# The rate of passage of foodstuffs through the alimentary tract of the goat

## 3. The intestines

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In most studies of the rate of passage of foodstuffs through the alimentary tract of the ruminant, the tract has been regarded as a whole with little or no differentiation between the rates through the various parts. There is good evidence, however, that the main part of the ingesta spends a longer time in the reticulo-rumen than in the rest of the digestive tract. The small amount of available evidence suggests that passage through the intestines is fairly rapid. The period of time between the feeding of a stained marker and its first appearance in the faeces gives an indication of the time taken for a single particle to traverse the entire tract with a minimum of time spent in the reticulo-rumen. Unfortunately, it does not measure the time spent in each of the compartments of the stomach, nor does it indicate to what extent food is mixed in the intestines.

The examination of rumen contents at intervals after a single stained meal can show how long the final traces of marker are retained in this organ, and the difference between this length of time and the time of final appearance in the faeces will give a rough indication of the time spent in the portion of the tract posterior to the rumen. Values calculated by this method are 4 days in the ox (Usuelli, 1933), 6–10 days in the sheep (Lenkeit, 1930) and 2–3 days in the goat (Biondo, 1953). The accuracy of these figures is, however, rather doubtful in view of the difficulty of determining the time of the final disappearance of the stained marker. An alternative method used by Ewing & Wright (1917) was to measure the length of time that food remained in the various compartments of the alimentary tract of cattle by killing the animals at intervals after they had been fed on a given diet and measuring the quantities of ingesta in the various compartments. In this way it was calculated that ingesta spent only $14\frac{1}{2}$ h in the small and large intestines.

Piana (1953), working with lambs, found that the times of final disappearance of a single stained meal from the faeces before and after rumenectomy were 19 and 5–6 days respectively. Complete removal of such an important organ, however, might well alter the whole pattern of the digestive processes in the other parts of the tract.

The introduction of markers into the different sections of the alimentary tract and their detection in the faeces would give a more accurate measure of the time which food spends in the various compartments of the tract. This technique has been used by Balch (1950) who introduced a suspension of ground stained hay in water directly

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into the abomasum of cows and simultaneously fed a marker by mouth; he then studied their excretion by counting the stained particles in the faeces. Balch found that the time at which 93–97 % of the abomasally introduced marker was excreted was the same as the time of 5 % excretion of a marker given by mouth. This finding supported his view that the time of 5 % excretion of a marker given by mouth could be taken as the length of time it spends in the omasum, abomasum and intestines. The present work on goats was undertaken to determine the time food spends in the intestines and its relation to the 5 % excretion time.

## EXPERIMENTAL

### *Plan of experiment*

In order to study the passage of food through the intestines alone duodenal cannulas were inserted in goats, thus enabling a fine stained marker, which was recognizable in the faeces, to be introduced directly into the duodenum. The problem was studied with especial reference to its relationship to the rate of passage through the entire tract. The dry-matter content of the faeces and possible diurnal variations were also studied.

### *Experimental animals*

Four adult castrated male goats (nos. 11–14) weighing respectively 27, 51, 64 and 40 kg were used. In each animal a small Perspex cannula closed by a screw-cap was inserted into the duodenum approximately 2 in. from the pylorus. The internal diameter of these cannulas was large enough ($\frac{3}{8}$ in.) to allow quantities of marker to be introduced. The four goats recovered rapidly from the operation and were eating normally within a week, but no experiments were conducted on them for at least 3 weeks. From the time of the operation onwards the goats were confined in crates designed for the collection of faeces.

Each goat was given 200 g calf nuts (20 % crude protein and 7·5 % crude fibre) twice daily, at 9.00 a.m. and 4.00 p.m. and meadow hay and water were available at all times. Refusals of food were weighed daily.

### *Technique for measuring rate of passage*

The rate of passage through the entire tract was measured by the method of Balch (1950), adapted for goats (Castle, 1956*a*), in which stained long hay was fed and the coloured particles were counted in samples of faeces collected at fixed times after feeding. Cumulative excretion curves were plotted from the counts, and the results expressed as mean retention times, *R*, were obtained by summing the times of excretion at intervals of 10 % between 5 and 95 % and dividing the total by 10 to give the value in hours. This procedure is explained more fully in an earlier paper (Castle, 1956*a*).

To measure the rate of passage through the intestines it was necessary to use a marker resembling the natural contents of this portion of the tract and yet easily counted in the faeces. Sieved, stained abomasal contents were used in preliminary experiments, but, owing to the difficulty of obtaining these, stained faecal fragments as

used previously (Castle, 1956*b*) were used instead. The stained faecal fragments were as easy to recognize in the faeces as abomasal contents.

