THE EFFECTS OF DIFFERING FEEDS ON THE WAVEFORM OF DEGLUTITION IN RUMINANT ANIMALS

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ABSTRACT

Ruminants comprise the most valuable class of animals to mankind. The grazing habits of both wild and domestic ruminant animals within a given ecosystem are of considerable environmental significance, and the efficiency of production of ruminants has major economic importance. A method to detect swallowing has been developed and will hopefully provide information for studying grazing patterns and food efficiency.

This technique involves the surgical implantation of esophageal electrodes, and the telemetry of impedance changes due to alterations in the geometry of the esophagus during swallowing. The instrumentation includes: (1) the implanted impedance detector-transmitter; (2) a neck collar repeater; and (3) a base station receiver-data recorder. Signals transmitted from free roaming animals provide information related to specific digestive events, e.g., swallowing forage, drinking, and regurgitation. It is anticipated that such instrumentation may provide the basic information necessary for the determination of forage intake and grazing habits of wild and domestic ruminant animals.

ACKNOWLEDGEMENTS

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INTRODUCTION

As the world's population continues to grow, grain, which is now used to finish cattle, will be needed to feed the human population of the world. Animal producers may have to turn to producing range-fed cattle (Allison 1978).

Variation in voluntary feed intake is unquestionably a major factor determining the efficiency of animal production (Allison 1978). It has been consistently shown that a relationship exists between voluntary intake and the digestibility of ruminant diets (Stobbs 1973). Understanding the mechanisms which limit forage intake is very important in achieving maximum utilization of this resource (Bae et al. 1979). Therefore, accurate methods of determining forage intake would provide information necessary for the development and implementation of grazing schemes and range supplementation programs (Allison 1978).

Historically, researchers have relied on visual observations and manual record-keeping techniques to study grazing behavior of ruminants (Castle et al. 1975). Presently, the techniques used by researchers are still relatively unsophisticated. Generally, these techniques are costly in terms of manpower and are inaccurate indications of species use patterns and interactions with other species (Stoner et al. 1980).

A great need exists for a more direct and accurate method to study forage intake and grazing habits. "The development of a device which measures forage intake and has the capabilities of being monitored from a remote location would yield direct information as to forage consumption, grazing patterns, habitat use patterns and species habitat interaction" (Stoner et al. 1979).

A new research technique has been developed which incorporates measurement of electrical impedance changes within the esophagus during digestive events. These impedance changes are measured as voltage changes which, in turn, create a waveform pattern for analysis.

It has already been determined, using a handwired system, that there are unique impedance change patterns for various digestive events: (1) swallowing water, (2) incidental swallowing, (3) swallowing moist roughage, (4) swallowing high density feed, (5) swallowing a regurgitated bolus, and (6) regurgitation (Stoner et al. 1979).

The use of the impedance technique has many advantages over other methods of forage intake determination. Interference due to head and body movement is minimal, and there is minimal tissue reaction to the implant and the electrodes. Since the transducer is entirely implantable it can be used in conjunction with telemetry to yield data relative to an animal's grazing pattern, as well as its forage intake. A pattern recognition algorithm is being developed to enhance computer recognition of the various waveforms. The application of the impedance technique is a relatively new approach to an old problem, but it seems to have extensive possibilities for research in the areas of forage intake and grazing pattern detection for both wild and domestic ruminants.

LITERATURE REVIEW

In order to understand the significance of the waveform pattern, it was deemed necessary to conduct a literature review. This review covers the entire swallowing process, from prehension to the completion of deglutition, in ruminant animals, and the nature of the bolus.

Prehension

Prehension is the conveyance of food to the mouth. In ruminant species the lips, teeth and tongue are the chief prehensile organs, but the relative importance of these may vary among species (Church 1976).

In the bovine, the chief organ of prehension is the tongue. The tongue is long, strong and mobile. It can be extended from the mouth and curved around forage. Forage material is then pulled up into the mouth where it is cropped by the incisor teeth and the dental pad (Dukes 1935). The tip of the tongue contains filiform papillae which are stiff and project caudally. These filiform papillae aid in the prehension of small particles. The lips of the bovine are relatively unimportant except when eating small particles of food or short, succulent grass (Church 1976).

In sheep, the major prehensile structures are the incisor teeth and tongue. However, their partially cleft upper lip permits very close grazing (Dukes 1935). This type of lip is complemented somewhat by the manner in which the tongue is used. This allows sheep to be quite selective when grazing or browsing (Church 1976).

