Considerations for Gastrointestinal Cannulations in Ruminants

D. L. Harmon and C. J. Richards
Department of Animal Sciences, University of Kentucky, Lexington 40546-0215

ABSTRACT: The complexity of ruminant digestion necessitates a greater variety and complexity of experimental methods than with any other species. The fact that dietary ingredients are first subjected to microbial fermentation requires elaborate measures to ascertain nutrients presented for absorption. Numerous approaches have been attempted to obtain representative samples of digesta at sites throughout the gastrointestinal tract. The choices of a researcher before an experiment include animal(s), site(s) for cannula placement, style of cannula, cannula material, and numerous other more subtle factors that may contribute to the success of an experiment. This review compares the advantages and disadvantages of various approaches, cannula types, and cannula materials that should be considered before experiments are conducted.

Key Words: Surgery, Cannulation, Ruminants, Small Intestine, Digestion


Introduction

The complexity of ruminant digestion presents opportunities and challenges for studying ruminant digestive physiology. Cannulas have been used for many years to sample digesta at specific points in the gastrointestinal tract. Phillipson and Innes (1939) and Jarratt (1948) described abomasal cannulation of sheep, and Ward et al. (1950) described the preparation of a duodenal fistula for cattle. Procedures for placing cannulas have been described for pigs (Laplace and Borgida, 1976; Decuypere et al., 1977; Gargallo and Zimmerman, 1980; Landers et al., 1989; Pluske et al., 1995), rabbits (Carman and Waynforth, 1984), ponies (Peloso et al., 1994), and dogs (Walker et al., 1994). Detailed surgical procedures and summaries of various experimental approaches for ruminants are also available (Hecker, 1974; Dougherty, 1981; McGilliard, 1982; Gay and Heavner, 1986; Bristol, 1990; Harrison, 1995). Alternatives to intestinal cannulation, such as ileorectal anastomosis, have been considered for sheep (van der Walt et al., 1990) and pigs (Laplace et al., 1994).

Cannulation permits access to the gastrointestinal lumen to sample digesta, infuse nutrients (Kreikemeier et al., 1991), or use alternative measures of digestibility, such as mobile nylon bags (Vanhatalo et al., 1995). Experimental goals will influence the type of cannula and its placement. Despite widespread use of intestinal cannulas, the search continues for improved cannulas and methods of cannulation to reduce postsurgical complications and experimental problems, increase the longevity of the preparation, and permit the collection of more reliable data.

Our comments on intestinal cannulation are intended to serve as a reference for the various approaches, cannula types, and advantages and disadvantages that may be considered before an experiment is conducted. We will focus on experimental approaches that have been used to partition ruminal and intestinal digestion. Some discussion is devoted to cannulas placed in locations other than the intestine. The ideal cannula or alternative approach is not yet available, and only through study of past approaches and the sharing of new ideas can we hope to proceed toward that goal.

Cannula Types and Applications

Current Practices

In compiling information for this review, 59 informal surveys were mailed to scientists involved in the study of ruminant nutrition and digestive physiology throughout the United States and Canada. Of these
surveys, 41 responses were received and used in an attempt to describe current practices of intestinal cannulation. This information will be included where appropriate throughout our review.

Cannula Types

Reentrant Cannulas. The placement of reentrant intestinal cannulas was one of the first approaches used to study digestion. Crocker and Markowitz (1936) described the preparation of an intestinal reentrant cannula to study digestion in dogs. This approach was first applied in sheep by Phillipson (1952). Ash (1962) described cannula manufacture and modifications of Phillipson’s procedure that included the use of a flexible (polyvinyl chloride plastisol) and curved cannula to decrease resistance of digesta flow. In this approach, the intestine is transected, and the transected ends are inverted and closed. Cannulas are placed in each transected end, then exteriorized and joined to reestablish digesta flow. The primary problems associated with the procedure is blockage of the cannula and loss of digesta when the cannula inadvertently becomes separated. Procedures for placement of similar types of cannulas in the duodenum and ileum of sheep were given by Brown et al. (1968) and, in cattle, by Conner et al. (1957) and Horney et al. (1972). These reports describe patency of 6 to 18 mo following postsurgical recovery; however, Horney et al. (1972) reported that leakage and loss of digesta around the cannula or blockage necessitated the administration of KCl to correct electrolyte imbalance.

