J. agric. Sci., Camb. (1980), **95**, 539–546
With 4 plates and 1 text-figure
Printed in Great Britain

A radiological investigation of the effects of cannulation on intestinal motility and digesta flow in sheep

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(*Received* 25 *February* 1980)

SUMMARY

Radiological examinations were carried out on ten sheep to see what changes in intestinal motility and flow of digesta were caused by intestinal cannulation. Barium sulphate was injected or infused into the abomasum via an implanted catheter; its passage through the intestine and associated muscular contractions were observed using X-ray image intensification. Once the normal pattern had been established for each individual, single or re-entrant cannulae were inserted into one of four positions in the small intestine.

All the cannulations caused some disruption of the normal flow of digesta, causing retention of digesta and distension of the intestine around and proximal to the intraluminal flanges of the cannulae. The duodenum was affected the most, particularly by one type of re-entrant cannula which reduced the degree of jejunal filling; peristaltic contractions often failed to propagate beyond these cannulae and also caused some retrograde movement of digesta between the cannulation site and the duodenal bulb during the irregular contraction phase (ICP) of the migrating myoelectric complex (MMC). These re-entrant cannulae also impaired the clearing effect of regular contraction phase (RCP).

INTRODUCTION

Since the technique of re-entrant cannulation was employed by Phillipson (1952) it has become a commonly used method for investigating various functions of the small intestine. However, little consideration appears to have been given to the effects of re-entrant cannulae, or even simple cannulae, on the propulsion of material through the small intestine. Poor appetite and general unthriftiness are sometimes reported on surgically prepared animals. A reduction of rumen outflow in cattle prepared with duodenal re-entrant cannulae was recorded by F. G. Whitelaw (personal communication), who also found that any blockage immediately suppressed appetite for about 3 days. Some studies have been made of digestibility, voluntary food intake and the transport of chemical markers in animals prepared with rumen, abomasal and intestinal cannulae (Reid, Shelton & Welch, 1961; Harris & Phillipson, 1962; Hayes, Little & Mitchell, 1964; Putman & Davies, 1965; MacRae & Wilson, 1977), to evaluate any changes associated with surgical interference. The general consensus of opinion appears to be that the animals are completely normal once they have recovered from the surgery and stabilized their post-operative weight losses, though MacRae & Wilson (1977) report major changes in the wool growth in sheep prepared with re-entrant cannulae. More recently J. C. MacRae (personal communication) found 25% increase in heat loss in cannulated sheep. Harris & Phillipson (1962) remarked that flow rates were reduced when they were collecting from duodenal re-entrant cannulae! Singleton (1961) when measuring duodenal flow through duodenal re-entrant cannulae electromagnetically recorded very high retrograde flow rates, up to 56% in goats and up to 17% in sheep. But on the whole he considered that the flow rates he found agreed with those of other workers using re-entrant cannulae. Radiological examinations of sheep prepared with caecal cannulae (MacRae *et al.* 1973) showed that some cannulation sites distorted and displaced this organ and could stop caecal function completely, but the sheep exhibited no ill effects. But we cannot find any reports of radiological examinations of the small intestine of surgically prepared sheep.

The aim of this study was to see what changes in

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0021-8596/80/2828-4440 $01.00

intestinal motility and digesta flow occurred in sheep after single or re-entrant cannulae were inserted in the ascending or transverse duodenum, the transverse jejunum or the terminal ileum. Single and re-entrant cannulation techniques in common use were examined together with a comparatively new method (J. F. Hecker and G. Wenham, unpublished).

MATERIALS AND METHODS

Animals

Four young Soay sheep (23–30 kg live weight), two Dorset Horn–Finnish Landrace crosses (35–40 kg) and four Scottish Blackface sheep (40–45 kg) of either sex were maintained on diets of dried grass or chopped hay. They were housed in individual pens and water was freely available. Two of the Soay sheep were bottle fed 600 ml of milk once each day, starting before they were weaned, to maintain the activity of the oesophageal groove reflex (Ørskov, Benzie & Kay, 1970).

All the sheep were prepared with abomasal polyvinyl chloride (PVC) catheters of 7 mm external diameter (Ørskov *et al.* 1979) to allow the injection or infusion of a barium sulphate suspension, 100 w/v (Micropaque; Nicholas Laboratories Ltd). 60 ml of barium sulphate was introduced either as a single bolus, or as a slow infusion, 0·8 ml/min, using a peristaltic pump. After 10–14 days each animal was examined to establish individual patterns of normal gut motility and digesta flow. Then, each sheep was prepared either with a single T-shaped cannula, with Ash re-entrant cannulae (Ash, 1962) or with the new Hecker procedure, either in the ascending duodenum (Ash only), in the transverse duodenum, in the transverse jejunum just after the ligament of Treitz (Ash only), or in the terminal ileum 200 mm orad to the ileo-caecal junction. The cannulae were positioned vertically in the ascending duodenum, horizontally in the transverse duodenum and jejunum, and ascending, horizontal or descending in the terminal ileum.

All the cannulae had gutter-shaped internal flanges 35–60 mm long and 15–18 mm wide and had barrels 8–13 mm internal diameter. The gutters were reduced in depth and the corners were removed to reduce the intraluminal bulk. The smaller cannulae were used in the Soays, the larger in the other breeds. All the sheep but one maintained themselves in clinically normal condition and maintained a normal intake of their diets. The exception is referred to below. However, four of the sheep, two Ash, one Hecker and one simple cannula, became unusable for contrast medium examinations after 6–8 months because of leakage through the fistulae around the cannula barrels.

