Intraruminal chromium controlled release capsules for measuring herbage intake in ruminants - a review

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ABSTRACT

This paper reviews the application of intraruminal chromium controlled release capsules (CRC, Captec (NZ) Ltd, Auckland) to the measurement of herbage intake in ruminants. The capsules are designed to provide for the linear release of Cr_2O_3 over c. 25 days in sheep and c. 20 days in cattle. Uniform release of Cr_2O_3 is achieved 2 to 3 days after oral administration of the CRC but steady state levels of Cr_2O_3 in the faeces are usually not achieved until day 7 or 8 in sheep and day 5 or 6 in cattle. Where cross-over or multiple feeding level experimental designs are applied, time should be allowed for Cr_2O_3 to adjust to a new steady state in the faeces before sampling for each new treatment. The period of time required varies from from 3 to more than 5 days depending on the size of feed intake change. The continuous mode of marker release in the rumen reduces diurnal variation of Cr_2O_3 in the faeces and this allows rectal sampling regimens to be applied at different times on each sampling day. Sward sampling of faeces reduces disturbance of animal grazing to a minimal level since Cr_2O_3 is delivered by a single CRC application. The effects of level of feed intake and feed type on the rate of Cr_2O_3 release are usually small, but release rates may be up to 13% lower in rumen-fistulated than in non-fistulated animals and may differ for capsules of the same type applied to different ruminant species. Reduced animal handling, flexible faecal sampling times and lower labour requirements with CRC technology, compared to daily drenching of Cr_2O_3, enable the number of experimental animals to be increased. This improves the likelihood of detecting differences in mean intake between groups. Intakes of individual animals will not be reliably estimated with chromic oxide CRC until the digestibility of herbage consumed by individual animals can be measured more accurately.

Keywords Ruminants; herbage intake; chromic oxide; controlled release capsule; methodology.

INTRODUCTION

Research into intake of grazing ruminants has traditionally been restricted by the absence of techniques which allow the measurement of feed intake with little disturbance to the animal's grazing behaviour. Most herbage intake studies in New Zealand have been based on the pasture difference technique (e.g. Rattray *et al.*, 1982), total collection of faeces (e.g. Ulyatt *et al.*, 1974) or the use of chromic oxide (Cr_2O_3) as a faecal marker (e.g. Carruthers and Bryant, 1983). The widespread application of these methods has been hampered by their high labour requirements, variable accuracy and, in the case of faecal markers, the absence of systems allowing their uniform release into the rumen (Meijs, 1981). The purpose of this paper is to review the application of a new technology, intraruminal chromium controlled release capsules (CRC), to the indirect measurement of feed intake in ruminants.

DEVELOPMENT AND APPLICATIONS OF CHROMIC OXIDE CRC

The prototype CRC, also referred to as the "controlled release device" (CRD), for delivering Cr_2O_3 into the rumen of sheep (Harrison *et al.*, 1981) was developed from a variable-geometry slow release device patented by Dr R.H. Laby of the CSIRO in 1969. The capsules have a plastic barrel into which a matrix of Cr_2O_3 sucrose mono-stearate (65:35 w/w) is inserted (usually as a series of tablets). This is followed by a plastic plunger and a compressed steel spring. An orifice of variable size (depending on required release rate characteristics) exposes the matrix to the rumen contents, forming a gel which is extruded through the force of the spring. A plastic strip, folded against the barrel for

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dosing, opens into a T-configuration (wings) to retain the CRC in the rumen (Lehane, 1982). In rumen-fistulated animals the capsules may be suspended in the rumen by a nylon filament attached to the fistula. Chromic oxide capsules for sheep with a 25 day linear release of 180-210 mg Cr_2O_3/d (Captec (NZ) Ltd. Auckland) were first marketed in 1987 (Ellis and Rodden 1987). Cattle CRC, with a 20 day linear release of 1650-1800 mg Cr_2O_3/d (Hirschberg, *et al.*, 1990), were made available the following year. Tests of alternative CRC designs and their performance in sheep have been reported by Ellis *et al.* (1981), Harrison *et al.* (1982) and Laby *et al.* (1984). Similar studies for cattle-sized CRC and their application in feed intake experiments have been published by Ellis *et al.* (1982), Bird *et al.* (1984), Grainger *et al.* (1987), Graham (1988) and Barlow *et al.* (1988). The first use of CRC (sheep type) in fallow deer was described by Kelly *et al.* (1985). These were later used by Parker and Ataja, 1990 to measure faecal output by 8-month old red deer stags.

