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An arteriographic study of mesenteric arterial disease

I Large vessel changes

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EDITORIAL COMMENT This is an important study of large vessel changes causing chronic arterial insufficiency of the intestines. Symptoms of intestinal ischaemia have not been seen in this series in patients in whom the cross-sectional area of the arteries was greater than two-thirds of the normal. Arteriography is demonstrated as a valuable procedure in assessing the possibility of intestinal ischaemia as a cause of symptoms.

The diagnosis of arterial insufficiency of the intestines as the cause of abdominal pain can be a matter of considerable difficulty. A classical story of cramping, upper and central abdominal pain, worse after meals, particularly if large or if followed by exercise, is by no means always obtained. Other features recorded as occurring in this syndrome, such as chronic diarrhoea, a malabsorption syndrome and relief of pain by assuming the knee-elbow position, are so seldom observed as to be of little diagnostic help. Although the quality of ischaemic pain—severe, prolonged, cramp-like, and aching—may be suggestive, almost always part of the diagnostic procedure lies in the exclusion of other possibilities. At the present time there is no readily applicable method of measuring blood flow to any part of the gastrointestinal tract, except actually at laparotomy.

Arteriography of the mesenteric vessels is an essential procedure in cases of suspected intestinal ischaemia; first to ascertain whether narrowing is present; secondly to outline the anatomical site and extent of the arterial changes; and thirdly to demonstrate the presence of any anastomoses. As regards the first point, little is known about the extent of narrowing which must be present before symptoms of arterial insufficiency are likely to occur. This investigation is concerned primarily with the extent of the changes which may be found in the large mesenteric arteries in patients without abdominal symptoms, and in comparing these with the abnormalities found in patients believed to have intestinal ischaemia. Secondly, it is concerned with describing some of the abnormal findings which may be demonstrated on mesenteric arteriography.

The physiological background of the clinical problem of intestinal ischaemia has been well reviewed by Hedberg and Kirsner (1965). Practical importance is lent to the present study by the numerous reports of the successful treatment of both acute and chronic intestinal ischaemia which have appeared in the past 10 years. These include surgical relief by embolectomy (Shaw and Rutledge, 1957), by thrombendarterectomy (Shaw and Maynard, 1958; Mikkelsen and Zaro, 1959), and by reconstructive bypass procedures (Morris and De Bakey, 1961; Ranger and Spence, 1962; Brolin and Hansson, 1964). Acute infarction of the intestinal tract is associated with a high mortality. Dunphy (1936) noted the short preceding history of symptoms in patients dying from mesenteric infarction, and Berman and Russo (1950) made a similar observation. It has recently been pointed out by Mavor, Lyall, Chrystal, and Tsapogas (1962) that some 50% of patients with acute mesenteric infarction had preceding abdominal symptoms. These are usually of short duration and, if mid-gut ischaemia is suspected, diagnosis is clearly a matter of some urgency.

As far as we can ascertain no systematic study has been made of the range of abnormalities which may be found on arteriography of mesenteric vessels in subjects without abdominal symptoms, nor has the extent of the changes which may be expected in patients with abdominal angina been defined.

Pathological studies bearing more closely on the occurrence of mesenteric atherosclerosis have, however, been carried out. Maljatzkaja (1934), in a pathological investigation of 85 cases at necropsy, found

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that atherosclerosis in the vessels of the mesenteric circuit tended to be progressively less severe towards the periphery, the maximal changes occurring nearest the aorta. The exception to this rule was the splenic artery, in which atherosclerosis occurred throughout its whole length without showing the usual diminishing trend. This author noted that severe mesenteric atherosclerotic disease was not found without severe aortic disease but the reverse did occur.

Reiner, Jimenez, and Rodriguez (1963), in post-mortem examination of 88 adults of all age groups, found that 68 were affected with mesenteric atherosclerosis. In 49 of these there was actual stenosis and 15 had had occlusions of one or more main arteries. The presence of mesenteric atherosclerosis showed considerable variability in the different age groups and was not closely correlated with age, nor with hypertension or diabetes. In the cases with severe mesenteric atherosclerosis, however, there was a high incidence of diabetes. These authors note the frequency of stenosis at the aortic ostia and that plaques tend to be concentrated in the first 9 to 12 cm. of the superior mesenteric artery. Stenosing lesions were particularly common in the main stems. They found a close correlation, both ways, between aortic and coronary atherosclerosis. They note, as did the previous author, that severe mesenteric artery disease was associated with severe aortic disease, but that the converse was not necessarily the case, a number of patients having severe changes in the aorta without any abnormality in the mesenteric arteries. There was a substantial rise in the number of patients who had had myocardial infarction in those with more severe grades of mesenteric disease, but the reverse correlation was not found. There was also a similar, one-way, but less marked, correlation with peripheral vascular disease.

Johnson and Baggenstoss (1949) studied at necropsy 60 patients who had had occlusion of a mesenteric artery. The causes were listed as thrombosis in 26, emboli in 19, and arteriosclerosis alone in four, periarteritis nodosa in three, and in two septic arteritis. In nine the cause was uncertain. They stress the association of heart disease, often with auricular fibrillation, in these patients, as did Klein (1921) in providing the precipitating factor for the occurrence of infarction, apart from the question of embolization.

Relevant to the present investigation are the papers of Derrick and Logan (1958) and Derrick, Pollard, and Moore (1959). In the former study the cross-sectional area of the superior mesenteric artery was calculated, in 75 unselected post-mortem specimens, from diameter measurements made in three places: (1) at the aortic opening; (2) at the narrowest segment, which they state was invariably 0·25-1·0 cm. distal to the aortic opening; and (3) at 1·5 cm. distal to the aortic opening where the vessels were usually pliable and free of arteriosclerotic changes. Twenty-eight of the 75 arteries showed a reduction of the lumen varying from 12% to 86% of the cross-sectional area. They note that the arteriosclerotic narrowing persistently occurred just distal to the aortic opening of the superior mesenteric artery. In the study by Derrick *et al.* (1959) 110 cases were examined in the same way and also by tying off the aorta and main branches and studying the specimen by radiography after distension with air. The coeliac axis was also examined and they note that in these cases 44% of the coeliac arteries showed some narrowing and 21% were found to have, at some point within 1·5 cm. of the aortic orifice, a reduction of 50% or more in the calculated cross-sectional area. They make the point that the geometric detail of stenosis makes calculation of the cross-sectional area very difficult.

PRESENT INVESTIGATION

The object of the present investigation has been to study the types and extent of abnormality found in the large mesenteric arteries in a variety of patients presenting for aortography. An attempt has been made to analyse their frequency and grade their severity in different groups of patients of varying ages. At the same time, by comparing the findings in these patients without abdominal symptoms with those in a group of patients suspected of having ischaemic gut disease, it is hoped to ascertain the extent of arterial narrowing which may be expected to result in ischaemic symptoms. The findings have been analysed and the types of abnormality found are described. In addition, details are given of the cases in which ischaemic gut disease was finally believed to be present.

This study is confined to changes in the large vessels. Many patients with symptoms due to intestinal ischaemia may have distal arterial narrowing and it is not known in what proportion narrowing of the large vessels is the important factor. The distal collateral circulation is generally very adequate, but critical areas are said to exist at the region of the splenic flexure of the colon, where the superior and inferior mesenteric circulations anastomose, and in the rectosigmoid region (Griffiths, 1961).

CLINICAL MATERIAL All patients, presenting for aortography, whatever the indication, and in whom lateral lumbar aortography appeared to carry no additional risk, have been included, as well as those in whom lateral lumbar aortograms had been performed because of a suspected diagnosis of intestinal ischaemia.