The Ash procedure (Ash, 1962) involves transection of the intestine, whether for pyloroduodenal cannulation or any other region. J. F. Hecker and G. Wenham (unpublished) recommend a technique whereby a section of intestine about 150 mm long is cannulated at each end with a single T-shaped cannula. The intervening section of the intestine is not transected; it is brought to a subcutaneous position and can be occluded by a loop of 5 mm diameter PVC catheter passed round the intestine through the mesentery and between the internal and external oblique muscles, then exteriorized through stab wounds. The external ends of the catheter when pulled firmly and tied over a roll of gauze or foam rubber compress the intestine between the external oblique muscle and the skin. Digesta can then be collected from the first cannula and returned through the second; and when not collecting the loop is released restoring uninterrupted flow. Because of the short length of transverse duodenum available, and to avoid the obstruction of flow possible when a stretched intestine is placed subcutaneously, this technique was modified for the present study by leaving the duodenum within the peritoneal cavity and passing the loop of catheter round it.

The surgery was carried out by three very experienced surgeons using established, published techniques and cannula design.

Radiology

The X-ray apparatus used was a three phase, 200 kV, 1000 mA Elema-Schonander generator. This supplied an ultra-rapid, fine-focus undercouch tube modified so that the anode rotated slowly during screening. The image was picked up by a 25/15 cm image intensifier and viewed by closed-circuit television chain (Siemens). A record was made on a videotape recorder (Wenham, 1974). Lapsed time and event timings were made possible by simultaneously recording the figures from a digital videotimer superimposed on the fluoroscopic image.

Before the sheep were examined they were trained to stand on the step of the motor driven table in the vertical position, so that they were not perturbed by the sight and sound of the apparatus moving around them.

The two bottle-fed Soay sheep were examined prior to abomasal catheterization by adding barium sulphate to their milk; after catheterization bottle feeding was stopped.

All the examinations were carried out with the X-ray tube on the left of the sheep and the image intensifier on the right, commencing 10–14 days after catheterization or cannulation and repeated at intervals of approximately 2 weeks, 4 weeks, 2 months and 3 months after cannulation. Occasional examinations were made on some sheep up to 9 months after surgery.

The duration of each examination was 2·5–5 h depending upon the site under study, but generally at least as long as it took one regular contraction phase (RCP) of the migrating myoelectric complex (MMC) to traverse the intestine from duodenum to ileo-caecal junction with a batch of barium-marked digesta moving ahead of it.

RESULTS

Duodenum and jejunum

The activity of the abomasum and small intestine observed in the two bottle-fed Soays showed no radiologically detectable difference after abomasal catheterization.

The normal duodenum and jejunum

The pattern of abomasal and proximal small intestinal activity was similar in all ten sheep. During the irregular contraction phase (ICP) of the MMC (Ruckebusch & Bueno, 1977) the abomasum contracted every 9–12 sec slowly filling and distending the duodenal bulb and the proximal ascending duodenum. The time taken to fill the duodenal bulb was extremely variable, ranging from 0·5 to 3 min. Not all abomasal contractions propelled material through the pylorus, nor did the ones which did always propel the same amount. The largest boluses and therefore the most rapid filling of the bulb occurred during the 10–15 min immediately preceding the RCP of the MMC. The distended duodenal bulb contracted to produce a long bolus 'rush' which, propelled by a rapidly propagated contraction, traversed the duodenum and transverse jejunum in 6–8 sec, often continuing through the jejunum for a further 10–20 sec. As the rapidly moving bolus passed through the jejunum it was reduced in volume by parts being dropped off its trailing edge until it became a series of small boluses moving jerkily in an aborad direction. These small boluses could be seen to coalesce and subdivide with the mixing activity of the intestine that occurred between the main contractions.

Occasionally the bulb contraction was not propagated and the contents which had been pressed up the ascending duodenum merely returned to the bulb as it relaxed. On other occasions the bulb contraction was propagated only far enough to propel the bolus through the hepatic flexure. The main bolus was then fragmented by a series of segmenting peristaltic contractions which propelled the digesta slowly into the jejunum proper. For the most part, except for a slight mucosal trace of barium, the duodenum and transverse jejunum was empty between rushes (see Plate 1).

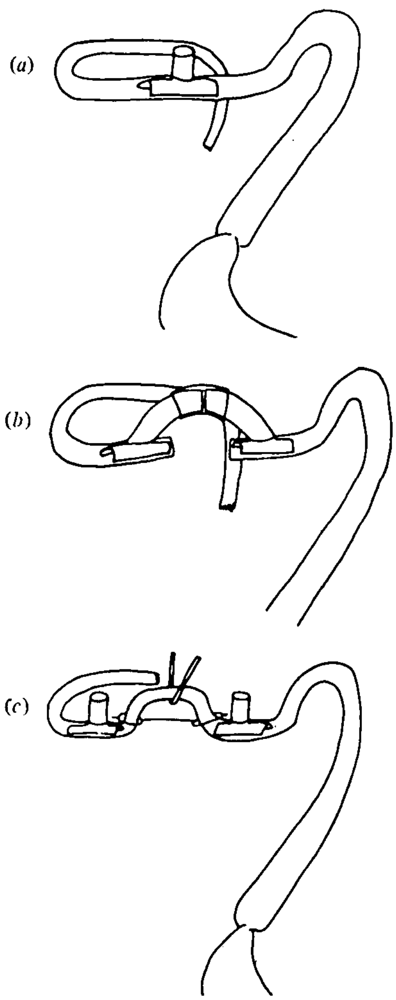
The regular contraction phase of the MMC usually started in the ascending duodenum once every 40–90 min. It was very distinctive, a series of contractions which occupied several cm of hypertonic, hyperactive duodenum propelling all digesta ahead of it. A small quantity of digesta remaining in the duodenal bulb was often forced back into the abomasum by the pressure exerted aborad to it. The abomasum remained quiescent and the duodenum and proximal jejunum empty for 5–18 min until abomasal activity returned and duodenal rushes recommenced. As a result there was always a section of empty intestine between the trailing edge of one block of digesta ahead of the RCP and the leading edge of the new digesta entering the jejunum. Sometimes the RCP was initiated in the jejunum and in this case the abomasum, duodenum and most proximal jejunum were barely affected, the main batch of digesta merely dividing at the region of RCP initiation. The first boli from the leading edge of a block of digesta passed through the ileo-caecal valve approximately 90 min after the RCP started in the duodenum.