ADMINISTRATION OF CRC

CRC are administered orally to sheep by a dosing-gun (Captec, Laverton, Australia) which releases the capsule at the back of the tongue. The swallowing motion of the animal then carries the capsule into the rumen. A Captec balling-gun is used to dose cattle with CRC in the same manner. Alternatively capsules can be placed down the oesophagus within a lubricated flexible rubber tube and released at the thoracic inlet. For both methods, administration occurs with the animal in a standing position and the wings of the CRC are temporarily restrained against the capsule barrel by a tape which dissolves after 30-40 seconds in the presence of rumen fluids. The animal should be observed for at least this period of time after administration to ensure that the capsule has been retained in the rumen. The 'back of the tongue' dosing procedure is more rapid and usually less stressful to the animal, but can result in jaw and teeth damage to the capsules if they are dislodged from the applicator in the mouth or are regurgitated from the oesophagus before swallowing to the rumen has been completed. Damaged capsules (<3%) should be discarded if the barrel is punctured or if indentations in the plastic would restrict plunger movement. Releasing the capsule at the thoracic inlet provides greater protection to the capsule, makes it less prone to regurgitation and is better suited to animals such as adult deer in which the larynx is relatively larger and located further down the throat than in sheep or cattle. Animals which are difficult to handle (e.g. adult deer, some classes of cattle) may be treated with a low dosage of a sedative (e.g. % Rompun, Bayer Ltd. Petone) to assist CRC administration. Regurgitation of CRC rarely occurs from sheep but a mismatch of CRC size and liveweight can result in the loss of capsules from cattle. Assigning numbered CRC to individual animals assists the management of this problem. Wilson (1989) recorded a 15% regurgitation of capsules in a trial with 32 mature dairy cows (430 kg average liveweight) but Hirschberg *et al.* (1990) reported no loss of capsules from 36 steers and bulls with liveweights ranging from 148-271 kg. An alternative wing design to improve the retention of capsules in the rumen of cattle is being developed.

ATTAINMENT OF STEADY STATE LEVELS OF Cr_2O_3 IN THE FAECES

Release of the Cr_2O_3 tablet matrix is initiated at the orifice of the capsule through wetting by rumen fluids. The extruding matrix is brushed off and mixed with the contents of the rumen and reticulum by their normal muscular activity. A uniform rate of release (correlation between plunger travel and time >0.98) is generally achieved 2 to 3 days after administration. However, steady state levels of Cr_2O_3 in faeces, at maintenance levels of intake, are usually not achieved until day 7 or 8 in sheep (Parker *et al.*, 1989; Lee *et al.*, 1990) and day 5 or 6 in cattle (Graham, 1988; Nasution, 1990). Kassano (1988) recommended a preliminary period of not less than 7 days before faecal collection in dairy calves (55-70 kg) dosed with sheep CRC. The attainment of steady state conditions in sheep is dependent on the level of feed intake and feed type, and is less rapid in rumen-fistulated animals than in intact animals (Parker *et al.*, 1989; Parker, 1990).

The 12 and 18 day periods of linear release of Cr_2O_3 after attainment of steady state concentrations, in the faeces of cattle and sheep respectively, provide the opportunity to apply experimental designs involving cross-overs or multiple feeding levels. However, before sampling for the new treatment commences, time

should be allowed for Cr_2O_3 to adjust to a new steady state level in the faeces. For relatively small changes in sheep feed intakes (c. < 0.4 maintenance (M)) a period of 3 days is usually adequate (Parker, 1990) but for larger changes 5 or more days may be necessary. This has implications for rotational grazing treatments where feed intakes can vary considerably between days. It is likely that the procedure adopted by Raymond and Minson (1955), of averaging the chromium concentration of samples taken across the grazing interval, should also be applied to CRC.

TIME OF FAECAL SAMPLING

The continuous mode of Cr_2O_3 release from CRC reduces within-day (diurnal) variation in faecal chromium concentration in sheep to about one third of the level achieved by twice-daily drenching of Cr_2O_3 in gelatin capsules (coefficient of variation (CV) 6.2 vs 20.1 %; Ellis *et al.*, 1981). This confirmed the work of Lambourne (1957) and Corbett *et al.* (1960) who respectively showed that increasing the frequency of drenching each day and increasing the time of Cr_2O_3 release in the rumen (by incorporation of the marker in paper) both acted to reduce diurnal variation. In more recent studies both Parker *et al.* (1989) and Lee *et al.* (1990) have reported non-significant levels of diurnal variation (CV 4-8%) in sheep dosed with CRC despite different patterns of feed intake. Similarly low levels of diurnal variation in the Cr_2O_3 content of faeces from cattle treated with CRC have been measured by Grainger *et al.* (1987) and Nasution (1990).