One hundred patients have been examined and these fell into four clinical groups:

(1) *Controls* (*27*) These were patients who showed no clinical evidence of arterial disease, beyond a slight degree of arteriosclerosis compatible with their age in the more elderly patients. Their blood pressure was normal. The majority were having aortography for suspected renal lesions, as, for example, renal carcinoma, renal cysts, polycystic disease without hypertension, etc. In some instances the examination was performed for the elucidation of an abdominal mass, including retroperitoneal reticuloses and giant lymphoma of the spleen.

In one patient the examination was undertaken because of suspected peripheral arterial disease, later proved not to be present, and in five because of an initial suspicion of intestinal ischaemia, not confirmed on investigation.

(2) *Hypertensives* (*56*) The criterion for hypertension was a diastolic pressure of 105 mm.Hg or higher, taken after a period of rest. Confirmatory evidence was usually present. The diagnosis of hypertension was taken as overriding groups 1 and 3, and, with the exception of cases of probable intestinal ischaemia, all patients with a diastolic pressure of 105 or over were placed in group 2. In fact, 54 patients in this group were having aortography to demonstrate the renal arteries and parenchyma, and two on account of intermittent claudication.

(3) *Arteriopaths* (*12*) Ten of these patients were having aortography on account of lower limb ischaemic symptoms and the great majority showed other clinical evidence of arterial disease, a number having ischaemic heart disease. One patient was suspected of an abdominal aneurysm and lower aortic stenosis, while the twelfth was thought to have ischaemic gut disease, subsequently disproved, and also had cardiac ischaemia.

(4) *Probable intestinal ischaemia* (*5*) Eleven patients had aortograms carried out because of a suspicion of this diagnosis, but in only five was it thought to be highly probable after investigation. In two it was confirmed surgically. The final diagnoses in the remaining six were as follows: prepyloric ulcer, retroperitoneal secondary carcinoma, Crohn's disease, ? hiatus hernia, undiagnosed abdominal pain, gastric ulcer. These six were subsequently placed in their appropriate group, five being transferred to the control group, and one, who also had coronary disease, to group 3.

The distribution of the cases into four groups according to age is shown in Table 1.

A few cases had to be excluded because satisfactory lumbar aortograms could not be obtained. An antero-posterior picture of one such patient in whom renal aortography was being performed for hypertension is shown (Fig. 7) because of the particularly good anastomotic circulation revealed. During the time these 100 cases were being investigated, lateral lumbar aortography was carried out on one case of Takayashu's disease, and in two of medial dysplasia, in all of which there was involvement of the mesenteric arteries, but in none at that time were abdominal symptoms present. These have been excluded from the series of 100 cases as representing a different problem, but the aortogram of one patient with medial dysplasia is shown (Fig. 7) to illustrate the anastomotic circulation. Routine clinical examination, with particular reference to the cardiovascular system, was carried out in all patients, but the extent of investigation varied according to the nature of the case. Almost all the cases had an electrocardiographic examination, and all patients originally suspected of having intestinal ischaemia had extensive abdominal investigations, including barium studies, cholecystography, and pancreatic function tests in most instances.

TABLE I

AGE DISTRIBUTION OF CASES

Age Group	*Control*	*Hypertension*	*Arteriopathy*	*Probable Intestinal Ischaemia*	*Total*
Under 40	7	20			27
40-49	4	15	3		22
50-59	9	12	6	1	28
60 and over	7	9	3	4	23
Total	27	56	12	5	100

TECHNIQUE The examinations were performed under surgical aseptic technique, the patient having been premedicated with one of the basal narcotics, and the examination was done, usually from the femoral artery route, under local anaesthesia using the Seldinger (1953) percutaneous method. A grey Kifa catheter with tip occluder was used so that injection of contrast was made into the lumbar aorta via catheter side holes only, thus obviating retrograde dilution and the use of a large volume of contrast medium. The usual volume used was of the order 25 ml., 60% Urografin with slight variations according to the patient's weight and size. Injection was made at 60 lb./sq. in. and rapid films were secured in both lateral and antero-posterior planes following correct siting of the catheter tip in the thoraco-lumbar aorta (D12) by means of a TV monitor and image intensifier unit.

The lateral film series were taken to show the origins of the mesenteric vessels, the normal appearance being illustrated in Figure 1. Anteroposterior films were taken with the object of demonstrating an anastomotic circulation, if present, either via Drummonds' (1914, 1917) marginal artery (Figs. 6, 7) or by the pancreaticoduodenal vessels (Figs. 7, 10C). Selective catheterization arteriograms (Figs. 10B, 10C) were undertaken if further clarification of arterial obstruction was required using an

Ödman (1956, 1958, 1959) catheter. No complications have been encountered in the series of cases examined. A point which should be mentioned is the occasional occurrence of hypotension following injection of the contrast medium in patients who are on a hypotensive drug. Severe abdominal pain may occur rarely in these patients.

RESULTS

TYPE OF ABNORMALITY The different varieties of abnormal appearance found in the main trunks on arteriographic examination are illustrated in the accompanying Figures 1 to 12. It must be stressed that the lateral aortogram shows the vessels in only one plane. The extent of reduction in arterial lumen may be much exaggerated if the atheromatous plaque is situated only on one of the sides visible, or entirely missed if it is *en face*. A correct assessment is only obtained when there is a uniform reduction in circumference.

Narrowing tends to occur at the ostia of the vessels and may be continuous with an aortic plaque. It also tends to occur in the first 2 or 3 cm. of the main trunks. Atherosclerotic plaques may result in various types of irregularity of the lumen. The varieties found in this series can be summarized as follows:

1 Ostial (nipping), which may result from a 'build up' of an atheromatous aortic plaque impinging upon the ostial origin of a mesenteric vessel (Fig. 2B).

2 Plaque formation within the vessel resulting in stenotic narrowing with or without post-stenotic dilatation (Figs. 2B, 3, 4, 8, 9, 10A, 10B).

3 Irregular stenosis (Fig. 6)

4 Annular smooth stenoses (Fig. 4)

5 Segmental stenoses which may be unilateral or bilateral (Fig. 2B).

Post-stenotic dilatation may be seen in some instances, and is a useful indication of preceding narrowing if this happens to be partially obscured. Spasm may be seen in the mesenteric vessels on arteriography, producing the so-called 'rosary' effect. It is of practical importance to distinguish this from organic narrowing.

Complete obstruction of the main trunk of the coeliac or superior mesenteric artery may be seen on occasion, but was not recorded in this series. This state of affairs must be distinguished from the occasional congenital absence of either the coeliac axis or the superior mesenteric artery, all the branches of which would normally arise from both trunks originating from whichever is present. For total obstruction of either vessel to develop in the absence of symptoms, a substantial anastomotic circulation must have developed *pari passu*. The inevitable presence of anastomoses when the absence of a main trunk is due to an acquired obstruction is an important point in differentiating this from a congenital anomaly.

The inferior mesenteric artery was not visualized at all on 40 occasions in this series of 100 cases. This is, of course, a much smaller artery. It is estimated that its cross-sectional area varies between 1/10th and 1/20th of that of the superior mesenteric artery. It is probable that at times it did not fill satisfactorily for technical reasons, and that selective arteriography may be necessary for its demonstration.