Aliyev (1982) described the placement of duodenal and ileocecal reentrant cannulas in sheep, bulls, and lactating cows. Their procedure used two beveled polyethylene cannulas to route digesta externally from the transected intestine and to return external digesta to the distal transected intestine. Rubber tubing was connected externally to the beveled ends to complete digesta flow. The polyethylene cannulas were placed directly into the intestinal lumen at the transection, thereby avoiding the blind pouch created with the Ash (1962) approach. This modification allowed digesta to flow directly into the cannula lumen. Their placement of ileal cannulas was also unique in that the ileocecal valve remained intact with the ileum. The reentrant cannula was then placed in the cecum, and ileal digesta was returned directly into the cecum.

The major advantage to reentrant cannulation is that digesta flow can be measured directly at the same time that subsamples are obtained (Phillipson, 1969). This sampling process has been automated for sheep (Axford et al., 1971; MacRae, 1975), calves (Sissons and Smith, 1978), and cattle (Zinn et al., 1980), such that total digesta flow is collected, mixed, subsampled, and pumped back into the animal. The major disadvantages of reentrant cannulation are the difficulty of the surgical procedures compared with other types of cannulation, potentially longer surgical recovery times, increased mortality, and higher postsurgical maintenance because of potential blockages of digesta flow at the cannula. Reentrant cannulas may also cause greater deviations from normal digesta flow because the transected intestine makes this approach more difficult in very high-producing animals for which higher feed intakes are needed to maintain production. Also, the ability to completely divert digesta flow does not guarantee reliable results. In our survey of current practices, only one laboratory reported current use of reentrant cannulas.

Simple-T Cannulas. Although reentrant cannulas offer the potential advantage of simultaneous sample collection and flow measurement, numerous procedures involving only a single fistula into the intestine have been described. McDonald (1953) described the preparation of a duodenal fistula and placement of a simple-T cannula in sheep. His approach involved the removal of a rib portion and required sectioning a portion of the diaphragm, which was reported to give greater support for the cannula. Young (1957) described the preparation of a duodenal fistula in the bovine whereby a section of duodenum was exteriorized after a section of the 12th rib was removed. This exteriorized section of duodenum was supported by a needle-like skewer until healing had commenced (3 d). At that time, the duodenum was incised, and a cannula placed. A similar approach was described by Hanuš and Zdeňková (1969), in which small sections of the gastrointestinal tract were exteriorized, secured to the skin, and a fistula was allowed to form. These fistulas then serve as sites through which to access the lumen either by injection or for sampling.

The preparation and placement of a double L-shaped simple-T cannula was described by Streeter et al. (1991). The cannula was constructed of cydopolyvinyl chloride water pipe fittings. This type of cannula is lightweight, inexpensive, and easily manufactured. The split design of the cannula permits a very small incision to be made in the intestine for cannula insertion, and allows cannula removal and replacement in the event it is damaged or dislodged. Streeter et al. (1991) reported excellent function of the cannula, based on sampling ease and management, in the duodenum and ileum of steers, with patency maintained for up to 2 yr. Comparisons of data obtained in experiments using double L-shaped cannulas with data obtained in experiments employing other simple-T cannulas yielded similar coefficients of variation for duodenal and ileal nutrient flows, suggesting similar sampling performance.