Ascending duodenum, Ash re-entrant

In the sheep with the re-entrant cannulae in the ascending duodenum there was comparatively minor disturbance of intestinal activity. When a duodenal bulb contraction occurred sufficient material was usually propelled through the cannulae to initiate a peristaltic rush at the aborad end. Some of the weaker contractions did not transfer enough digesta aborad to start a major contraction and there was frequently some downwards movement of digesta back through the cannulae as the duodenal bulb relaxed. The only change seen after the 4-month period was that the duodenal bulb was dilated to approximately 1·5 times its original size. The RCP was initiated aborad to the cannulae and effectively emptied the proximal intestine leaving some residue in the bulb and in the cannulae and connecting tube.

Transverse duodenum, single cannula (Text-fig. 1a)

In this preparation a pool of barium-marked digesta was left within and around the internal flange of the cannula after each propagated contraction. As the intestine relaxed, the barium from the pool first passed onwards into the distal duodenum and proximal transverse jejunum, then flowed back towards the hepatic flexure. As a result some residual material was present along much of the proximal intestine, mainly near the cannula. If this residual pool became large, particularly following weak unsustained contractions, there was often some reflux to the duodenal bulb (see Plate 2 and its accompanying Figure). The RCP did not



Text-fig. 1. Line drawings of the duodenum and transverse jejunum illustrating the types of cannulae examined. (*a*) Simple T-shaped cannula; (*b*) Ash re-entrant cannulae; (*c*) Hecker cannulae.

clear out the cannulated region completely, leaving a little residue at the base of the cannula.

Transverse duodenum, Ash re-entrant cannulae (*Text-fig.* 1*b*)

This preparation presented considerable resistance to the flow of digesta. A bolus propelled from the duodenal bulb rarely passed through the cannulae completely. The residue, often most of the bolus, remained in the cannulae and proximal to them distending the duodenum. This distension was often relieved by retrograde peristalsis moving some digesta back to the bulb, sometimes filling the intestine from bulb to cannula. When enough digesta did pass through, or was displaced by proximal pressure into the intestine distal to the cannulae, a propagated contraction was initiated which propelled the bolus well into the jejunum. Lesser quantities were usually dispersed into a number of small, slowly moving boli by segmenting peristalsis. If only a small volume passed out of the cannulae, it could remain quiescent for a minute or more before the digesta was either moved on by weak irregular contractions, or was joined by more digesta propelled by a subsequent bulb contraction (see Plate 3 and its accompanying Figure). About a quarter of duodenal contractions displaced no digesta at all to the distal side of the cannulae. Even the regular contraction phase did not empty the duodenum completely.

Transverse duodenum, Hecker cannulae (*Text-fig.* 1*c*)

Before occlusion, some obstruction to digesta propulsion was observed. This was partly because, as with the previous preparations, contraction of the intestine on the flanges of the two simple cannulae did not completely close the lumen to maintain onward pressure. In addition there was a slight constriction where the plastic tube passed round the intestine. As a result the long bolus rush did not traverse the preparation completely; part remained near to the first cannula and often returned to the duodenal bulb by retrograde peristalsis. Barium passing beyond the constriction was propelled normally into the jejunum, though a little remained around the base of the second cannula (see Plate 4 and its Figure). Except for some residue at the bases of the cannulae, the regular contraction phase emptied the duodenum completely.

During occlusion, the first cannula was opened and a very vigorous and persistent peristalsis was initiated from the hepatic flexure to the cannula (see Plate 2*d*). This additional peristalsis occurred only when the occluding loop was tight and not when it was slack, despite the distension caused by residual digesta and barium. It appeared therefore that it was external pressure and not distension which stimulated this peristalsis, suggesting that during sampling periods retention may not be a problem. Filling and contraction of the duodenal bulb continued normally at this time superimposed on the peristalsis.

Transverse jejunum, Ash re-entrant

The re-entrant cannula placed in the transverse jejunum just beyond the ligament of Treitz also caused a very marked alteration to the pattern of transport through the duodenum. Barium was infused into the abomasum during the quiescent period following a regular contraction phase, so that the first material to leave the abomasum with returning irregular contractions was marked. When the first peristaltic rush was initiated at the bulb, the bolus would be carried only to the region orad to the cannula where it would stop. The next peristaltic rush would push the first bolus just inside the proximal cannula. And so it would progress with each subsequent rush pressing the first bolus a little further through the cannula. It sometimes took more than 30 min for the first barium-marked digesta to leave the aborad end of the cannula and enter the jejunum proper, a process which took only some seconds in the uncannulated sheep. The result was that the whole length of the duodenum always contained a considerable amount of material during the ICP. The RCP did not empty the duodenum and cannulated region completely, leaving some residue to be incorporated with the first bolus of the next ICP.

Little or no change in the pattern of activity was observed in these duodenal preparations over the ensuing months. The dilation of the intestine proximal to the cannulae and round the internal flange increased.

Terminal ileum

The normal terminal ileum

Ahead of the advancing wave of the RCP of the MMC was a section of ileum filled with digesta; this section was about 1·5–2 m in length although the convoluted anatomy of the ileum prevented accurate measurement. The only major breaks in the continuity of this column of digesta were caused by gas bubbles. Along this filled intestine the motility pattern produced by the ICP varied between complete quiescence and vigorous, propagated, propulsive contractions, interspersed with non-propulsive mixing contractions. The RCP pushed all visible contents ahead of it into the caecum-colon, leaving the intestine behind it empty as far as the leading edge of the next block of digesta.