The finding of anastomoses is of considerable importance, apart from indicating the presence of stenoses, in suggesting possible means of surgical relief. It should be mentioned that, while the presence of an anastomosis is good evidence of stenosis elsewhere, grossly dilated anastomotic channels are seen much more frequently in patients without symptoms of intestinal ischaemia than in those in whom this is present. Whether or not ischaemia develops presumably depends on the rate of development of the stenosis and whether anastomotic channels form sufficiently rapidly to compensate, a situation analogous to that seen in the heart and in the lower limbs.

The two main anastomotic developments seen have been in the pancreatico-duodenal circuit and in the marginal artery of the colon. In the first instance an anastomosis develops between the superior pancreatico-duodenal branch of the gastro-duodenal artery, which arises from the hepatic artery and the inferior pancreatico-duodenal artery arising from the first part of the superior mesenteric artery. Development of this anastomotic channel is the main compensatory mechanism for stenosis of either the coeliac or the superior mesenteric artery, the blood flowing from the superior mesenteric into the branches of the coeliac axis in the case of coeliac stenosis (Fig. 10C) and in the reverse direction into the superior mesenteric branches when the opening of the superior mesenteric artery is narrowed (Fig. 7).

Secondly, an anastomosis may develop between the ascending division of the left colic branch of the inferior mesenteric artery and the left division of the mid colic branch of the superior mesenteric artery. Again this may form in response either to an obstruction of the inferior mesenteric artery (Fig. 6), or of the proximal part of the superior mesenteric artery. In the latter case blood is supplied from a much hypertrophied inferior mesenteric artery into some of the superior mesenteric artery branches (Fig. 7). This dilated marginal artery of the left colon is known as Drummond's artery (Drummond, 1914).

EXPRESSION OF FINDINGS An estimate was made of the degree of any narrowing present in the coeliac,

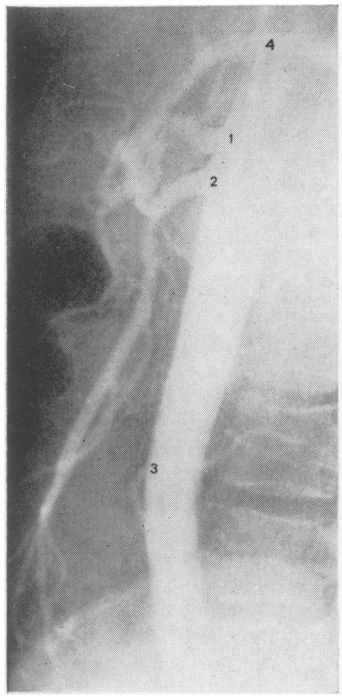

FIG. 1. *B.G. F.59yr.* Normal appearance. *Recurrent urinary infections. Aortography because of doubt regarding kidney size and outline on I.V.P. Normal coeliac artery (1). Superior mesenteric artery (2) and inferior mesenteric artery (3). The splenic artery (4) is large but within normal limits*

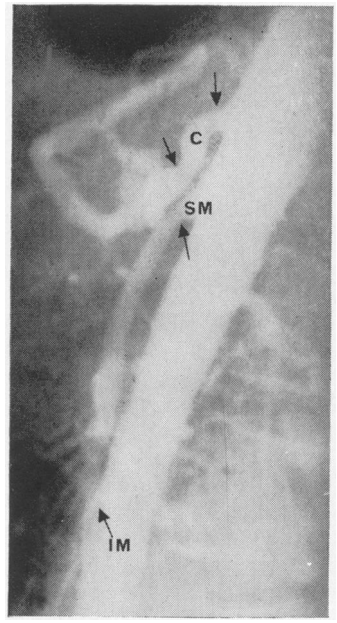

FIG. 3. *E.B. F.58yr.* Hypertensive (*blood pressure 230/110 mm.Hg*). *Bilateral renal artery stenosis. No abdominal symptoms. Aortic atheroma* (+). *Coeliac artery narrowed to* ½ *at 0·5 cm. from origin and to* ½ *at 2 cm. from origin* (←—). *Superior mesenteric artery narrowed to* ¾ *at 1 cm. from origin* (←—). *Inferior mesenteric artery narrowed to* ¾ *at its origin* (←—).

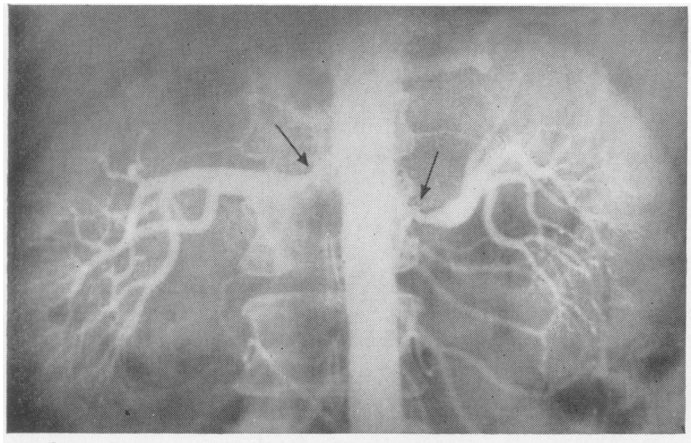

FIG. 2a.

FIG. 2A. *F.D. M.42yr.* Hypertensive (*blood pressure 180/120 mm.Hg*). *Bilateral renal artery stenosis.*

FIG. 2B. *Aortic atheroma* (+). *Coeliac artery narrowed to* ½ *at origin. Superior mesenteric artery narrowed to* ¾ *over long segment, starting 2 cm. from origin. Inferior mesenteric artery narrowed to* ½ *at origin.*

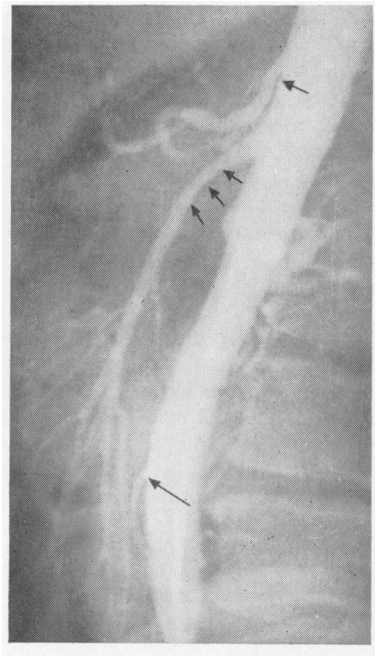

FIG. 2b.

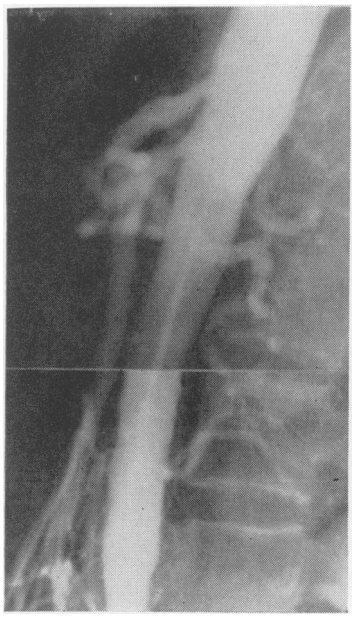

FIG. 4. *D.D. F 62yr.* Arteriopath (*blood pressure 125/80 mm.Hg*). *Aortography for suspected abdominal aneurysm. Aortic atheroma* (+) *and iliac arteries were tortuous. Coeliac and superior mesenteric arteries narrowed to* ½ *at 0·5 cm. from origin. Inferior mesenteric narrowed to* ¼ *at origin.*