In order to introduce the fragments through the cannula, it was found necessary to suspend them in a viscid medium to avoid sedimentation and thus blockage of the cannula. This was done by mixing 0·5 g stained fragments and 0·3 g tragacanth powder with 20 ml. normal saline, bringing the mixture to the boil, and allowing it to cool. The suspension was introduced into the cannula by means of a rubber tube about 18 in. long fitted over the end of the cannula, and was followed by approximately 50 ml. normal saline to wash down the final traces.

Faeces were first collected 10 h after the introduction of this marker, at hourly intervals for the next 4 h, at 2 h intervals for the next 4 h, and finally at 4 h intervals until almost all the marker was excreted. Coloured particles were counted in samples of the faeces and the dry-matter content of the faeces was determined. Cumulative excretion curves were plotted from the results exactly as in the previous experiments to determine the rate of passage through the entire alimentary tract (Castle, 1956*a*). The mean retention time was calculated as described previously, but for intestinal passage it was termed *Ri*.

In the experiments designed to investigate the relationship between the rate of passage through the entire tract and through the intestines, the hay given by mouth was stained red, whereas the faecal fragments introduced into the duodenum were stained green in the manner described previously (Castle, 1956*b*). Both the hay and the particles were given between 9.20 and 9.40 p.m.

In the study of diurnal variations in intestinal rate, faecal fragments stained green were introduced into the cannula at 9.30 p.m. and others stained red at 9.30 the following morning.

## RESULTS

### *Relationship between the rate of passage through the intestines and that through the entire tract*

Two experiments were conducted on each of the four goats. In all, the green faecal fragments that had been introduced into the duodenal cannula were first detected in the faeces 9 to 12 h later. The maximum concentration in the faeces occurred 1–2 h after their first appearance, and from this time onwards they rapidly decreased in number and were undetectable 20–24 h after insertion. The time of 95% excretion varied from 14 to 19 h.

The particles of red hay that had been fed by mouth appeared in the faeces from 1 to 4 h (mean 2·5 h) later than the green faecal fragments. From this time onwards the excretion pattern accorded with that for adult goats (Castle, 1956*a*), the particles reaching a maximum concentration about 30 h after feeding and finally disappearing 5–7 days after feeding.

As can be seen from Fig. 1, the cumulative excretion curves obtained from the two markers were quite different in shape. That for faecal fragments rose very rapidly to 90% excretion and then tailed off rather more gradually, whereas that for the stained hay given by mouth rose more slowly and was sigmoid, tailing off gradually at

both the beginning and end of excretion. The *Ri* value in the four goats ranged from 11·0 to 14·4 h (mean 13·0, S.D. of single value 1·2) and the *R* value ranged from 36·1 to 60·0 h (mean 44·6, S.D. of single value 8·8) (Table 1).

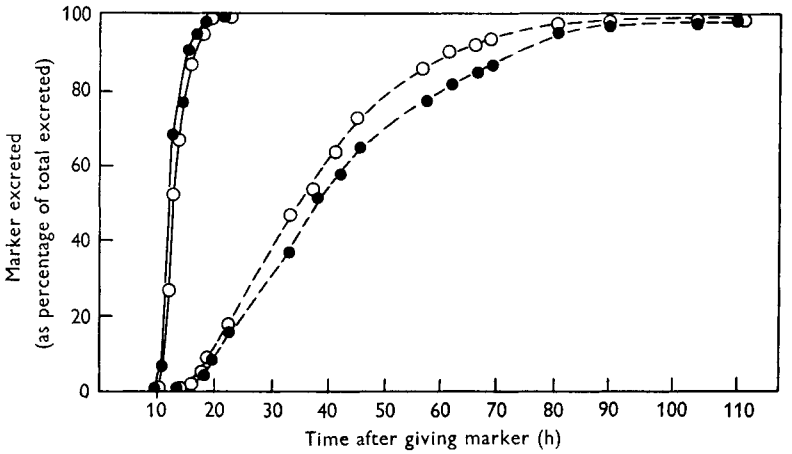


Fig. 1. Rates of excretion of undigested residues of stained hay given by mouth, and of stained faecal fragments introduced through a duodenal cannula. Two experiments on goat no. 13. o----o, Exp. 1, stained hay ($R^*=39{\cdot}4$); o—o, Exp. 1, faecal fragments ($Ri^\dagger=13{\cdot}7$); ●----●, Exp. 2, stained hay ($R^*=44{\cdot}0$); ●—●, Exp. 2, faecal fragments ($Ri^\dagger=13{\cdot}2$). * See p. 339: † See p. 340.