Single cannula

There was some resistance to digesta flow which tended to cause breaks in the continuity of intestinal filling between the cannula and the ileo-caecal junction. There was no apparent disruption of the MMC, the RCP passing through the point of cannulation and emptying the ileum completely except for a little digesta trapped within the cannula flanges. This preparation deteriorated a little with time, with increased dilation occurring proximal to and at the base of the cannula.

Ash re-entrant cannulae

Digesta passed through the re-entrant cannulae with difficulty. Peristaltic contractions approached the proximal cannula in succession, each forcing small amounts of digesta into the cannulae and connecting piece and on into a passive terminal ileum. The leading edge of the barium-laden digesta reached the proximal cannula several minutes before any appeared at the distal end. This resistance caused an increasing pool of digesta to accumulate, dilating 10–20 cm of the ileum proximal to the cannula; this was only cleared by arrival of the RCP. Only after 10–15 cm of the terminal ileum had been passively filled did a propagated contraction occur, driving all the contents into the caecum; there appeared to be no intermediate activity between quiescence and propulsive contractions. The RCP faded out before reaching the proximal cannula and did not reappear on the distal side. This left a pool of residual digesta proximal to the cannulae and in the barrels. This pool moved backwards during the relaxed quiescent phase and became incorporated in the leading edge of the next batch of digesta. The residual pool in the terminal ileum beyond the cannulae was propelled rapidly into the caecum several minutes after the regular contractions died away proximal to the cannulae.

One preparation deteriorated badly with time. After 12 weeks the sheep was not eating and rapidly losing condition. A barium examination revealed that the pyloric region of the abomasum had been caught up in adhesions around the distal ileum cannula; two or three loops of the distal ileum and the distal duodenum were incorporated in adhesions around the proximal cannula, causing constrictions which greatly increased the resistance to digesta flow. The animal was slaughtered and the findings confirmed post mortem.

Hecker cannulae

Before occlusion, the leading boli of digesta propelled by the ICP were delayed at the proximal cannula, causing some distension, but once there appeared to be sufficient pressure to overcome the resistance, there was good propagation of propulsive contractions. The barium moved through the subcutaneous section, past the second cannula with minimal delay, and along the terminal ileum. When the intestine was occluded and the proximal cannula was opened the normal propulsive segmenting peristalsis persisted. A RCP approaching the cannulae faded out and left a pool of digesta behind proximal to the first cannula and in the subcutaneous intestine, and the contractions were not propagated through to the ileo-caecal junction.

The residue in the subcutaneous intestine was then moved orad by retrograde peristalsis to join the pool at the first cannula. This combined pool passively backfilled 10–15 cm of relaxed quiescent ileum, and later it was incorporated in the leading edge of the following batch of digesta.

DISCUSSION

Any surgical procedure which places rigid materials in the intestinal lumen or causes digesta to flow through rigid re-entrant cannulae and anchors the normally mobile intestine to the body wall inevitably interferes with intestinal contractions and obstructs the flow of digesta to some extent. Our objective was to examine the extent and causes of this interference so that improvements in cannula design and surgical procedures might be devised to reduce such malfunctions.

The single T-shaped cannula caused the least disturbance; it seemed that the internal flange or gutter caused a small permanent dilation of the intestine which contractions were unable to occlude to maintain the onward pressure. While a fairly substantial flange seems necessary to prevent the cannulae being pulled out, it may be advisable to use flattened or solid flanges against which the gut can contract without leaving dead space.

When a re-entrant cannula is placed in the ascending duodenum it seems important that the segment of duodenum between the pylorus and the proximal cannula should contain enough digesta to initiate a contraction when propelled through to the distal end of the cannula. When this happened there was virtually no disturbance to the normal transport of digesta through the duodenum. If the proximal cannula flange projects through the pylorus it can cause incompetence, allowing digesta to flow back into the abomasum as the bulb contracts.

The Ash re-entrant cannulae in the transverse duodenum, jejunum or ileum caused gross abnormalities of propulsion and flow. Many peristaltic contractions did not reappear beyond the cannulae, digesta flow was delayed or reversed, and dilated segments of intestine proximal to the cannulae remained filled for much of the time. The main difficulty, apart from the flange effect seen also with simple cannulae, appeared to be the resistance of the rigid cannula barrels and connecting piece which blocked the effectiveness and the force of the contractions. The sheep with duodenal or jejunal re-entrant cannulae seemed to show less jejunal filling during the ICP than was seen before cannulation. Also the length of ileum that was filled with digesta moving ahead of the RCP appeared shorter, i.e. the size of each block of digesta was reduced, so that the total volume of digesta flow was possibly lower. However, one cannot be sure of this because of the convoluted nature of the jejunum and ileum, and the changed shape and disposition of the intestine after cannulation make any quantitative interpretation of the radiological appearances rather uncertain. However, Singleton (1961) considered that retrograde flow in the cannulated ascending duodenum had a considerable influence on the net volume of material leaving the stomach. This clearly indicates the functional abnormality of this preparation; retrograde flow of digesta in the ascending duodenum of the normal, intact sheep is very slight, except when bulb contractions fail to propagate, and has never been seen in the small intestine to any great degree, beyond the hepatic flexure of normal sheep over long periods of direct observations.

The Hecker cannulation procedure was intermediate in its effects. When the intestine was not occluded between the two cannulae the contractions were usually propagated through the cannulated segment of intestine with only a little more delay and disturbance than was caused by a single cannula; the subcutaneous sections of the terminal ileum remained free and contractile. During occlusion the contractions were reinforced by the persistent peristalsis seen.