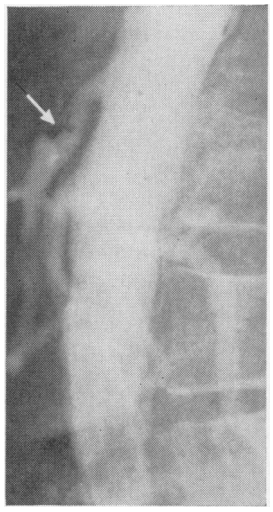

FIG. 5. *E.W. F.76yr.* Arteriopath (*normotensive*) *Aortic atheromatous irregularity* (+). *Coeliac stenosis, irregular in type, narrowed to* ½ *at 2 cm. from origin* (←—). *Bilateral renal artery stenosis was demonstrated in AP aortogram series.*

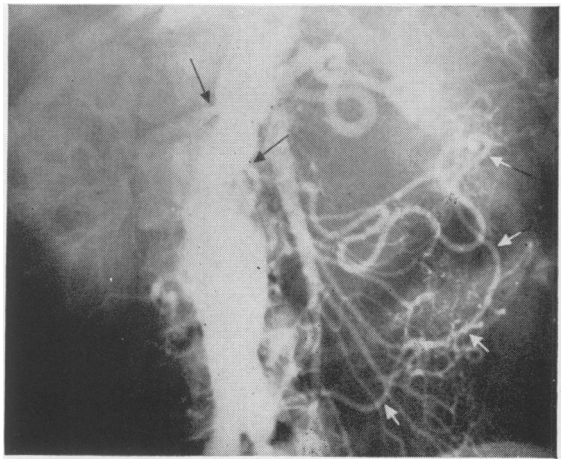

FIG. 6. *E.S. F.36yr.* (*blood pressure 220/110 mm.Hg*). *No abdominal symptoms. Severe aortic* (+++) *and iliac atheroma. Bilateral renal artery stenosis* (←—) *with ischaemic left kidney. No nephrogram visible. Anastomosis of left colic branch of inferior mesenteric artery with mid colic branch of superior mesenteric artery extending up to splenic artery region and forming the so-called marginal or Drummond's artery* (←—). *Not in series but included to show anastomosis.*

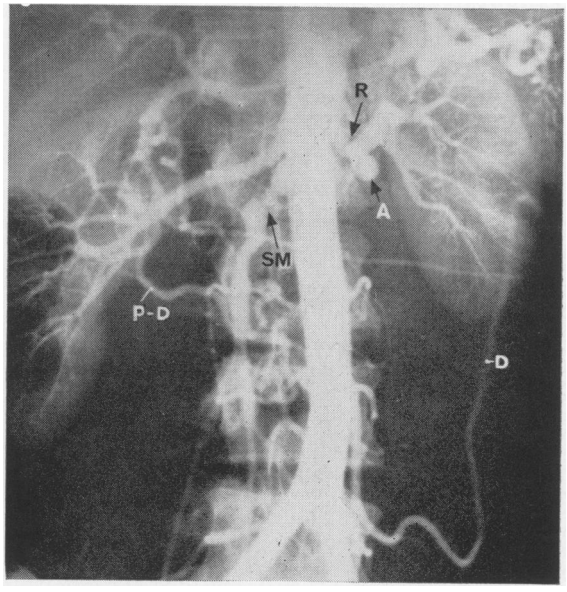

FIG. 7. *D.B. F.27yr. Case of fibromuscular dysplasia causing stenosis involving both renal* (←—R) *and superior mesenteric* (←—SM) *artery. Aneurysms of left renal artery* (←—A). *Not included in series. This demonstrates a well-developed Drummond's artery* (←—D), *with blood flow upwards from inferior mesenteric as a result of partial obstruction of superior mesenteric artery in contra-distinction to previous case* (*E.S.*) *in which blood flow was in the reverse direction. Pancreatico-duodenal anastomosis* (←—P-D) *also increased.*

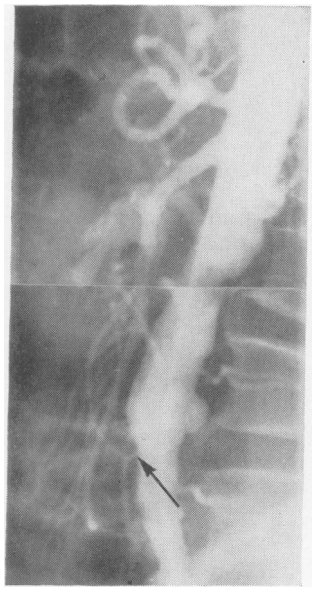

FIG. 8. *J.S. M. 60 years.* 'Positive' case (*blood pressure 170/90 mm.Hg*). *Aortogram showing atheroma* (+++) *with posterior lower lumbar aneurysm. Coeliac artery narrowed to* ½ *at 0·5 cm. Superior mesenteric artery irregular but not narrowed. Inferior mesenteric artery narrowed to* ½ (←—). *Operation* (*Mr. Ian Ranger*) *with relief of symptoms.*

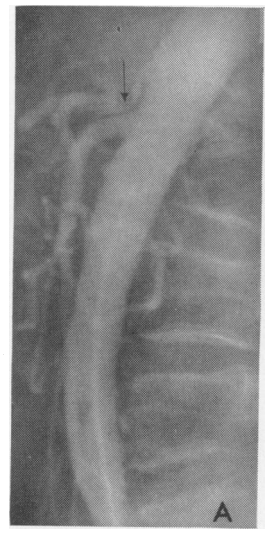

FIG. 10a.

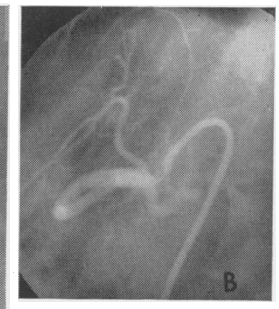

FIG. 10b.

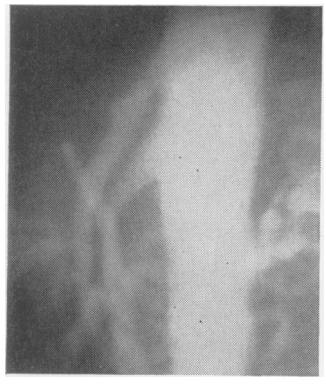

FIG. 9. *W.M. M. 63 years.* 'Positive' case (*blood pressure 200/110 mm.Hg*). *Aortogram showing atheroma* (++). *Coeliac artery narrowed to* ¾ *at 1 cm. Superior mesenteric artery narrowed to* ½ *at 2·5 cm. Inferior mesenteric artery not seen.*

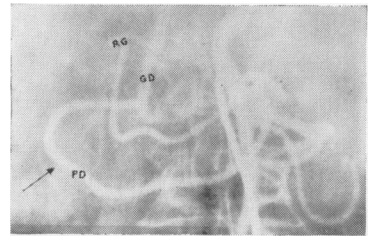

FIG. 10c.

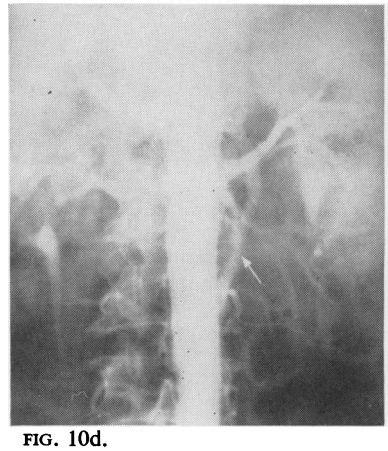

FIG. 10d.

FIG. 10e.

FIG. 10A. *G.P. M. 60 years.* Case of intestinal and hepatic ischaemia (*normotensive*). *Aortic atheroma* (+). *Coeliac stenosis—narrowed to* ¼ (←—).

