.

The quality of the x-ray films left a great deal to be desired; tube current and tube voltage were very low so that exposure times occasionally lasted minutes.

Since they also wished to document the results of fluoroscopy, the images were quickly drawn by hand during the examination.

The examination of the digestive tract was only carried out incidentally and was predominantly functional in character. Measured by our modern standards, the requirements set were not high; interest was centered mainly on the stomach and the rate at which it emptied. Only very gross morphological abnormalities could be shown indirectly, such as a cardiospasm, an almost complete stenosis due to tumor growth or a hourglass stomach. For example, HOLZKNECHT (90) based a diagnosis of pylorus carcinoma on the following symptoms:

bismuth residual after 6 hours,
normal stomach shadow,
capsule intact after 5 hours.

and a diagnosis of gastric ulcer on:

small bismuth residual after 6 hours,
normal stomach shadow,
localized tenderness during palpation.

* From: GIANTURCO C. (68); HOLZKNECHT G. (90); RIGLER and WEINER in: *Alimentary tract roentgenology* (131); KNOX R. (101); LEDOUX-LEBARD G. (116).

** In earlier publications it is not always possible to discover which bismuthsalt was used.

However not until 1904 did the examination of the digestive tract find greater acceptance due to the pioneering publication by RIEDER (180). He described in great detail the examination of the stomach in fixed standard positions and listed the times when the subsequent transit pictures of the intestine should be made. He also introduced a standard meal for the examination, called Rieder gruel, which consisted of a mixture of 200 g semolina pap and 30 g bismuth. In this publication, RIEDER also demonstrated that the use of larger quantities of bismuth as contrast medium was not detrimental. In addition he listed several diagnostic criteria which, for the small intestine, were restricted to the rate of transit and signs of obstruction. Study of the mucous membrane was not possible; the duodenum could only be recognized by its shape. Around the jejunum and ileum, loops could not even be distinguished, so that these parts of the small intestine received no further attention.

Later RIEDER replaced his thick gruel with a suspension of 30 g bismuth in buttermilk, a mixture which was used until the twenties. This resulted in an improvement in the image quality, but satisfactory images of the ileum could still not be obtained. RIEDER therefore believed that it was better to carry out a retrograde examination of the ileum using a colon enema. In the meantime, differential diagnosis had been extended to include the diagnosis of tuberculosis which could be suspected if there were obstructions in the small intestine. Whether or not the appendix filled during a small intestinal passage also became a consideration of some significance.

In general there seems to have been a tendency to increase the bismuth content of the contrast meal and to replace food by water. One example is JOLLASSE's recipe of 1907: (98) he mixed 30 g bismuth with 15 g sugar and some water as needed. JOLLASSE had observed that the administration of a physiological contrast meal served no purpose since the bismuth settles and remains behind after the food has left the stomach. He was certainly one of the first to realize that the uppermost fluid level seen fluoroscopically during a stomach examination usually represents the food mixture. Before his publication this fluid level was always attributed to secretion due to PAWLOW's response. Apparently there was an exaggerated idea of the flavor of and the appetite aroused by the contrast meal. JOLLASSE saw that during the examination of the stomach, the level of the bismuth decreased but the contrast intensity increased. The samples which he obtained from the fluid levels with a tube confirmed his opinions.

In 1907 KAESTLE also considered the problem of sedimentation; his extensive publication is the oldest on this subject (100). He thought that this problem would not exist for a gastrointestinal examination because a good flour pap causes practically no sedimentation (p. 18). For the colon examination, on the other hand, bismuth was mixed with water only and sedimentation was very troublesome. He combatted this phenomenon by adding 5 parts bolus alba for each part bismuth to the contrast fluid. The composition of the resulting mixture, which was suited for eventual oral use, was as follows:

30 g bismuth carbonate,
150 g bolus alba,
300 ml water.

KAESTLE also tried to overcome sedimentation by adding tragacanth or arabic gum to the contrast fluid but the results were not satisfactory.

It is interesting to note the ideas prevalent at that time about the origin of the segmentation of the contrast column in the small intestine. It was believed that the stiffness of the 'bismuth sausage' was so great that it broke into fragments of necessity since otherwise the curves in the small intestinal loops could not be passed.