It was not the purpose of this work to assess how much, if at all, the disturbances caused by these procedures significantly affect the overall digestion of food; indeed it has been shown that intestinal cannulation has little effect on digestibility (Reid *et al.* 1961; MacRae, 1967; MacRae *et al.* 1973). It has also been stated that the rates of passage of liquid and solid phase markers are unaffected by cannulation (MacRae, 1975; MacRae & Wilson 1977), though it is unclear how the transport of these markers through the small intestine of cannulated sheep was compared with that in the small intestine of intact sheep. This series of radiological observations on the passage of digesta marked with barium sulphate showed that there are marked local delays in transit particularly with the Ash type of re-entrant cannula. The disturbance of propulsive motility seems likely to influence absorption or secretion in the cannulated regions of the small intestine. It might also explain in part the changes in the metabolism of sheep with re-entrant cannulae reported by MacRae & Ulyatt (1972) and MacRae & Wilson (1977).

Even though the sheep were prepared by three very experienced surgeons, using well established techniques, it must be accepted that ten sheep from one centre cannot provide a basis for exact predictions of the type and degree of functional abnormality to be expected universally. The consistency of the effects does however make it seem very likely that similar abnormalities must often occur.

Very few researchers have the opportunity or facilities to look 'inside' their live surgically prepared animals, but it seems advisable to keep some reservations in mind when drawing general conclusions from cannulated animals.

Grateful thanks to Dr R. N. B. Kay for his help and encouragement in the preparation of this paper, and to Mr I. Robb for producing the Plates from cine film.

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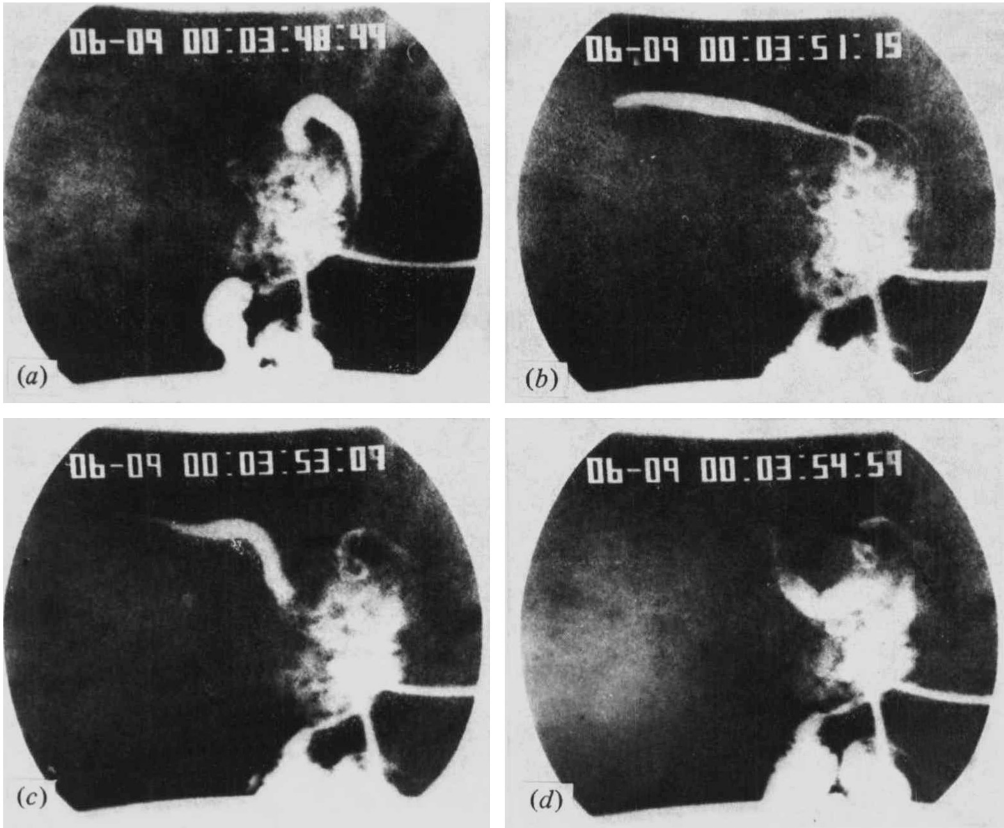
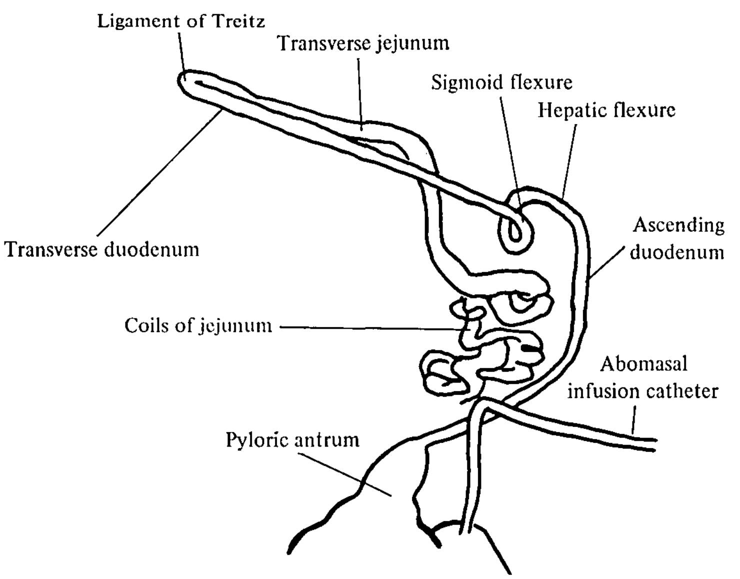
EXPLANATION OF PLATES

All the photographs are reproduced from single frames of cine-radiographic records. Digital video-timer records indicate month-day, h: min: sec: 1/10 sec and 1/100 sec.