FIG. 10B. *Selective coeliac arteriography confirms stenosis.*

FIG. 10C. *Selective superior mesenteric arteriography showing large pancreatico-duodenal anastomoses.*

FIG. 10D and FIG. 10E. *Anterio-posterior and lateral post-operative aortograms showing retrograde filling of coeliac artery from aorta via implanted splenic artery* (←—) *anastomosis.*

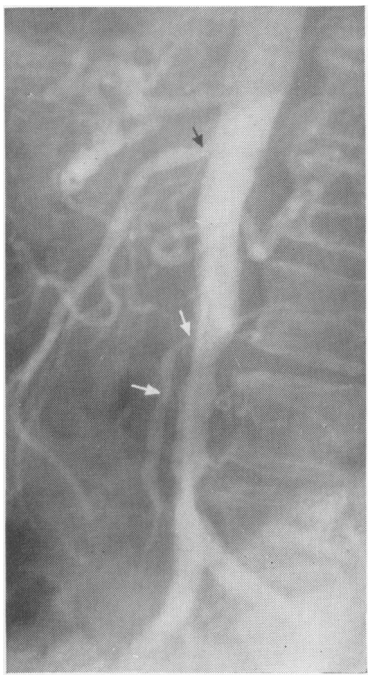

FIG. 11. *F.S. 76 years.* 'Positive' case (*blood pressure 170/110 mm.Hg*). *Gross aortic atheroma* (+++). *Coeliac artery normal. Superior mesenteric artery narrowed to ½ at 0·5 cm.* (←—). *Inferior mesenteric artery narrowed to ½ and showing well-marked atheroma* (←—).

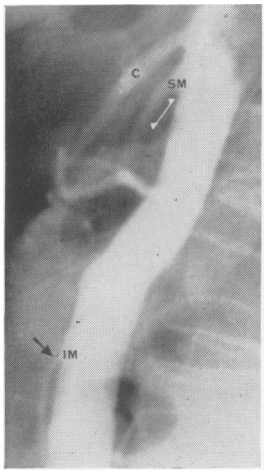

FIG. 12. *E.C. F. 87 years.* 'Positive' case (*blood pressure 210/105 mm.Hg*). *Aortic atheroma* (+). *Coeliac artery narrowed to ¾ at 0·5 cm.* (←—). *Superior mesenteric artery narrowed to ½ over long segment* (←—). *Inferior mesenteric artery narrowed to ¾ at origin* (←—).

superior mesenteric, and inferior mesenteric arteries. Whenever possible this was done by measurement of the narrowed area or segment, but on occasion there appeared to be no normal artery with which to compare the narrowed segment, and under these circumstances the amount of narrowing could only be estimated. It was not felt possible to measure the degree of narrowing more accurately than by quarters, and the findings are expressed for each artery as 4, 3, 2, 1, and 0, that is, from fully patent to completely obstructed.

At the same time the degree of atheroma in the lumbar aorta was estimated as normal 0, 1, 2, or 3 plusses. When visible a note was made of the state of the iliac arteries. In the case of the renal arteries it was not felt that any narrowing could be estimated more accurately than in thirds, and these were graded as 3, if normal, 2, 1, or, in the case of complete obstruction, 0.

As lateral lumber aortography only shows the vessels in one plane, irregular distribution of atheroma around the wall of the vessel may give an erroneous impression of the degree of, or absence of, narrowing in individual cases. In some instances, in order to demonstrate anastomoses, antero-posterior films were also taken, but visualization of the origin of the main trunks is usually not possible in antero-posterior pictures because of the overlap of the shadow with that of the aorta.

The trunk of the superior mesenteric artery is, as a general rule, slightly larger than the coeliac artery, whereas the inferior mesenteric artery is a relatively small vessel. Consideration of the relative diameter of these vessels in a number of control patients led to the conclusion that the ratio of the diameter of the coeliac to the superior mesenteric artery to the inferior mesenteric artery was 4:4·5:1. The cross-sectional area of an artery is clearly much more closely related to its functional capacity than is the diameter, although, of course, blood flow depends on many other factors. If the diameters are converted into cross-sectional areas the ratio 64:81:4 results for the coeliac, superior mesenteric, and inferior mesenteric arteries respectively, giving an aggregate of 149 for the normal.[1]

Figure 13 shows the relationship of diameter to

[1]We know of no detailed survey of the relative sizes of the mesenteric arteries at necropsy. Dr. D. H. Melcher, of the Central Laboratory, Portsmouth, has measured the size of the main trunks of the coeliac, superior mesenteric, and inferior mesenteric arteries in 25 patients in different age groups dying from causes other than arterial disease. The diameter of the vessels was measured in two planes, an average obtained and the cross-sectional area calculated. The ratio of the cross-sectional area of the coeliac, superior mesenteric, and inferior mesenteric arteries was 7·5:11:1, which, if multipled by 8, gives a ratio of 60:88:8. This ratio is very much the same as ours with the exception of the inferior mesenteric artery. If our results had been calculated on this ratio it would have made no difference to the conclusions or the statistical significance of the findings noted below.

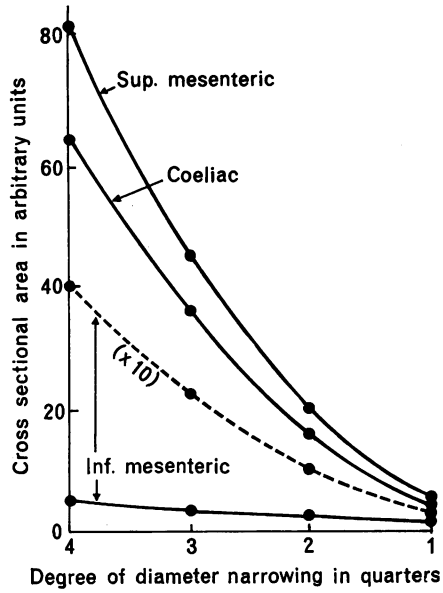

FIG. 13.

FIG. 13. *Conversion of diameter into cross-sectional area in arbitrary units, the three arteries being shown in proportion.*

FIG. 14. *Sum of cross-sectional area of coeliac, superior and inferior mesenteric arteries in 100 patients, expressed in arbitrary units plotted against age.*