It is not known exactly how bismuth came to be chosen as the contrast medium; even in 1902 CANNON had mentioned that in addition to bismuth, barium could also be used. CANNON however chose bismuth powder on purpose because he knew that it could be obtained in a purer form than barium powder. The preparation of pure barium powder was not found at that time in the American pharmacopeia; bismuth powder on the other hand was listed.

KAESTLE, who was not happy with the pronounced tendency of bismuth toward sedimentation, also searched for other contrast media. He considered however only those elements with an atomic number greater than that of bismuth, such as thorium and uranium. These two elements of course could not be considered because of their rareness and high prices. At that time their radioactive properties were still unknown. Collargol, a soluble silver compound could not be satisfactorily used in the amounts considered safe because of the lack in contrast. He probably did not test barium, which is slightly lighter than bismuth, for the following reasons:

The contrast intensity of the films and fluoroscopic images obtained with bismuth was so low that a decrease could not be tolerated. In fact since only 30 g bismuth was used for approximately 300 ml contrast medium, the specific gravity of the mixture could not have been much higher than 1.1. Presumably because he had so little experience with barium, he did not dare use 30 g, thus a higher volume dosage. However at a radiological congress in 1910, KRAUSE of Bonn propagated the use of barium as a contrast medium. In spite of the fact that barium has the advantage of costing much less than bismuth, he did not succeed in introducing barium. Less than a year later however, his compatriots BACHEM and GÜNTHER were successful; they also suggested that chemically barium sulfate can be made purer than bismuth salts. Nevertheless bismuth was still preferred as contrast medium, certainly after publications appeared about the detrimental side-effects of barium, probably resulting from impurities. Not until the first world war did barium completely replace bismuth. Bismuth was necessary for the war industry and was therefore very scarce and expensive. After this war, bismuth was essentially no longer in use; positive experience in the use of barium had been gained in the meantime.

It was still common practice to administer a physiological food mixture, now however mixed with barium instead of bismuth. For example, we can find many recipes of this type in HOLZKNECHT's handbook dating from 1931. Several are listed below; together they also demonstrate that at that time a standard contrast meal no longer existed.

1. universal contrast medium:
   40–80 g $BaSO_4$ in 500 ml water.
   Stir until just before use to prevent sedimentation.
2. barium pap:
   100–150 g $BaSO_4$,
   3–4 tablespoons semolina,
   250 ml water.
3. paste suitable for prolonged storage:
   mixture of equal parts of $BaSO_4$ and paraffin oil.
4. barium pap of Schlesinger:
   180 g $BaSO_4$,
   20 g chocolate powder,
   3 g mondamine,
   250 ml water.
5. barium pap of Günther:
   150 g $BaSO_4$,
   150 g mondamine,
   20 g cocoa,
   15 g sugar,
   500 ml water.
6. paste of Schwarz:
   mixture of barium and apricot jam.
7. paste of Schlesinger:
   mixture of 80 g barium and 6 teaspoons applesauce.
8. for infants:
   mixture of barium and mother's milk.
9. for examination of the colon:
   100 g bismuth in 1000 ml water.

To obtain films of the digestive tract, HOLZKNECHT recommended a voltage of 55–60 kV, although the maximum obtainable tube voltage was 80–90 kV. The tube current was 30–40 mA; the exposure times were on the order of several seconds. Several clinics, including the Leiden University Hospital, preferred pictures which are interpreted more easily over the use of a physiological contrast medium, but they remained a minority until the second world war.

Only after CROHN's article in 1932 (37) on stenosing ileitis not caused by tuberculosis and the article by SNELL and CAMP (198) about chronic idiopathic steatorrhea was the interest in small bowel examination awakened. There were still some however who failed to see any point in the radiological examination of the small intestine. Even in 1937, WELTZ (214) wrote that for the small intestine morphological diagnosis is in principle impossible in contrast to functional diagnosis. It is in any event likely that his films were difficult to read because he used a calory-rich contrast meal. In 1932, COLE's co-workers (36) wrote that the ileum could only be identified by segmentation, and the jejunum by flocculation.

PRÉVÔT (171) did not agree; since more is known about the anatomy of the small intestine than the physiology, he considered a morphological evaluation more feasible than a physiological evaluation. He believed that the differences between the mucosal pattern on an x-ray film and on the autopsy table must be ascribed to the influence of tone and peristalsis. The fact that his patients underwent laxation before the passage examination in order to prevent mixture of the contrast medium with the bowel contents proves that he was far ahead of his times.