PLATE 1

(*a*) Normal duodenum of a Soay sheep 15 days after abomasal catheterization. Long bolus rush passing through upper ascending duodenum and hepatic flexure. Barium sulphate fills the pyloric antrum, proximal convoluted jejunum and abomasal catheter. Some residual barium remains in the duodenal bulb.
(*b*) 2·66 sec later, bolus filling transverse duodenum up to the ligament of Treitz. Traces of barium delineate the hepatic and sigmoid flexure.
(*c*) 1·92 sec later, the bolus fills the transverse jejunum. The leading edge of the bolus turns to enter the jejunum proper. A faint trace of barium is seen on the mucosa of the hepatic flexure.
(*d*) 1·52 sec later, the trailing edge of the bolus enters the jejunum proper. A faint trace of barium can be seen on the mucosa of the hepatic flexure and transverse duodenum. The pyloric antrum is dilating again.
The accompanying Figure should assist in interpretation of Plate 1.

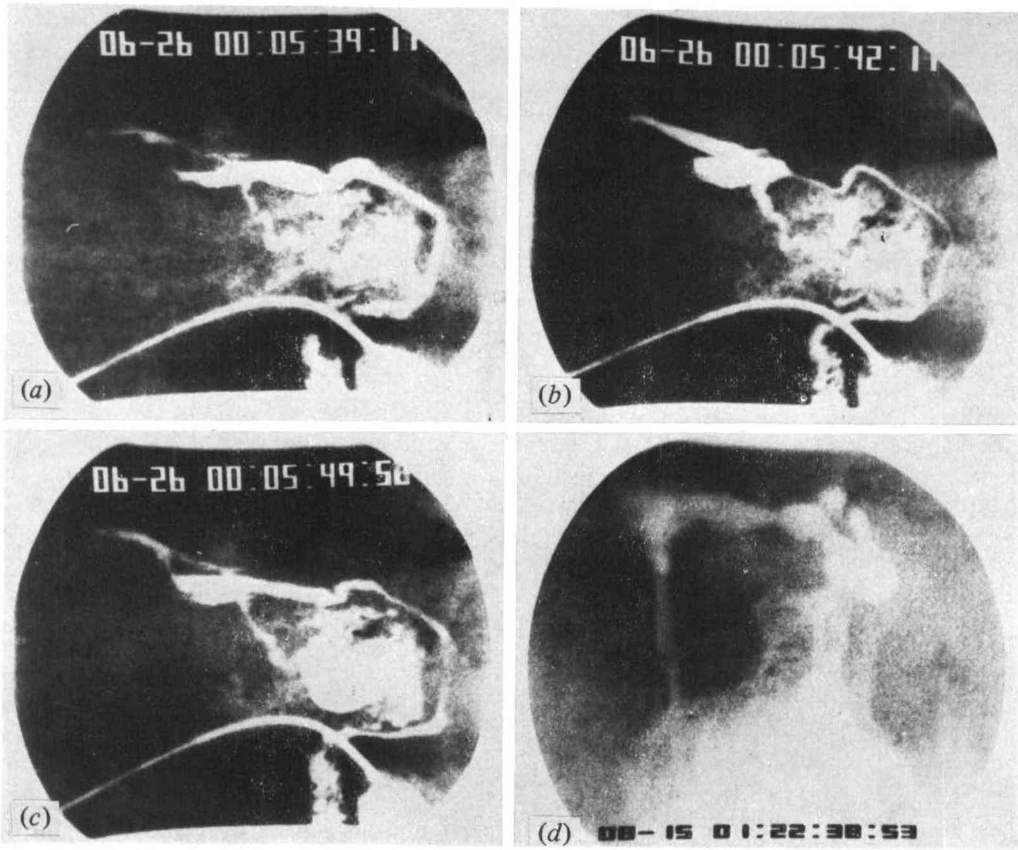


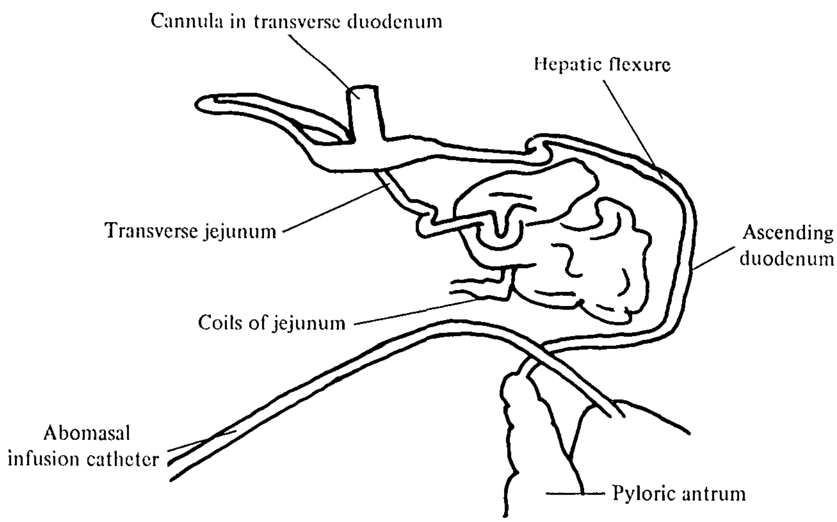


Artistic composite line drawing of Plate 1 illustrating radiographic anatomy.