The design and construction of a flexible duodenal cannula for sheep manufactured by molding silicone was reported by Horigane et al. (1992). Little leakage was noted using these cannulas, with function maintained for more than 1 yr. Buttle et al. (1982) also described the preparation of a silicone T cannula. Their cannula differed from that of Horigane et al.
in that it was constructed from silicone tubing and had a machined stainless steel inner T flange. The cannula was used in the abomasum, duodenum, and ileum of dairy cows for periods of more than 1 yr. Cannulas machined from polytetrafluoroethylene were described by Hirst et al. (1982); these cannulas were lightweight and induced minimal tissue reactivity.

Experimental approaches using simple-T cannulas offer simplicity; they are easy to prepare and offer few postsurgical complications. The difficulty with T cannulas lies in obtaining representative samples of digesta. MacRae (1975), in his review, described early approaches to quantitative digesta collection by placing a second T-shaped cannula distal to the first through which balloons could be introduced. These balloons, when inflated, would occlude digesta flow distal to the first cannula and make quantitative digesta collection at the proximal cannula possible. However, distension caused by the inflated balloon decreased digesta flow over time (Phillipson, 1952). Borhami et al. (1980) described a TT-shaped duodenal cannula for sheep. The cannula was made of soft rubber prepared by vulcanizing two simple-T cannulas. This cannula provided two sampling ports, with the distal port used to introduce a balloon filled with small pieces of foam to provide a more flexible occlusion and thereby prevent the distension-induced decreases in digesta flow observed previously. They reported no decrease in 12-h duodenal digesta flow using this approach.

Hecker and Wenham (1983) described a unique alternative to reentrant cannulation for sheep. Two simple-T shaped cannulas were placed in the intestine approximately 10 to 12 cm apart. The section of intestine between the cannula was routed subcutaneously and supported with a plastic tube placed perpendicular to the intestine as the incision was closed. The ends of the plastic tube could then be drawn together and packed with sponges, applying pressure to the section of intestine between the two cannulas. This pressure occluded digesta flow and permitted collection of total digesta flow at the proximal cannula. Less disturbance to normal digesta flow was noted compared with conventional reentrant cannulation methods; these observations were confirmed in later comparative experiments (Poncet et al., 1982).

**Closed-T Cannulas.** An alternative reentrant cannula that did not require gut resection was first described for use in pigs by Ivan (1974) and later applied to sheep (Ivan, 1977; Ivan and Johnston, 1979, 1981). The cannula (Ketchum Manufacturing, Ottawa, Canada) was one piece with a closed-T or Y configuration constructed of molded polyvinyl chloride plastisol (Ivan and Johnston, 1981). The cannula was inserted so that the ends of the T resided within the intestinal lumen. When not sampling, all digesta would flow through the cannula lumen. The cannula was inserted through a small, 5-cm incision in the antimesenteric border of the intestine. The intestine was then wrapped with Dacron arterial graft material. The graft material supported the cannula and was placed tight enough to ensure that all digesta must flow through the lumen of the cannula. When sampling, a valve was rotated that routed all digesta to the exterior where it could be subsampled and returned via the distal side of the cannula. This approach required no intestinal transection and caused little damage to the blood and nerve supplies of the intestine. Sheep prepared with this type of cannula have been sampled for extended periods (up to 12 mo) with few blockage problems. These cannulas are not available for cattle.

Komarek (1981a) described the use of a closed-T cannula for cattle and sheep. The cannula was manufactured from Teflon and incorporated a closed crosspiece of the T that resided within the intestine. Thus, all digesta flowed through the lumen of this crosspiece within the intestinal lumen; this was ensured by wrapping the intestine with a surgical mesh, similar to the approach described by Ivan and Johnston (1981). For collection of total digesta flow, the lumen of the cannula was occluded with a collection gate (a tube with a 45° angle on the end) to route digesta externally. A double-lumen collection gate for simultaneous collection and return of digesta was also described. No difficulties with cannula obstruction were reported across a wide range of diets in either cattle or sheep. Feed intakes up to 10 kg were reported for cattle with preparations functioning for more than 2 yr.