Table 1. *Results for various excretion times of stained hay given to goats by mouth and of stained faecal fragments introduced simultaneously through a duodenal cannula*

| Goat no. | Time (h) of: Mean retention of stained hay $R^*$ | Mean retention of stained faecal fragments $Ri^\dagger$ | 5 % excretion of stained hay | Percentage of faecal fragments excreted at the time of 5 % excretion of the stained hay |
|---|---|---|---|---|
| 11 | 36·1 | 11·0 | 16 | 98 |
| | 38·2 | 12·1 | 18 | 98 |
| 12 | 40·7 | 11·9 | 18 | 97 |
| | 42·0 | 13·8 | 20 | 97 |
| 13 | 39·4 | 13·7 | 18 | 95 |
| | 44·0 | 13·2 | 19 | 98 |
| 14 | 56·7 | 13·5 | 19 | 91 |
| | 60·0 | 14·4 | 21 | 98 |

* See p. 339. † See p. 340.

The correlation coefficient relating the *R* and *Ri* values for the series of eight experiments did not quite reach statistical significance ($r=+0{\cdot}68$; 5 % value $=+0{\cdot}70$).

In the experiments in which goats were given markers by the two different routes it was found that as the 5 % excretion time of the stained hay increased, so did the *Ri* value and the 5 % excretion time for the hay corresponded to the time of excretion of 91–98 % of the faecal fragments (Table 1). A correlation coefficient calculated between

the *Ri* values and the times for 5% excretion of stained hay showed a significant positive relationship ($r = +0{\cdot}88$, $P < 0{\cdot}01$, $y = 3{\cdot}9 + 1{\cdot}14x$, where $y$ is the *Ri* value in h and $x$ the 5% excretion time in h) (Fig. 2).

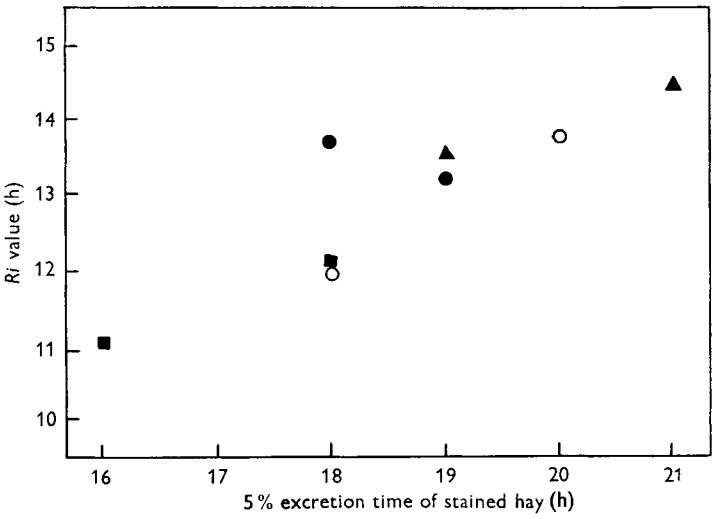


Fig. 2. *Ri** values for stained faecal fragments introduced through a duodenal cannula, and 5% excretion time of stained hay given simultaneously by mouth. Two experiments on each of four goats. ■, goat no. 11; ●, goat no. 13; ○, goat no. 12; ▲, goat no. 14. * See p. 340.

*Diurnal variations in rate of passage through the intestines*

Eight experiments were conducted on each of two goats, nos. 13 and 14. Day and night experiments were performed alternately for two periods of 48 h in consecutive weeks on each goat. Cumulative excretion curves were plotted and *Ri* values calculated for each experiment. The shape of the curves was similar throughout and the same as in the first investigation described in this paper. *Ri* values (Table 2) varied

Table 2. *Mean retention times* (Ri) *for stained faecal fragments introduced through a duodenal cannula at* 9.30 *a.m. and at* 9.30 *p.m.*

| Goat no. | Time (h) of mean retention (*Ri*)* 9.30 a.m. | 9.30 p.m. |
|---|---|---|
| 13 | 14·0 | 13·0 |
| | 12·5 | 13·0 |
| | 11·7 | 12·4 |
| | 12·5 | 12·1 |
| | Mean 12·7 | 12·6 |
| 14 | 12·0 | 11·0 |
| | 10·7 | 11·4 |
| | 11·7 | 13·3 |
| | 11·3 | 12·2 |
| | Mean 11·4 | 12·0 |
| Mean for both goats | 12·1 | 12·3 |

* See p. 340.

very little, ranging from 11·7 to 14·0 h in goat no. 13, and from 10·7 to 13·3 h in goat no. 14. There was no large difference in excretion pattern between marker given in the morning or at night in either goat, and mean figures for the four *Ri* values obtained with marker given in the morning and evening were 12·7 and 12·6 h respectively in goat no. 13 and 11·4 and 12·0 h in goat no. 14. The differences between these means are small and no marked diurnal differences in intestinal passage would seem to exist.