▽ *Control*
■ *Hypertensive*
▲ *Arteriopath*
○ *Ischaemic gut disease*

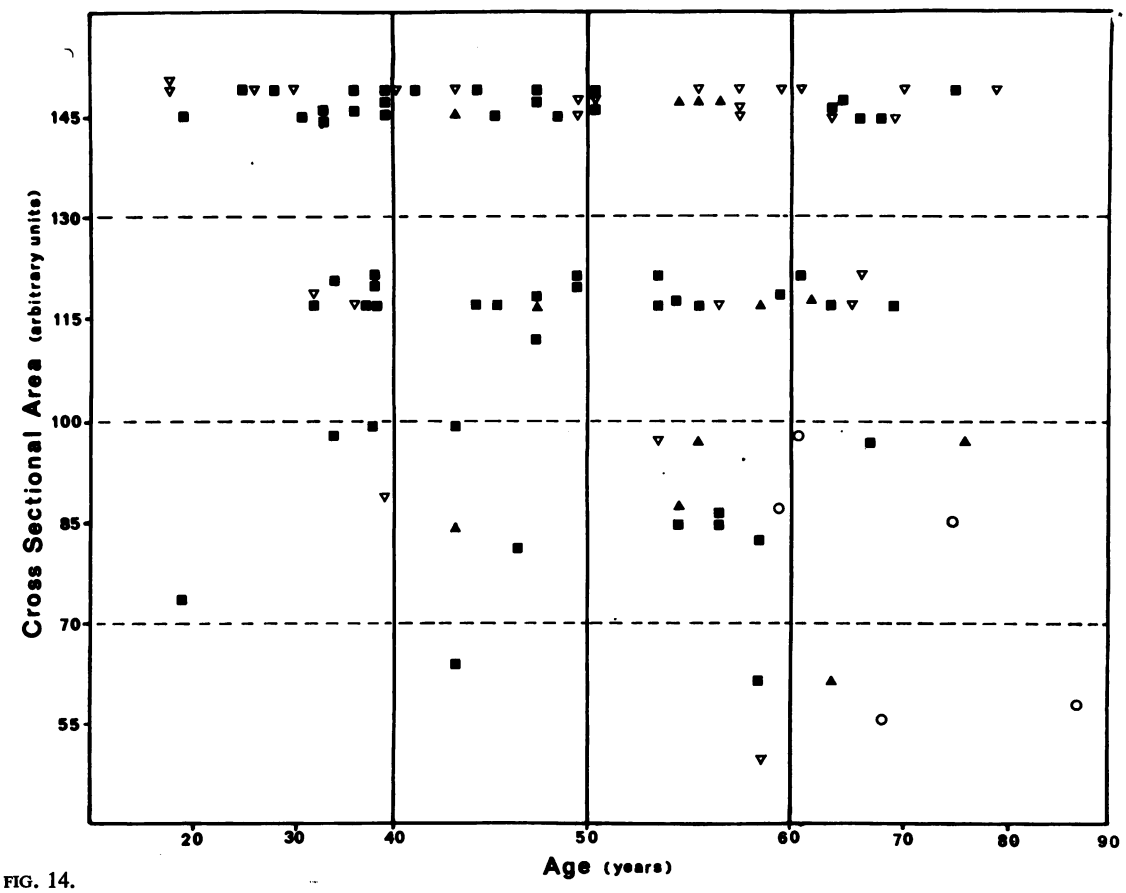

FIG. 14.

cross-sectional area expressed in arbitrary units for the three vessels in proportion. In each patient, the degree of narrowing of each individual artery, having been estimated in quarters, was converted into cross-sectional area. These three figures added together gave an estimate or index of the total cross-sectional area of the three arteries, for each patient, in relation to the normal maximum of 149.

FINDINGS ACCORDING TO GROUPS The arteriograms of each of the 100 patients were examined and, as described above, an index of the total cross-sectional area of the three mesenteric arteries was obtained for each case.

The patients in the four groups—control, hypertensive, arteriopath, and probable ischaemic gut disease—have been separated into age groups: under 40, 40-49, 50-59, 60 and over. The figure obtained for each patient is shown in the accompanying scattergram.

Inspection of the data plotted in Fig. 14 shows very little tendency for the scores of all the patients taken as a whole to decrease with age (Tukey's corner test does not suggest any association, $0{\cdot}05 < P$). Further inspection of Fig. 14 does not reveal that the scores of the control patients, or of those in any of the disease groups, decline much with age. Consequently no account has been taken of age in the following analysis.

Figure 15 shows the mean scores for the four groups of cases. Ninety-five per cent. confidence limits for these means are also shown. (The means of large comparable groups of cases may be expected to lie within these limits.) Significance testing shows that the difference between the control and hypertensive groups of $11{\cdot}3 \pm 5{\cdot}8$ units is not statistically significant ($0{\cdot}1 > P > 0{\cdot}05$), nor is the difference between hypertensives and arteriopaths, as may be seen from Figure 15. All other differences between groups are unlikely to be due to chance, including the difference between arteriopaths and probable ischaemic gut disease cases ($0{\cdot}05 > P$).

DEGREE OF AORTIC ATHEROMA The amount of atheroma in the abdominal aorta was recorded as being +, ++, +++, or if absent as 0. The findings are shown in Table II.

TABLE II

AMOUNT OF AORTIC ATHEROMA

Group	*Degree of Aortic Atheroma*					*Not Seen*
	0 (0)[1]	+ (1)	++ (2)	+++ (3)	*Total*	
Controls	22	5	—	—	27	
Hypertensive	28	21	5	—	54	2
Arteriopath	1	7	4	—	12	
Probable ischaemic gut disease	1	1	2	1	5	
All groups	52	34	11	1	98	

[1]Scores are shown in brackets.

The average amount of atheroma in the aorta observed in the four groups forms a similar pattern to the findings in the mesenteric arteries, most aortic atheroma, 1·6 units, being seen in those with probable ischaemic gut disease, 1·25 units in the arterio-

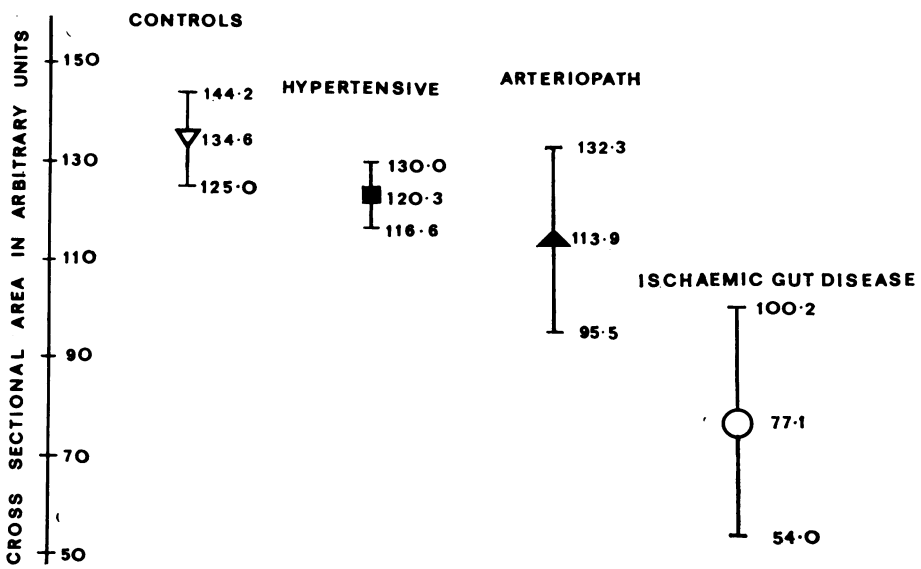

FIG. 15. *Mean scores and 95% confidence limits in the four groups of cases.*

paths, 0·7 units in the hypertensives, and 0·19 units in the controls. The only difference not statistically significant is that between the group with probable ischaemic gut disease and the arteriopaths.

It was observed also that almost all the patients who had an appreciable degree of mesenteric arterial disease, in any group, had some degree of aortic atheroma, whereas there were a number of patients with a moderate degree of aortic atheroma in whom there was little or no mesenteric arterial narrowing, as noted by previous authors (Maljatzka, 1934; Reiner *et al.*, 1963).

RENAL ARTERY ABNORMALITIES Of the 57 hypertensive patients on whom renal aortography was being performed, 22 showed anomalies of the kidneys or renal arteries, other than an aberrant or accessory renal artery. These were made up as follows:

Stenosis of one or both renal arteries	19
Renal cyst	1
Neoplasm of kidney	1
Horse-shoe kidney	1

POSITIVE CASES Five cases were finally considered to have ischaemic gut disease with a high degree of probability. They were aged 59, 60, 68, 75, and 87. All showed some other evidence of arteriosclerosis, three having ischaemic heart disease. The abdominal symptoms were variable, but four had pain worse after food, varying in the closeness with which it was related to meals. In two, exercise was a definite aggravating factor. The most noteworthy feature of the pain, although difficult to evaluate as a diagnostic point, was its cramp-like, aching quality, similar to ischaemic pains elsewhere in the body. This was observed in all cases, but was particularly striking in the two cases with severe prolonged attacks of pain who came to surgical treatment.