Robinson et al. (1985) evaluated the Komarek (1981a) closed-T and two additional designs of cannulas in lactating dairy cows. The closed-T cannula (Komarek, 1981a) was placed in two cows; one functioned for 26 mo. A similar cannula, except that the barrel was divided to provide a double lumen, was placed in one cow. Sharp right angle bends in the digesta return tube of the double lumen cannula made blockages a problem and digesta return difficult. A third closed-T cannula with Y-shaped flanges similar to that described by Ivan and Johnston (1981) was placed in three cows. Excellent digesta flow for sampling and return was reported. The longevity of these preparations was somewhat limited (6 to 8 mo). Problems were largely associated with slippage of the surgical mesh around the intestine and blockage of digesta flow. In a second report, Robinson and Kennelly (1990) evaluated a modified Komarek (1981a) cannula that was sized for use in dairy cows (26 mm i.d.). Their evaluation was based on a comparison of duodenal DM flow obtained using multiple markers. Their hypothesis was that when duodenal samples were truly representative, markers associated with different phases of digesta would give equal estimates of duodenal DM flow. No difficulties were reported with the cannulas during this experiment despite wide variation in estimates of duodenal DM flow.
DM flow. However, they concluded that the differences in duodenal DM flow could have resulted from their methods of marker administration and not from poor function of the cannula.

Cannulas described previously with the closed-T lumen offer the advantage that when properly placed, collection of total digesta flow is possible. This advantage can be critical in diets for which duodenal digesta have a greater tendency to segregate or when digesta tend to be more heterogenous. Examples are diets containing rolled corn or sorghum, or diets with different particle sizes or densities. Closed-T lumen cannulas are, however, more difficult to place than simple-T cannulas and offer a greater variety of postsurgical problems. For example, the surgical support boot must remain in place or digesta flow can be blocked or bypass the cannula (Robinson et al., 1985). This may mean a more limited life span, and closed-T cannulas are more likely to occlude during postsurgical recovery.

**Omasal Cannulas.** Oyaert and Bouckaert (1961) described the placement of a cannula at the omasal-abomasal orifice that permitted sampling of digesta as it entered the abomasum of sheep. The cannula consisted of a funnel-shaped portion through which digesta flowed into the abomasum. A side-arm sampling tube was placed on the side of the funnel and exteriorized to provide sampling access. Willes and Mendel (1964) described the preparation of an omasal fistula that permitted direct sampling of omasal contents. Tadmor and Neumark (1972) described a modification of the Willes and Mendel (1964) approach, whereby an omasal fistula was maintained without placing a cannula. Although these previous approaches permitted spot sampling of omasal digesta or ruminal outflow, McSweeney (1986) described a procedure that allowed collection of total omasal efflux. A T-shaped cannula similar to that described by Komarek (1981b) was placed so that the inlet of the cannula occupied the omasal-abomasal orifice, and all omasal effluent flowed through the lumen of the cannula. The distal end of the T was exteriorized perpendicular to the flow of digesta. A collection gate was then placed in the lumen of the cannula to occlude effluent flow and permit sample collection. Engelhardt and Hauffe (1975) and Michalowski et al. (1986) also described procedures for collection of total omasal effluent in sheep. A flexible sleeve (funnel) was placed inside the abomasum and secured around the omasal-abomasal orifice. A cannula was placed in the abomasum, through which the end of the flexible funnel could be exteriorized for sample collection; this approach was also applied to cattle by Rupp et al. (1994).

Experimental access to the omasum, although possible, is difficult. Many of the preparations described above report short (3 to 4 mo) periods of functionality. Procedures directly cannulating the omasum, although suitable for obtaining samples of omasal digesta, would be unsuitable for obtaining representative samples of ruminal outflow. Because of the difficulties and relatively short functional life of preparations that collect total outflow at the omasum, these approaches are not well suited for diet comparisons that require long experimental periods. They may be best suited for experimental questions that offer no alternative approach. Rupp et al. (1994) reported similar DM flows for samples collected using the omasal funnel compared with samples obtained using a duodenal closed-T cannula, indicating that accurate estimates of ruminal outflow could be obtained at the duodenum.