*Passage through the intestines, and faecal dry-matter content*

In each experiment designed to measure the *Ri* value, the dry-matter content of the faeces passed throughout the whole period of excretion of marker was determined.

Table 3. *Mean retention times* (Ri)*, *and dry-matter content of faeces, when stained faecal fragments were introduced through a duodenal cannula*

| Goat no. | *Ri** value (h) | Dry-matter content of faeces (%) |
|---|---|---|
| 11 | 11·0 | 35·4 |
| | 12·1 | 44·2 |
| 12 | 11·9 | 40·5 |
| | 13·8 | 40·0 |
| 13 | 11·7 | 32·0 |
| | 12·1 | 29·9 |
| | 12·4 | 30·8 |
| | 12·5 | 32·0 |
| | 12·5 | 37·0 |
| | 13·0 | 30·8 |
| | 13·0 | 36·4 |
| | 13·2 | 40·4 |
| | 13·7 | 39·5 |
| | 14·0 | 40·6 |
| 14 | 10·7 | 42·4 |
| | 11·0 | 41·9 |
| | 11·3 | 44·0 |
| | 11·4 | 39·1 |
| | 11·7 | 44·6 |
| | 12·0 | 45·4 |
| | 12·2 | 42·6 |
| | 13·3 | 44·5 |
| | 13·5 | 44·5 |
| | 14·4 | 48·5 |

* See p. 340.

For the purpose of the present investigation, however, the faecal dry-matter content in each experiment was taken as the mean value for faeces passed between the time of first appearance and of 85% excretion of the stained faecal fragments, thus ensuring that only faeces passed over the main period of experiment were included.

Considerable variations in dry-matter content of faeces were encountered both between and within individuals (Table 3). For example, the dry-matter content of the faeces from goat no. 13 varied between 29·9 and 40·6% in different experiments, and from goat no. 14, it varied between 39·1 and 48·5%. In general, a high faecal

dry-matter content coincided with a high *Ri* value, and a low faecal dry-matter content with a low *Ri* value, suggesting the possibility of a relationship between these two factors but a correlation coefficient calculated from the results of all the experiments on all four goats showed no relationship ($r = +0{\cdot}196$). But when the results from goats nos. 13 and 14, on each of which ten experiments to determine *Ri* had been conducted, were taken separately and $r$ calculated, a positive relationship between the *Ri* value and faecal dry-matter content was seen to exist for each goat (goat no. 13, $r = 0{\cdot}86$, $P < 0{\cdot}01$, $y = 27{\cdot}97 + 4{\cdot}962x$ and goat no. 14, $r = 0{\cdot}71$, $P < 0{\cdot}05$, $y = 29{\cdot}12 + 1{\cdot}464x$, where $y$ is the percentage faecal dry-matter content and $x$ is the *Ri* value in h). It can be seen from Fig. 3 that the relationship between these two factors appears to be an individual characteristic of each goat.

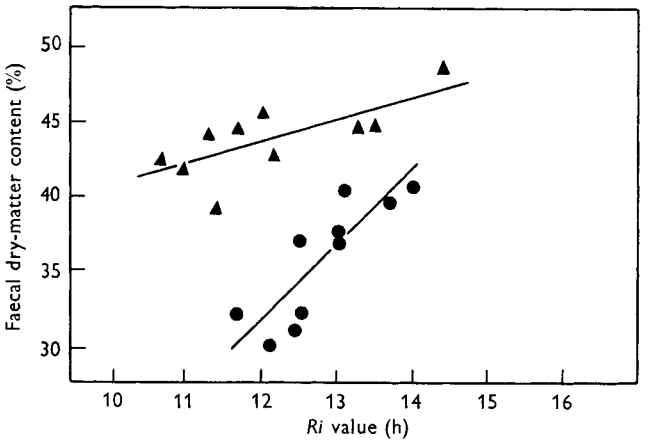


Fig. 3. Values for faecal dry-matter content and *Ri**. Ten experiments on each of two goats. ●, goat no. 13; ▲, goat no. 14. * See p. 340.

The results of this investigation suggest that the dry-matter content of the faeces reflects the rate of passage of the ingesta through the intestines when different results on the same animal are compared, but is an unreliable guide when making comparisons between different animals.