All the positive cases had a reduction in the total mesenteric arterial cross-sectional area as estimated by the method described above, to between two-thirds and one-third of normal. The index figures in these five cases were 98, 87, 85, 58, and 56 out of a possible maximum of 149.

In two of the patients surgical treatment was possible. Both showed a gross narrowing of the coeliac artery at its origin. In one of these no anastomosis was shown, but in the other there was a large pancreatico-duodenal anastomosis from the superior mesenteric artery. In both cases at laparotomy the liver was found to be blanched and shrunken, and in one, part of the intestine appeared ischaemic. In both instances it was practicable to free the splenic artery, after splenectomy, and anastomose it to the aorta below the origin of the inferior mesenteric artery. A retrograde blood flow from the aorta into the coeliac axis beyond the stenosis was thus established, with relief of symptoms, in one case complete.

G.P., a man, aged 59, had for 18 months bouts of severe, aching central abdominal pain lasting up to several days. The pain bore no definite relation to food or effort, and was gradually becoming worse. He was mildly overweight, and normotensive.

An aortogram (Figs. 10A-10C) showed mild aortic atheroma; coeliac stenosis to $\frac{1}{4}$ at origin; superior mesenteric artery normal; inferior mesenteric artery narrowed to $\frac{1}{4}$. Index was 87. Selective coeliac arteriography confirmed the stenosis and showed a large pancreatico-duodenal anastomosis.

Five months later the patient had a very severe attack of aching abdominal pain, and at laparotomy (Mr. Ian Ranger) the liver appeared blanched and shrunken at the periphery and the upper small intestine was ischaemic. Splenectomy was performed with anastomosis of the splenic artery to the aorta below the inferior mesenteric origin. Symptoms were completely relieved by this procedure and have remained so since over the past 18 months. Post-operative arteriograms (Figs. 10D, 10E) showed retrograde filling of the coeliac artery from the aorta by the implanted splenic artery.

J.S., a man aged 60, for two years experienced attacks of upper abdominal pain radiating to the back, chest, and neck, and at times to the left arm. Pain was brought on by exercise, but also by food, and was relieved by glyceryl trinitrate. For 18 months more severe, cramping upper abdominal pain, much worse after food. The patient was thin, arteriosclerotic, and old for his years. Blood pressure was 170/90 mm.Hg. An E.C.G. showed left bundle branch block, and a barium meal a small hiatus hernia. An aortogram (Fig. 8) showed gross aortic atheroma with a posterior lower lumbar aneurysm, the coeliac artery narrowed to $\frac{1}{2}$ at 0·5 cm. and inferior mesenteric artery narrowed to $\frac{1}{2}$. There were no anastomoses. Index was 98. The symptoms were considered to be mainly due to cardiac ischaemia, but also the patient was thought to have intestinal angina, in spite of a high index, because of the narrowed coeliac artery and absence of anastomoses.

Six months later he was admitted after increasing abdominal pain. Selective superior mesenteric arteriograms showed little anastomosis of the mid and inferior colic branches, and pancreatico-duodenal anastomosis was not increased. A lateral lumbar aortogram confirmed the previous findings.

At operation (Mr. Ian Ranger) the spleen and liver were shrunken and hepatic artery pulsation was feeble. The spleen was removed and the splenic artery mobilized and anastomosed to the abdominal aorta below the origin of the inferior mesenteric artery. Increased pulsation in the hepatic artery resulted. The patient obtained very considerable relief of the abdominal pain after food but still had some indigestion and also anginal pain on effort.

The three remaining cases were not proven, but the symptoms were very suggestive and extensive

investigation for other causes of the pain were all negative.

W.M., a man aged 63, for 10 years had central and lower abdominal pain radiating to the back, worse after food, and for two years continuous pain with severe exacerbations. He was a thin, arteriosclerotic man. Blood pressure was 200/100 mm.Hg. Extensive radiological studies, pancreatic function tests, etc., showed no cause for the pain. An aortogram (Fig. 9) showed moderate aortic atheroma, the coeliac artery narrowed to $\frac{3}{4}$ at 1 cm. and the superior mesenteric artery narrowed to $\frac{1}{2}$ at 2·5 cm. The inferior mesenteric artery was not seen. Index was 56.

This patient's symptoms subsided on a régime of frequent small meals.

F.S., a man aged 76, for two years had attacks of severe, cramp-like upper abdominal pain after food, particularly on exercise after food, and more recently several prolonged and severe attacks. Symptoms improved on frequent small meals and pain was eased by glyceryl trinitrate. He was overweight. Blood pressure was 170/110 mm.Hg. An E.C.G. showed ischaemic changes. Other abdominal investigations were negative.

An aortogram (Fig. 11) showed gross aortic atheroma. The coeliac artery was normal, the superior mesenteric artery narrowed to $\frac{1}{2}$ at 0·5 cm., and the inferior mesenteric narrowed to $\frac{1}{2}$ and showing marked atheroma over long segment. Index was 58.

Improvement was maintained over a period of one year.

E.C., a woman aged 87, for two months had continuous upper abdominal pain worse a quarter of an hour after food. She was afraid to eat. All abdominal investigations were negative. She was overweight. Blood pressure was 210/105 mm.Hg.

An aortogram (Fig. 12) showed mild aortic atheroma, the coeliac artery narrowed to $\frac{3}{4}$ at 0·5 cm., and the superior mesenteric artery narrowed to $\frac{1}{2}$ over long segment. The inferior mesenteric artery was narrowed to $\frac{3}{4}$ at its origin. Index was 56. The patient showed some improvement on a medical régime.

DISCUSSION

It is clear that the cross-sectional area calculated from the estimate of diameter and the degree of narrowing of individual vessels in each case is subject to error as discussed above. This must be taken into account in the interpretation of findings in individual cases.

The mean value for the sum of the cross-sectional areas of the coeliac, superior, and inferior mesenteric arteries is significantly less in the cases of mid-gut ischaemia than in the hypertensive and arteriopathic groups. There is also a significant difference between the control group and all other groups with the exception of the hypertensives, but there is considerable overlap. Two of the hypertensive patients had a very low index at 62 and 64 out of 149 units respectively, less than the mean figure of 77 units for the group of probable ischaemic gut disease. One of these hypertensive patients had a well-developed anastomotic circulation.

An unusual patient was a man of 58 who presented with weight loss and abdominal pain, for which no cause could be found on extensive investigation. Lateral lumbar aortography showed narrowing of the coeliac and superior mesenteric arteries with absence of the inferior mesenteric artery, the index being 50. Ischaemic gut disease was thought a probable explanation, but the patient went downhill rapidly and died. Necropsy showed neoplastic infiltration of the posterior abdominal wall surrounding the aorta and roots of the main vessels where there was in fact no atheroma. The only explanation of the narrowing found on aortography was external constriction by the neoplasm, histological examination of which showed a secondary adenocarcinoma. The probable source was thought to be bowel but no primary lesion could be found.