PLATE 2

(*a*) Same Soay sheep as Plate 1, 16 days after simple cannulation of the transverse duodenum. The leading edge of a long bolus rush has reached the distal side of the cannula flange showing the outline of the distended intestine around it. There is an increase in the barium residue behind the contraction.
(*b*) 2·94 sec later the bolus fills the transverse jejunum leaving a pool of residual barium at the base of the cannula. Residual barium outlines the duodenum from pylorus to cannula.
(*c*) Relaxed intestine between rushes, 7·47 sec later. Forward and retrograde movement of barium from the residual pool at base of cannula fills the intestine from pylorus to jejunum proper (see accompanying Figure).
(*d*) (See also Plate 4 and its accompanying Figure.) The Hecker preparation when the intestine is occluded, showing vigorous, propulsive peristalsis in the sigmoid flexure and transverse duodenum. The vertical shadow of the collecting tube attached to the open first cannula can be seen.





Artistic composite line drawing of Plate 2 illustrating radiographic anatomy and cannula position.

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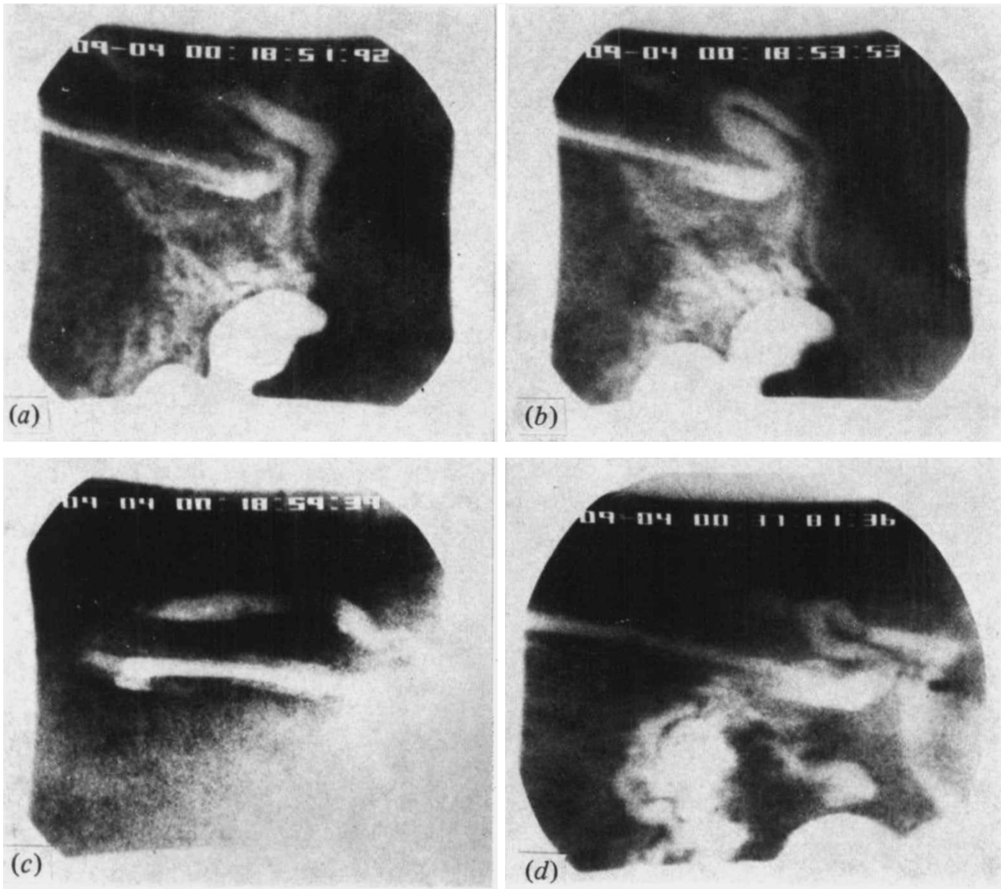
PLATE 3

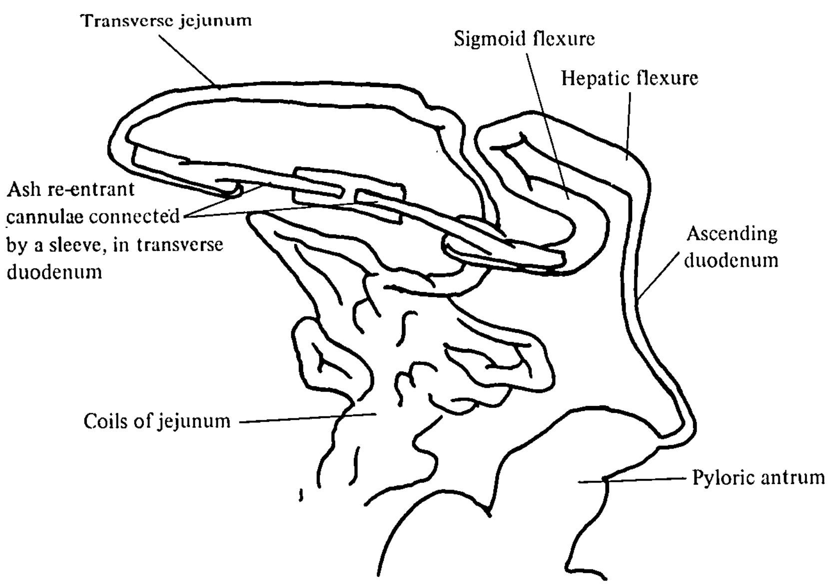
(*a*) Blackface sheep 1 month after preparations with Ash re-entrant cannulae in the transverse duodenum (see accompanying Figure) showing long bolus rush in the ascending duodenum and hepatic flexure. Residual barium from preceding rushes are seen in and around the cannula, ahead of the bolus (compare with Plate 1*a*).

(*b*) 1·62 sec later the bolus is dilating the blind sac of the duodenum around the flange of the proximal cannula.