**Abomasal Cannula.** Dougherty (1955) described procedures for placement of an abomasal cannula. He reported difficulty maintaining cannulas placed in the fundic region of the abomasum; however, those placed in the pyloric region were successful. Alonso et al. (1973) described a procedure for inserting a plastisol cannula into the fundic region of the abomasum in steers, with preparations lasting up to 2 yr. Cheney and Kramer (1967) described procedures for placement of abomasal cannulas in steers by resecting the lower portion of the 9th rib. Placement of abomasal cannulas in 5-d-old calves was described by Stewart and Nicolai (1964), who reported less leakage when the cannulas were exteriorized high on the left side of the animal. The insertion of cannulas prepared from rubber stoppers was described by Kondos (1967). He described the use of surgical adhesive for adhering the cannula to the abomasum. A small diameter silicone abomasal cannula suitable for infusing but not sampling was described by Driedger et al. (1970). Komarek (1981b) described the placement of abomasal cannulas in sheep. These cannulas were constructed of epoxy-filled polyurethane and required the use of a special insertion device for exteriorizing them through the body wall. Komarek (1981b) also described a bullet-shaped plug that extended into the abomasum to prevent abomasal folds from occluding the cannula. These cannulas remained functional for approximately 2 yr.

Cannulation of the abomasum was quite common in early experiments, but only 11% of the laboratories we surveyed reported current use of cannulas in the abomasum for digestion studies. The decreased use of abomasal cannulas is a result of the special challenges they present. The low pH of abomasal contents makes the choice of cannula material critical. Many of the more pliable types of cannula materials will not withstand the acidic environment of the abomasum. The motility of the abomasum and folds of tissue within it make retention of a cannula more difficult, and the abomasum in cattle is prone to prolapse after extended periods. These problems, along with the potential for greater sampling difficulties than more
distal cannulation sites, have diminished the use of abomasal cannulas for digestion experiments.

**Effects on Digestion and Motility**

Wenham (1979) and Wenham and Wyburn (1980) reported a radiologic study to determine how intestinal cannulation influenced motility. Reentrant cannulas such as those described by Ash (1962) were particularly detrimental to digesta flow. Procedures that transected the intestine limited the propagation of peristaltic waves distally and resulted in retrograde movement of digesta. These detrimental effects were particularly pronounced for the duodenum. The placement of simple-T cannulas had only minor effects on the flow of digesta. Some digesta pooled around the flanges of the cannula, but normal patterns of intestinal motility were maintained. Wenham and Wyburn (1980) suggested that the flanges created a region where intestinal motility could not maintain pressure to sustain digesta movement. Overall, simple-T cannulas were the least detrimental to intestinal motility and digesta flow. Similar conclusions were drawn by Poncet et al. (1982). They monitored intestinal digesta flow electromagnetically and compared data from animals with reentrant cannulas (Ash, 1962), and closed-T or simple-T cannulas (Ivan and Johnston, 1981). The simple-T cannulas were the least disruptive to digesta flow and the reentrant the most; the closed-T cannula was intermediate. Because of retrograde digesta flow with the reentrant cannula, flow could not be measured electromagnetically until a one-way check valve was installed in the reentrant cannula.

Despite these apparent influences of intestinal cannulas on motility, changes in digestibility following intestinal cannulation have not been reported. Hayes et al. (1964) compared data from intact steers with data from their twin siblings cannulated in the abomasum or intestine and found no differences in digestibility of feed. Similarly, MacRae (1975) reported no differences in digestibility by intact sheep compared to sheep with duodenal and ileal reentrant or simple-T cannulas.