There was in addition a patient of considerable interest in the arteriopathic group. She was a woman aged 62 who was suspected of an abdominal aneurysm. She also had pain in the lower back and intermittent numbness in the buttocks, thought possibly to be due to lower aortic obstruction. This was disproved on aortography nor was an aneurysm found. Apart from these symptoms she had indefinite lower abdominal discomfort after food. The coeliac and superior mesenteric arteries were narrowed to $\frac{1}{2}$ and inferior mesenteric to $\frac{1}{4}$ (Fig. 4), giving an index of 62. The abdominal pain was slight and not troubling her appreciably at that time, and from the point of view of this study she was placed in the arteriopathic group. Five months later she was admitted with a three-day history of fairly severe abdominal pain, and laparotomy showed impaired blood supply to the greater part of the gut. It was not practicable to carry out any surgical procedure.

Apart from the arteriopathic patient discussed above there were a number of other patients in the hypertensive and arteriopathic groups, making a total of 11, whose index figures were below that of one patient with ischaemic gut disease, at 98 units, in whom the diagnosis was confirmed at surgery. There was in addition one control patient, apart from the patient with neoplastic disease, who had a figure just below this. Of the five patients with ischaemic gut disease, the two in whom the diagnosis was proven at surgery had the highest figures at 87 and 98 respectively.

It is not possible to state a critical figure for the degree of reduction of cross-sectional area at which development of ischaemic symptoms is highly prob-

able or inevitable, as clearly the presence and size of an anastomotic circulation is an important factor. Symptoms of intestinal ischaemia have not been seen in this series in patients in whom the total cross-sectional area of the large arteries was greater than two-thirds of the normal as estimated by this method. In many patients, however, a reduction to almost half the cross-sectional area was not associated with ishcaemic symptoms and in most of these no anastomotic circulation was demonstrated. In two hypertensive patients, as noted above, the figures were even lower, at 64 and 62. One arteriopath with an index of 62 subsequently developed ischaemia of the bowel. In no case, however, was the cross-sectional area as low as one-third with the exception of the patient with neoplastic infiltration in whom it was impossible to know whether intestinal ischaemia played any part in producing his pain. It has been stated that symptoms of ischaemic gut disease do not occur unless obstruction equivalent to loss of two out of three of the main arterial trunks is present. This statement is, however, of no value unless qualified, as the cross-sectional area of the inferior mesenteric artery is so much less than that of the other two vessels.

The tendency for atherosclerotic change to occur in the first few centimetres of the main trunks has been stressed by several authors (Maljatzkaja, 1934; Reiner *et al.*, 1963). Derrick *et al.* (1959) state that narrowing is confined to the proximal 1·5 cm. but this has not been so in all our cases. Our own findings confirm that changes most commonly occur, and are greatest in extent, in the proximal 2 cm. of the arteries, but the occasional case has shown more distal narrowing in the superior and inferior mesenteric arteries, as far as 4 cm. from the aortic ostia. Whether or not atherosclerotic narrowing does occur in the smaller arteries is of considerable relevance to the problem of chronic intestinal ischaemia from both the theoretical and diagnostic aspect.

The position as regards chronic mid-gut ischaemia is clearly different to that of acute ischaemic lesions of the intestines where embolization is a common cause, or even where intestinal infarction may occur on occasion with no demonstratable abnormality in the vessels in association with heart disease (Berger and Byrne, 1961). It may be, of course, that a situation occurs in the intestinal vessels analogous to that described by Gunning, Pickering, Robb-Smith, and Russell (1964) in the cerebral circulation, where thrombi form on plaques in the main vessels and result in embolization at the periphery. It is questionable, however, whether embolization of numerous small arteries at the periphery in the intestinal tract would produce a situation where chronic ischaemia would result. The collateral circulation at the periphery is generally so good that it would seem probable that under these circumstances either infarction results, if sufficient vessels are involved, or that the bowel wall survives with reversion to normality or with some subsequent fibrosis as described by Wolfe and Marshak (1956) and Marston, Pheils, Thomas, and Morson (1966). It seems likely that the majority of, if not all, patients with symptoms of intestinal angina have narrowing of some part of the proximal arterial tree. Impairment of the cardiac output as a result of heart failure or diversion of the blood flow by exercise after a meal may result in the development of ischaemic symptoms where the degree of stenosis is marginal.

Much interest has been shown recently in the syndromes produced by ischaemia of the colon (Hannan, Jackson, and Pipik, 1964, Varga and Currie, 1965; Irwin, 1965) and the whole subject has been reviewed by Marston *et al.* (1966). The lesion usually occurs in the splenic flexure and in the adjoining part of the transverse and descending colon where the circulation from the superior and inferior mesenteric arteries meets. Although these cases do not apparently present until a subacute phase, when at least some mucosal necrosis is present, they would have considerable relevance to the present study if arteriographic findings were available. Marston *et al.* (1966) in their series of 16 cases demonstrated an absent or blocked middle colic artery on aortography in two. Although there is little detailed information available about changes occurring throughout the arterial tree in such cases, much is now known about the type of abnormality found in barium studies in these patients (Boley, Schwartz, Lash, and Sternhill, 1963; Marshak, Maklansky, and Calem, 1965). Similar localized ischaemic lesions in the small intestine with recovery have been described (Wolfe and Marshak, 1956), but again arteriographic studies are not available.

All patients with probable intestinal ischaemia in this series were elderly, the ages being 59 and 60 in the two proven cases, and 68, 75, and 87 in the other three probable cases. The further patient, who developed ischaemic symptoms after the survey was completed, was aged 63 at the time definite abdominal symptoms appeared. The present study has revealed no fresh clinical features of the syndrome of chronic intestinal arterial insufficiency, the clinical picture of which is well reviewed by Bircher, Bartholomew, Cain, and Adson (1966). In fact, the symptoms in several cases in this series were characterized by their indefinite nature, and inevitably an essential part of the diagnostic procedure lies in the exclusion of other possibilities.

It is of interest, as might be expected, that there was no significant difference in the amount of aortic

atheroma observed in the arteriopathic group and the group with ischaemic gut disease. As noted by previous authors, however, some degree of aortic atheroma was almost always found in the presence of an appreciable degree of mesenteric vascular disease, in patients of all groups, whereas the reverse was quite frequently not the case.

In conclusion, it may be stated that aortography is an invaluable procedure in assessing the possibility of intestinal ischaemia as a cause of symptoms and is essential in deciding on the possibility of surgical relief in individual cases. It is hoped that further studies by selective arteriography may throw light on the part played by narrowing of the smaller arteries in the production of chronic ischaemia.

SUMMARY

The large vessels of the mesenteric arterial system have been examined in 100 cases by lateral lumbar aortography. Three groups of patients without abdominal symptoms, in whom aortography was being carried out for other reasons, were studied. These consisted of 27 'control' patients, with no clinical evidence of arterial disease, being investigated on account of abdominal masses, renal cysts, etc., a second group of 56 hypertensive patients having renal aortography, and 12 arteriopathic patients mostly with intermittent claudication. A fourth group consisted of five patients with chronic intestinal ischaemia.

The types of narrowing and anastomoses found are described, together with the findings in the positive cases, two of whom were successfully treated by surgery.

A method of estimating the sum of the cross-sectional areas of the coeliac, superior, and inferior mesenteric arteries is described. The findings in the four groups of patients are compared. A significant difference was found between the means of total cross-sectional areas in the cases with ischaemic gut disease and in all other groups, and between that in the arteriopaths and the controls. There was, however, considerable over-lap of individual cases. No case was seen with intestinal ischaemia in whom the total cross-sectional area of the main arterial trunks was not reduced to below two-thirds of the normal.

There was a significant difference between the amount of aortic atheroma found in the control group and all other groups and between the hypertensive group and all other groups, but not between the arteriopaths and those with probable ischaemic gut disease.

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