Because it was necessary to reject bismuth as a contrast medium, the beginning of the first world war actually concluded a phase in the development of the examination of the small intestine.

About 1940, again at the beginning of a world war, another period in this development was closed. The differential diagnoses at that time included the following diseases: polyposis, diverticula, tuberculosis, regional ileitis, leukemia infiltrations and M. Hodgkin (169).

Up until 1940 development of the radiological examination of the small intestine proceeded slowly; this can certainly be attributed to the limited detail reproduced by the contrast fluids used up to that time. The common practice of mixing barium with food was another important factor contributing to this lack of detail. During the second world war, most radiologists could not obtain the barium preparations they were used to. It then became necessary to use another brand or to prepare a suspension themselves. For many radiologists this resulted in the discovery that the characteristics of the diverse barium preparations vary greatly. They were therefore encouraged to try to improve the composition of the contrast medium. This resulted in a considerable improvement in the detail reproduced which in turn led to an expansion of the differential diagnosis.

A second important factor in the further development of the examination of the small bowel since 1940 was the appearance of numerous publications by ROSS GOLDEN. As no other, this radiologist studied the diseases of the small intestine and their radiological recognition. Only the conventional method of examination and the equally conventional contrast medium used at the height of his career limited the enormous significance of this man for the development of the radiological examination of the small intestine. ROSS GOLDEN can certainly be called the founder of modern differential diagnosis of the small bowel. His work has stimulated others to greater activity and intensive study of all aspects which might be important for a better understanding of the roentgenological pictures of the small intestine. These studies encompass anatomy, physiology, composition of the contrast medium and the method of examination. In the following chapters, these subjects will each be discussed separately.

III
ANATOMY

More important for a correct interpretation of the pictures obtained than for the technical execution of the examination is a thorough knowledge of the anatomical structure of the wall of the small intestine. It is however difficult to differentiate between examination and interpretation, at least when the radiologist is actively involved in both as is the case for gastric and colon examinations.

For 90 per cent of the patients, the jejunum is located in the left upper quadrant and the ileum in the right lower quadrant of the abdomen; according to ZIMMER, a small convolution usually lies in the middle and forms the transition between these two intestinal sections (223). The lack of this 'intermediate convolution' may be the most frequent anomaly. Now and then we are confronted with an inversion of the small intestine; the jejunum then lies in the right upper quadrant of the abdomen and the ileum in the middle or in the left lower quadrant. Quite rare are the cases of a total stomach-intestine inversion or an anomaly whereby the jejunum lies in the middle of the upper abdomen, the ileum in the middle of the lower abdomen and the stomach and cecum completely to the left.

The wall of the small intestine consists of the following layers, starting from the outside:

1. the serosa,
2. the tunica muscularis, which consists of an outer longitudinal layer and an inner circular layer,
3. the submucosa, which contains many blood and lymphatic vessels in a loose connective tissue so that the tunica muscularis can move freely with respect to:
4. the mucosa; this layer is made up of three parts:
   a. the muscularis mucosa which, like the tunica muscularis, consists of an outer longitudinal layer and an inner circular layer. The muscular strands of this inner circular layer extend into the folds of Kerkring and some even extend through the tunica propria into the villi which cover the surface of the mucosa. The villi vary in number from 10 to 40 per mm^2; they are 0.2–1 mm high and have a centrally located, blind ended lymphatic vessel. Between the villi are the crypts of Lieberkühn.
   b. the tunica propria, like the submucosa, consists of a loose connective tissue containing blood and lymphatic vessels as well as nerve fibers. Occasionally conglomerates of lymphocytes are found in this layer.
   c. a layer of simple columnar epithelial cells which can move freely with respect to the tunica propria. The surface of each epithelial cell is covered with hundreds of microvilli (200).

The folds of Kerkring begin 3–5 cm beyond the pylorus; in the proximal part of the jejunum, they are 3–6 mm high and 1–3 mm apart. Distally the folds are less high and they become more widely separated. The thickness of the folds is 1–2 mm in both the jejunum and the ileum; in the ileum however they tend to lie in a more longitudinal direction. During a contraction, the folds in the jejunum also extend in a more longitudinal direction (118).