**Cannula Materials**

A summary of materials used to construct cannulas is provided in Table 1. The length of the list indicates that the perfect cannula material has not been found. Characteristics of the ideal material depend somewhat on personal preferences but should include 1) minimal tissue reactivity, 2) tolerance of the environment in which they are placed, and 3) durability for extended periods of use. Flexible cannula materials lend themselves to simple placement, in that they can be bent or folded. They also offer the potential to be replaced when they are dislodged. However, flexible cannulas are also more likely to become dislodged. A unique approach to counter this problem was described by Buttle et al. (1982) using a silicone cannula that is flexible but has a rigid T flange.

Rigid cannulas offer security, in that they are difficult to dislodge, but some can be broken. Some of the materials such as stainless steel are quite heavy, and the weight of the cannula can cause pressure necrosis within the intestinal lumen and dislodging. Generally, rigid cannulas require larger incisions to place, and most must be placed during surgery. Harder materials cause greater tissue irritation and are more difficult to maintain, particularly in the ileum, where mucosa can grow over them, closing the fistula.

One of the oldest and most commonly used cannula materials is polyvinyl chloride or plastisol. It is inexpensive, flexible, and cannulas can be readily manufactured using simple molds and heating. The majority (62%) of laboratories that we surveyed reported using plastisol cannulas. The portions of the cannula within the lumen of the gut harden with time and may crack, which can lead to the cannula being dislodged. However, plastisol cannulas have a functional life span of often more than 1 yr. We have experienced difficulties with this type of cannula in the ileum of larger animals. The intestine and cecum are mobile, with the mass and motility moving them away from the body wall during recovery from surgery, sometimes dislodging the cannula. Properties of Tygon® (a polyvinyl chloride tube) would be...
similar to the molded polyvinyl chloride cannula described, but stiffer initially.

Rubber cannulas have received little attention in recent literature, probably because of their tendency to harden or become brittle and crack. However, their flexibility makes them easy to replace and nonirritating to tissue. Silastic materials retain their flexibility for long periods and are the most compatible with tissue.

Acrylic is hard and lightweight; however, acrylic cannulas require machining for construction, necessitating greater expense. The life span of acrylic is very good. Titanium and stainless steel would have properties and limitations similar to acrylic. Titanium has the advantage that it is extremely lightweight.

The cyclopolyvinyl chloride cannulas described by Streeter et al. (1991) are lightweight and durable. They can be readily manufactured, are inexpensive, and their two-piece design allows them to be replaced should they become damaged or should a cannula with a longer shaft be needed as the animal fattens.

Polytetrafluoroethylene (Teflon) cannulas are good in that the material is inert to tissues but it tends to be soft and thereby suffers wear on the exposed portions. Teflon cannulas also must be machined and can be expensive.

The use of high-density polyethylene is relatively new, and such cannulas are available commercially (Ankom, Fairport, NY). This material is very lightweight, durable, and offers good tissue compatibility.

Experimental Considerations

After being presented with available cannula styles and materials, individual researchers must choose which one to use. All have advantages and disadvantages.

Simple-T Cannula. Certainly the most common cannula, simple-T cannulas can be placed at virtually any point in the digestive tract. Seventy-two percent of the laboratories in our survey reported using simple-T cannulas. The greatest problem associated with their use is incomplete diversion of digesta flow. The extent of this problem depends on two major factors: heterogeneity of digesta and markers. Grains and dense particles tend to separate, making the collection of a representative sample difficult. This is a greater problem in the duodenum than in the ileum, where digesta tends to be more homogenous. A discussion of markers and associated problems is beyond the scope of this review. Marker inaccuracies were the most common difficulty reported by laboratories in our survey (57%). The use of the simple-T cannula depends completely on the correct application of digesta markers and sampling techniques. However, even the most rigorous sampling procedures cannot overcome a poorly designed or incorrectly placed cannula.