Mastication

Mastication is the mechanical reduction of food particles into smaller sizes (Church 1976). The purpose of mastication is twofold. It serves to break the food into smaller particles, which can be swallowed, and, in so doing, it creates more surface area, which in turn promotes the action of the saliva (Dukes 1935) and the microbial digestion in the rumen (Gill et al. 1966).

According to Dukes (1935), grinding occurs between the molar teeth. The principal movement of the jaw is in the vertical plane, however, there also is well-defined lateral movement. The upper jaw is wider than the lower jaw, thus increasing the efficiency of the grinding by ensuring adequate particle reduction between the molar teeth. This results in the occurrence of mastication on only one side at a time. Furthermore, the lateral jaw movement results in the molar teeth wearing into "chisel-shaped" grinding surfaces. The oblique surfaces of ruminant teeth are constructed of substances which vary in degree of hardness. This variance causes rough wearing of these surfaces, which is also important to the efficiency of mastication.

The incisor teeth are not used for grinding, but instead are used only for cropping. In place of incisor teeth on the upper jaw there is a dental pad. To keep from injuring this pad, the lower incisors are loose and obliquely placed in their sockets.

Apart from pure grinding movements, mastication consists of concomitant tongue and cheek movements which keep the food between the molar teeth (Dukes 1935). As a rule, however, ruminants only chew enough to mix the food with saliva to form a bolus of proper size and consistency to be swallowed.

Saliva, which is generally associated with mastication, aids in the formation of the bolus and serves as a lubricant during swallowing (Trautman and Fiebiger 1952). The chemical action is associated by the thin, watery secretion of the serous cells, which adjust the pH, dilute or dissolve the food, make taste possible, and hydrolyze higher carbohydrates (Trautman and Fiebiger 1952).

While ruminants are eating food, saliva is secreted by the parotid, submaxillary, and sublingual glands. The submaxillary and sublingual glands secrete only while the animal is eating. The parotid gland, however, secretes continuously, although its activity is greatly enhanced during mastication (Bailey 1961). The parotid secretion is a thin, watery fluid which exhibits three phases of activity in neighboring zones -- storage, secretion and exhaustion. In the storage phase, acidophil protein substances are transformed into secretory granules. In the secretory stage, the cells become lower and the lumen becomes larger. In the exhaustion stage, the cells fill with acidophil protein substances (Trautman and Fiebiger 1952). The parotid secretion was found to be alkaline and contained considerable quantities of bicarbonate and phosphate as sodium and potassium salts (Phillipson 1961). There is a small amount of urea in saliva which has been recycled by the animal. Limited amounts of lipase and some amylase activity also occurs which may be due to secretions of the nasolabial glands found in the muzzles of some ruminant species (Church 1976).

Mastication is an act under control of the will and may be varied voluntarily. As usually performed, however, the muscles involved are stimulated entirely by reflex with the normal stimulus being introduction of food into the mouth (Dukes 1935).

The masticatory muscles are the masseter, pterygoideus, temporalis, and digastricus. These shall be further discussed later.

Deglutition

For the purpose of simplification, deglutition (swallowing) will be divided into three phases: (1) Oro-pharyngeal, (2) Pharyngo-esophageal, and (3) Esophageal. It must be remembered, however, that deglutition is a continuous event.

Oro-pharyngeal Phase -- After the activity of the masseter muscles stop (mastication ceases), the food is rolled into a bolus which lies in the curve of the tongue (Keele and Neil 1971). Then, according to Suzuki et al. (1977), the digastricus muscles and the temporalis muscles fix the mandible. The digastricus muscles pull the mandible ventrally to open the mouth while the temporalis muscles antagonistically pull the coronoid process backward to close the mouth.

The mylohyoideus muscles raise the floor of the oral cavity. The genioglussus muscles pull the tip, back, and root of the tongue toward the centromedial line of the oral floor. Following the movement of the root of the tongue, the basihyoid bone is pulled up toward the oral cavity. The geniohyoideus muscles act to pull the hyoid apparatus toward the oral cavity. The styloglossus muscles and the hyoglossus muscles act to move the hyoid apparatus closer to the root of the tongue. From this activity the back of the tongue is protruded against the hard palate.