In addition, the number and height of the villi decreases in the distal direction. WILSON computed mathematically that for a length of small intestine of 5.5 m, the surface of the mucosa is about 2.2 m^2 (215). If we assume an average diameter of 2 cm for the lumen, then the folds of Kerkring and the villi increase the surface of the mucosa more than 6 times, more in the jejunum and less in the ileum. The microvilli also increase the surface of the epithelial cells at least 15 times (200). The total increase in the surface due to the folds, villi and microvilli can therefore be estimated as 100 times.

The intramural nervous system of the intestinal wall is very complicated; the histological handbooks (BLOOM and FAWCETT, HAM, BUCHER and STÖHR) describe 4 systems:

1. the subserosal plexus,
2. the myenteric plexus of Auerbach, which lies between the circular and longitudinal layers of the muscle coat,
3. the plexus muscularis profundus in the circular muscular layer,
4. the submucosal plexus of Meissner which consists of several layers of interconnected fiber networks. The most important layer lies close to the muscularis mucosa. Some fibers from this layer extend to the muscularis mucosa and others continue through the tunica propria to the villi, glands and epithelial cells. There is also a layer close to the inner circular muscular layer of the tunica muscularis.

The anatomy of the wall of the small intestine is shown schematically in fig. 1.

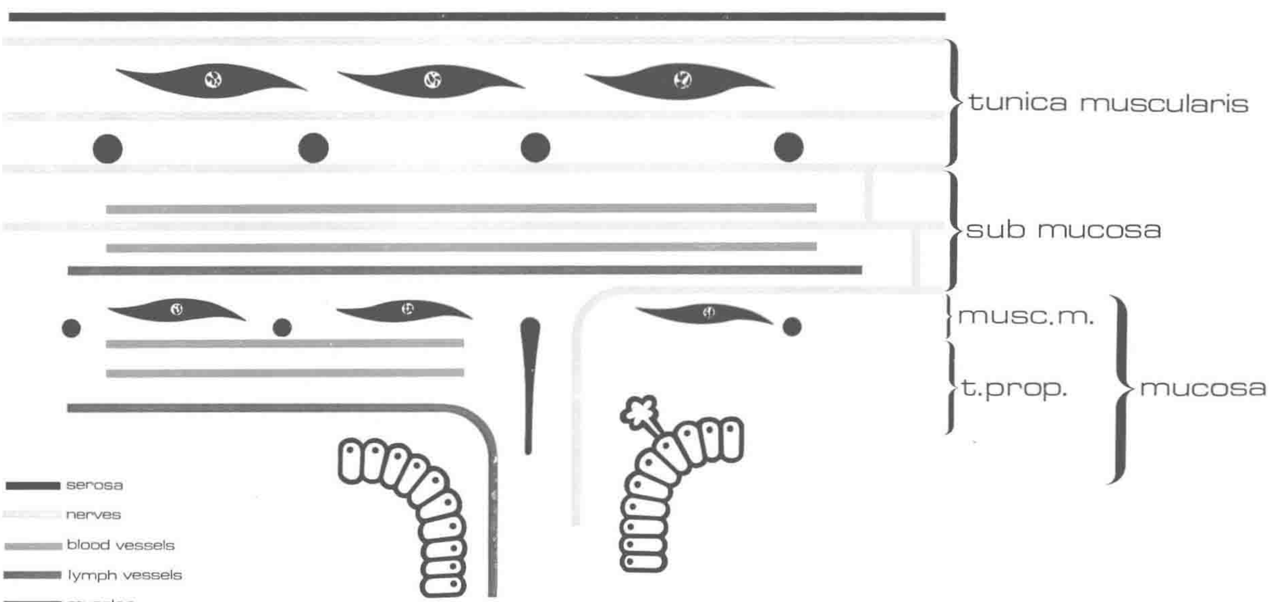

Fig. 1
Schematical cross-section of intestinal wall

Although several studies have been published concerning the length of the small intestine, the definitive answer has yet to be found. Most handbooks list values varying between 5 and 7 meters and the small intestine is assumed to be $\frac{3}{5}$ of the total length of the digestive tract. It is known that the length of the small intestine is highly dependent upon the tone, so that the results of measurements taken post-mortem or under anaesthesia will be too high.

Some authors state that an asthenic will have a slightly longer small intestine than a pycnic. In fact

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