(*c*) 5·84 sec later the fragmented bolus has reached the transverse duodenum. The transit is much slower than in the uncannulated sheep (compare with Plate 1).

(*d*) Relaxed duodenum between rushes. Large amounts of residual barium fill the duodenum from bulb to cannula. There are anti-peristaltic contractions in the hepatic flexure and upper ascending duodenum.





Artistic composite line drawing of Plate 4 illustrating the cannula positions and radiographic anatomy.

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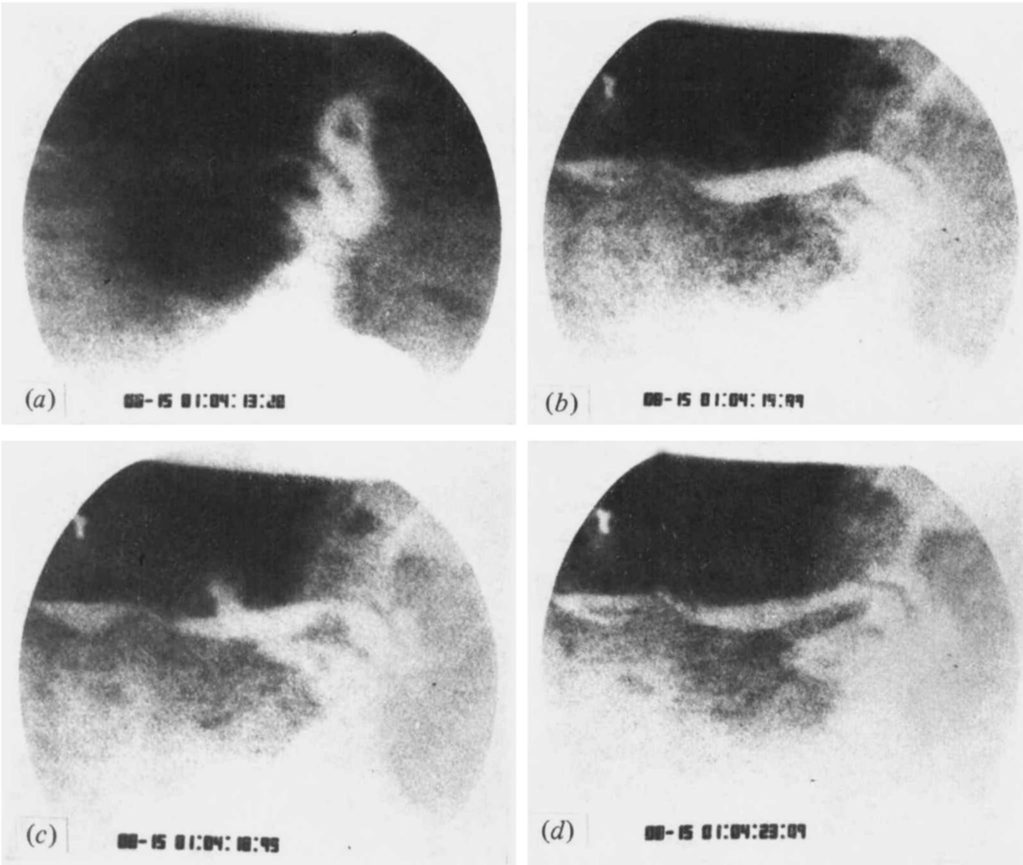
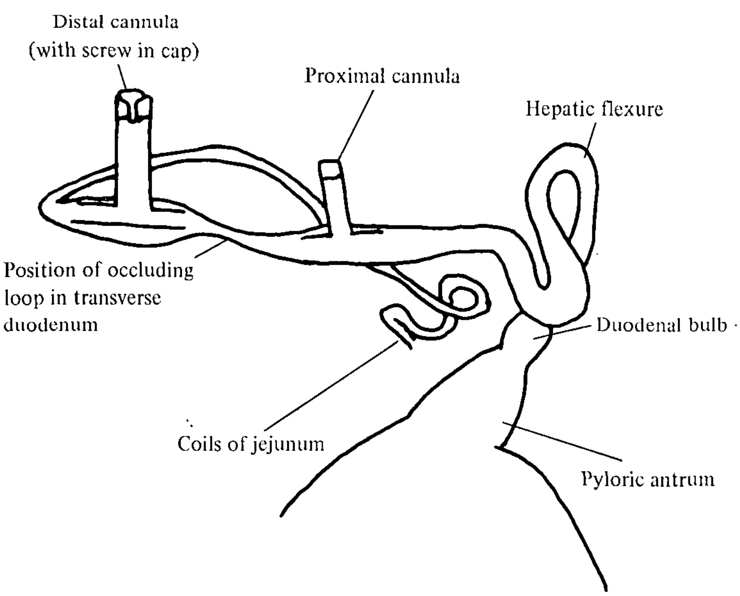
PLATE 4

(*a*) (See accompanying Figure.) Blackface sheep 2 weeks after cannulation of transverse duodenum using the Hecker technique. A long bolus rush fills the hepatic and sigmoid flexures.
(*b*) 1·71 sec later the leading edge of the bolus has reached the second cannula, showing dilations round the intraluminal flanges of the cannulae and a constriction in between.
(*c*) 3·96 sec later the trailing edge of the bolus is just entering the jejunum proper (compare with Plate 1*d*). Barium left behind this duodenal rush can be seen pooled mainly at the bases of the cannulae. Anti-peristaltic contractions can be seen orad to the first cannula and in the sigmoid flexure.
(*d*) Retained barium is seen in the relaxed duodenum between rushes.
See Plate 2*d* which shows peristaltic contractions stimulated by duodenal compression.





Artistic composite line drawing of Plate 3 illustrating position of cannulae and radiographic anatomy.

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