Low within-day variation allows flexible faecal collection regimes. This is demonstrated by the estimates of faecal output for ram lambs when faecal samples were obtained per rectum at different times of the day (Table 1). Rectum samples obtained once daily over three days provided estimates similar to those derived from twice-daily grab samples and total bagged collections.

The uniform linear release of Cr_2O_3 following a single CRC application (r > 0.98; Laby *et al.*, 1984; Parker, *et al.*, 1989; Parker, 1990) allows faecal samples to be collected from the sward if minimum disturbance of grazing is desirable, individual animal data are not required or problems with animal handling (e.g. ewes with young lambs at foot) prevent sampling per rectum. We have compared estimates of faecal output by sampling faeces over an 8 day period from marked sites of 2 m radius on the sward (Raymond and Minson 1955) with total collection of faeces and sampling per rectum from 5 ram lambs dosed with CRC and grazed to maintain a uniform pasture height. Total collections were obtained on alternate days to sward and rectum samples. Differences between the mean (±sd) faecal output of 363±26, 366±27 and 355±47 g dry matter (DM)/d for total collection, sward ring sampling and rectum grab sampling respectively, were not significant.

The uniform mixing of Cr_2O_3 in the rumen and hence in the faecal material allows faecal samples to be analysed by chemical digestion without prior grinding. For example, estimates of mean (±sem) intake of yearling rams, fed lucerne chaff ad libitum indoors, were 1165±78 g DM/d for faeces assayed after being bulked intact on an equal weight basis across 5 days, 1221±81 g DM/d for faeces bulked across 5 days and ground

TABLE 1 Actual and predicted group mean faecal outputs (g DM/d) of 5 ram lambs for alternative 3-day rectum grab sampling routines commencing on d 8 (period 1) and d 14 (period 2) after capsule administration. Figures in brackets are predicted values expressed as a percentage of actual values obtained by total collection of faeces.

Routine	Samples[a]	Period 1	Period 2
Actual	3	352±13	355±9
AM-PM	6	360±13 (102.3)	334±15 (94.1)
AM-PM-AM	3	348±12 (98.9)	341±16 (96.1)
PM-AM-PM	3	373±14+[b] (106.0)	326±12** (91.8)
AM only	3	356±12 (101.1)	346±17 (97.4)
PM only	3	363±15 (103.1)	322±18** (90.7)

[a] Number of samples collected per animal.

[b] Significance of paired t-tests between predicted and actual (bagged) faecal output: + P<0.1, * P<0.05, ** P<0.01.

through a 1.00 mm mesh before assay and 1281±97 g DM/d for faeces assayed intact on a daily basis for the same period. These values were not significantly different from the actual mean intake of 1195±88 g DM/d (Parker, 1990). Grinding of faecal samples, to improve the uniformity of the sample, is usually employed when daily administration of Cr_2O_3 is adopted (Corbett *et al.*, 1960; Carruthers and Bryant, 1983).

FACTORS AFFECTING THE RATE OF CHROMIC OXIDE RELEASE

The rate of release of Cr_2O_3 is primarily controlled by orifice diameter, matrix composition, plunger spring strength (Laby *et al.*, 1984) and the length of Cr_2O_3 matrix (Ellis *et al.*, 1988). With a 65% Cr_2O_3 matrix and a 9.00 mm orifice diameter, release rates of 160-175 and 190-210 mg Cr_2O_3/d respectively are achieved from CRC with a 6.0 cm or 3.0 cm length of pressed tablet matrix. This provides for Cr_2O_3 release over 30 and 75 days respectively (Parker, 1990). With a 50% Cr_2O_3 matrix, 7.00 mm orifice diameter and 6.0 cm of matrix, a 100 day release period is obtained (Parker *et al.*, 1989). Uniformity of release is also maintained by the passage of rumen gases into the capsule barrel by osmosis to relieve the vacuum formed as the matrix diminishes (Laby, 1986). Thus movement of the matrix can actually be reversed if rumen dysfunction occurs.