## DISCUSSION

The results of this investigation suggest that once food has left the fore-stomachs of the goat, its remaining journey through the rest of the tract is relatively short. Stained hay eaten normally can still be detected in the faeces 5–6 days after feeding, but a stained marker by-passing the fore-stomachs and introduced directly into the duodenum is completely eliminated within 1 day.

Values calculated from the results of Biondo (1953), also with goats, indicate that food remains from 2 to 3 days in the intestines alone but, as mentioned previously, the difference between his results and those of the present work is probably due to the difficulty in the measurement of the last appearance of marker from the rumen and faeces.

The results obtained by Balch (1950), who introduced a marker directly into the abomasum in cattle, are very similar to those obtained in the goats in the present experiment, and the excretion curves for both species are almost identical, even though the site of introduction of the marker was not quite the same. It is probable that a marker introduced directly into the relatively small abomasum passes rapidly to the duodenum. The time spent in the intestines appears to be more variable in the cow than in the goat, since Balch found that the time of 95 % excretion of a marker introduced into the abomasum varied from 16 to 32 h, whereas in the goats it varied only from 14 to 19 h. The time of 5 % excretion of marker fed by mouth also extends over a much wider range in cattle (Balch, 1950) than in goats (Castle, 1956*a*).

Experiments conducted to determine the relationship between the passage of marker given by mouth and the passage of marker introduced directly into the duodenum support the view of Balch (1950) that the 5 % excretion time of ingested stained hay can be taken as a measure of the time that the marker takes to pass through the posterior portion of the alimentary tract, i.e. omasum, abomasum and intestines. In the present experiments the time of 5 % excretion of stained hay given by mouth coincided with the time of excretion of 91–98 % of the faecal fragments introduced into the duodenum. Balch found in cattle that 5 % excretion of the stained hay coincided with 93–97 % excretion of the marker introduced into the abomasum.

The first appearance in the faeces of marker introduced into the duodenum preceded the first appearance of hay fed by mouth by 1–4 h, which suggests that this is the time it takes for the first fragments of ingested hay to leave the abomasum and enter the duodenum. Balch (1950) found that this difference was 3–7 h but that it varied according to whether the ground hay introduced into the abomasum was suspended in 0·5 or 2·0 l. of water. The more water he gave the larger the difference. To what extent the 70 ml. of fluid used to introduce the faecal fragments into the cannula would affect the emptying of the more anterior portions of the tract is not known.

No marked difference in *Ri* value was obtained by introducing the faecal fragments at 9.30 a.m. or 9.30 p.m. This finding does not exclude the possibility of any diurnal differences; to show them the marker would have to be introduced at other times of the day as well as those chosen, but it does support the view that the rate of passage of food through the intestine during the day does not differ greatly from the rate at night.

Previous work (Castle, 1956*a*, *b*) in both kids and adult goats showed a relationship between the 5 % excretion time of stained hay fed by mouth and the mean faecal dry-matter content over the whole 5-day period of the experiment. No such relationship was found between the *Ri* values and the faecal dry-matter content in the present work. A possible explanation is that in the present work quite small day-to-day differences in faecal dry-matter content were detected, each experiment lasting less than 1 day, whereas in the previous work only gross changes were evident. Also, in the present work ten experiments were conducted on each of two goats with a fairly narrow range of faecal dry-matter contents, whereas in the earlier work two experiments were conducted on each of ten goats with a wide range of faecal dry-matter content. It may be that if two goats have faeces of very different dry-matter contents it is justifiable to

assume that they have different rates of passage through the intestine, but if the faecal dry-matter content differed by only a small amount, no conclusions could be drawn.

SUMMARY

1. In order to study the passage of food through the intestines, small Perspex duodenal cannulas were inserted into four adult goats to allow the introduction of a marker consisting of stained faecal fragments. The coloured particles were then counted in samples of faeces collected at specified intervals and the results were expressed as mean retention time, *Ri*, in h.

2. When stained hay was given by mouth and faecal fragments stained another colour were introduced through the cannula simultaneously, the mean retention time (*R*) for the hay ranged from 36·1 to 60·0 h, and that for the fragments (*Ri*) from 11·0 to 14·4 h. There was a significant positive correlation between the *Ri* values and the time of 5% excretion of stained hay.

3. In two of the goats faecal fragments stained one colour were introduced into the duodenum in the morning and those stained another colour were introduced 12 h later. There were no significant differences in *Ri* values for the two times of administration.

4. When all the goats were considered together there was no relationship between *Ri* and the dry-matter content of the faeces, but when the two goats on which ten separate experiments were conducted were considered individually, a significant positive relationship was found.

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