Closed-T Cannula. The closed-T cannula is becoming more common in reported research. Twenty-five percent of the laboratories in our survey are currently using these cannulas. Closed-T cannulas are more difficult to place, but they offer the major advantage that complete diversion of digesta flow is possible, which can be critical, particularly for heterogenous duodenal samples. These cannulas can be placed in the duodenum and ileum, but the viscous nature of ileal digesta makes flow through the lumen of the cannula more difficult, and blockages are possible. Feeding a diet with a small particle size before surgery may facilitate the return of digesta flow and recovery (Streeter et al., 1991). The rigid nature and design of these cannulas makes them difficult, if not impossible, to dislodge. The greatest problems associated with their use are blockages and the loss of the intestinal support boot that prevents flow of digesta around the cannula (Robinson et al., 1985). This type of cannula can also present problems as the animal fattens if the exteriorized neck of the cannula is too short.

Cannula Location. The majority (89%) of the laboratories we surveyed reported placing cannulas in the duodenum for digestion experiments. The duodenum, by nature of anatomy, is an ideal site for cannula placement. The proximal duodenum is mobile and in close proximity to the body wall. Duodenal contents have a low pH and present less chance for postsurgical infection. The cannula can be exteriorized between the last two ribs (Streeter et al., 1991) or caudal to the ribs (Komarek, 1981a). The anatomy dictates very little cannula movement, and few problems are typically encountered.

Conversely, only 55% of the laboratories we surveyed reported placement of cannulas in the ileum. Unlike contents in the duodenum, ileal contents have high bacterial numbers. The ileum and cecum are mobile and can twist and pull away from the body wall following surgery. Location for exteriorizing the cannula is more critical (Streeter et al., 1991). The use of a rigid cannula results in greater incidence of pressure necrosis and growth of mucosa within the intestinal lumen that can close the fistula. This problem can be overcome by ensuring that cannulas are loose and can be moved within the intestinal lumen daily after an adhesion to the body wall has formed (7 to 10 d following surgery).

Recommendations

The first and probably most critical aspect of experimental success is selection of animals. The temperament of the animals should be suited for intensive sampling. Animals should be trained to be tied and lead, and be accustomed to handling before surgery. Too often, lack of planning necessitates performing surgery on animals that become excited and damage themselves or the cannula following
surgery. The animals should be adapted to their environment before surgery, and their pen or stall should be evaluated for anything that may damage the cannula. Common problems are openings in a fence or gate that can catch and pull out a cannula, openings where a cannula can be knocked out when an animal gets up or lies down, or access by adjacent animals that can damage a cannula. Solid walls generally provide the safest environment.

Cannulas for partitioning ruminal and postruminal digestion are best placed in the duodenum. These cannulas offer fewer problems than omasal or abomasal cannulas and have excellent longevity. The use of the closed-T type cannula (Ivan and Johnston, 1981; Komarek, 1981a) will decrease sampling errors by the ileal mucosa.

Intestinal cannulation remains a valuable component of ruminant nutrition research. Despite the widespread use of intestinal cannulas, there is no clear consensus on the best style of cannula, cannula material, or method of placement. All cannulas have advantages and limitations. A review of the applications and limitations of each cannula before an experiment will improve success.

Implications

Placement of cannulas in the ileum offers the greatest challenge. The viscous nature of the digesta and lack of heterogeneity warrant the placement of a simple-T style cannula. Furthermore, the motility of the ileum and cecum cause a high incidence of postsurgical complications. Rigid-style cannulas offer greater safety following surgery, but flexible cannulas have greater longevity. Difficulties may be overcome by 1) strict asepsis during cannula placement because of the nature of ileal contents, 2) immobilization of the region of the ileoceleal fold by suturing to the body wall, and 3) strict animal maintenance to ensure that ileal cannulas are loose and movable within the intestinal lumen to prevent necrosis and overgrowth by the ileal mucosa.

Literature Cited