Studies of plunger travel in CRC recovered from ewes by serial slaughter have shown that release rates are reduced if very low levels of intake (<0.6 M) are imposed for 4-7 days (Parker, 1990). Plunger travel returned to the expected rate when intakes were restored to maintenance levels or above but this result indicates that intake measurements are potentially less reliable where sub-maintenance feeding under rotational grazing occurs. In a second slaughter trial, rates of plunger travel in ewes set stocked to maintain a low, medium or high residual pasture mass (c. 500, 1000 and > 1250 kg DM/ha respectively), showed a 4% increase in release rate between the low and high pasture treatments (Parker, 1990). This confirmed the findings of Laby *et al.* (1984) and Parker *et al.* (1989) that consistency of plunger travel is maintained across a wide range of feed types and feed intakes. However, release rates will increase by 2-6% if feeds which create a more abrasive rumen environment are consumed (Parker *et al.*, 1989; Parker, 1990). The CV in CRC release rates between sheep is typically 3 to 6% while variation between CRC within animals is low (CV 1-3%)(Parker *et al.*, 1989,1990).

Trials at Massey University have shown that plunger travel in rumen-fistulated sheep is 10-13% slower than in non-fistulated animals. This difference can probably be attributed to temperature fluctuations associated with the removal of the capsule from the rumen for measurement. Different gaseous conditions in a fistulated compared with an intact rumen are also likely to be a contributing factor. In contrast, Laby *et al.* (1984) implied that there were no differences between fistulated and non-fistulated sheep. Until further research defining the differences between the two rumen types is completed, plunger travel measurements from fistulated animals can only be used as a guide to the daily output of Cr_2O_3 in intact animals. Actual Cr_2O_3 release can be determined by recovering CRC from animals through slaughter at appropriate times but this is often impractical and expensive. Alternatively, release rate can be estimated by monitoring the time of Cr_2O_3 disappearance from the faeces, i.e. "endpoint" determination (Ellis *et al.*, 1988). Experiments with CRC containing a second marker in the final tablet of the matrix to more distinctly label the end of Cr_2O_3 release are in progress. CRC with a second marker are also being investigated to provide differentiation between the faeces collected, by sward sampling, from two or more treatment groups of animals grazed together.

At present little is known about the relative release rate characteristics of CRC in different animal species. We have shown for sheep and deer grazed separately but on similar pastures that average (±sem) plunger travel rates of sheep CRC, recovered by slaughter, are lower in deer than in sheep (0.78±0.01 vs 0.95±0.04 mm/d). Preliminary results also suggest that plunger travel of sheep CRC may be more rapid in a cattle rumen. Caution therefore needs to be exercised when applying Cr_2O_3 release rates across ruminant species as described by Kelly *et al.* (1985).

CONCLUSIONS

The reduction in animal handling required to administer Cr_2O_3 and flexible once-daily faecal sampling regimes

associated with CRC usage have allowed the number of experimental animals to be increased compared to previous methods of Cr_2O_3 administration (e.g. Barlow *et al.*, 1988; Lee *et al.*, 1990). In most situations costs will be lower with CRC technology than with twice-daily drenching of chromic oxide gelatin capsules or Cr_2O_3-impregnated paper (Corbett *et al.*, 1960). For example, a single sheep CRC provided Cr_2O_3 for 25 days at a cost of $NZ 14.00 in 1990 compared to c. $NZ 50 for two gelatin capsules per day over the same period. The additional cost for labour to administer gelatin capsules each day is likely to exceed the cost of estimating the release rate of Cr_2O_3 from CRC, particularly for trials where *in vivo* data can be obtained by coordinating the time of slaughter with capsule administration. Parker *et al.* (1990) estimated that, under ideal conditions and with group sizes exceeding 50 animals, differences in intake between groups of <5% could be detected. Cruickshank *et al.* (1987) calculated that a 10% difference in mean intakes could be detected at $P<0.10$ with group sizes of 6 animals using estimates of faecal output from animals dosed with CRC. Reliable estimates of individual animal intakes are unlikely to be measured with CRC technology until the digestibility of herbage consumed by individual animals can be determined more accurately (Parker *et al.*, 1990). Thus while chromic oxide CRC have a potentially important role in studies of ruminant nutrition, they could not be used to identify individual animals with superior feed conversion efficiency (e.g. for selection purposes).

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