The mylohyoideus muscles, by raising the oral floor, assist in protruding the tongue against the hard palate. Then, the styloglossus muscles pull the protruded part of the tongue toward the hyoid apparatus

(Suzuki et al. 1977). This pushes the bolus from the oral cavity back between the pillars of the fauces onto the post-pharyngeal wall, while also interrupting the pathway of the oral cavity and the pharynx temporarily (Suzuki et al. 1977). The soft palate is elevated and thrown against the post-pharyngeal wall to close off the naso-pharynx (Keele and Neil 1971). The vocal chords are approximated and breathing is inhibited temporarily. The posterior pillars of the fauces approximate to shut the mouth cavity (Keele and Neil 1971).

When the geniohyoideus muscles pull the hyoid apparatus toward the oral cavity, the larynx follows. The esophagus, which is located in the back of the larynx, is also pulled toward the cavity to facilitate transportation of the bolus to the esophagus. This is a very important aspect of deglutition.

When the larynx is pulled toward the oral cavity, the epiglottis covers the inlet of the larynx (Suzuki et al. 1977). Aspiration of food into the larynx is prevented by reflex apnoea (Keele and Neil 1971).

The pterygopharyngeus muscles and the stylopharyngeus muscles contract to push the bolus from the pharynx to the inlet of the esophagus (Suzuki et al. 1977).

Elicitation of swallowing is dependent on oro-pharyngeal sensitivity. The reflexive elicitation of swallowing cannot be fully replaced by other mechanisms.

In the pharynx there are three constrictors, the superior, the middle, and the inferior. These contract late in the oro-pharyngeal phase and are what actually initiate paristalsis, as will be discussed later.

Swallowing is considered to be elicited in two ways, cerebro-cortically and reflexive (Mansson and Sundberg 1975). Cerebro-cortical elicitation has been shown by Carr (1970) in animal experiments. As shown by Mansson and Sundberg (1974), the swallowing reflex can be elicited by stimulation of oro-pharyngeal receptors or their afferent nerves. It was shown by Harding et al. (1977), that swallowing can also be initiated by stimulation of the laryngeal mucosa. This oro-pharyngeal sensitivity is also important for the coordination of the pharynx and pharyngo-esophageal sphincter in swallowing (Mansson and Sundberg 1974), and for the coordination of deglutition and respiration (Ogura et al. 1964).

It has been shown by Miller (1972) that the persistent motor pattern of active muscles does not require tonic sensory inflow from these peripheral nerves. He says, "The buccopharyngeal component of the swallowing reflex proceeds despite alterations in the motor output to most of the active muscles, despite deletions of sensory input from the majority of muscles and joints active during swallowing, and after almost complete elimination of mucosal input from the oro-pharyngeal and laryngeal regions known to evoke swallowing."

Miller (1972) confirms previous suggestions that electrical stimulation of the internal laryngeal nerve which elicits swallowing (Doty 1951), triggers the central nervous system to respond with a predetermined and stereotyped motor response. When these specific sensory nerve fibers discharge in this pattern, the central neural control elicits the corresponding motor response in the pertinent muscles regardless of present activity of sensory feedback. This suggests that the brain stem reflex is controlled to a great extent by a "pre-wired network" of neurons which activate brain stem and spinal cord motor neuronal pools when stimulated by patterned peripheral input (Miller 1972). Jean et al. (1975) states that it is the medullary neurons which initiate and program the motor response of the swallowing reflex.

Pharyngo-esophageal Phase -- The pharyngo-esophageal phase starts with the beginning of activity in the thyroarytenoideus muscles. These muscles close the aperture of the larynx, which indirectly may assist in opening the inlet of the esophagus.

In accordance with the opening of the esophagus, the bolus is transported into the esophagus by the activities of the hyopharyngeus muscles, the thyropharyngeus muscles, and the cricopharyngeus muscles (Suzuki et al. 1977).

Before going into the third phase of swallowing, the esophageal phase, a word should be said about the structure of the esophagus.

The esophagus is a tube which runs from the pharynx to the stomach. It begins with an upper esophageal sphincter at the junction of the pharynx and the esophagus (Ingelfinger 1958). From there it extends into the area of the diaphragm where Church (1976) says there is "apparently a diaphragmatic sphincter where the esophagus passes through the diagragm." From there, the esophagus extends distally to the reticulum. At the junction of the reticulum and esophagus is the cardial sphincter (Church 1976). According to Keele and Neil (1971) there is no anatomical sphincter there, it is just sphincteric in its action. For clarity, the esophagus shall be divided into two areas. The upper third will be referred to as the cervical area and the lower two-thirds will be the thoracic area.

The ruminant esophagus is made almost entirely of striated muscles (Church 1976). The cervical part of the esophagus is mostly made of isolated bundles of longitudinal fibers. In the thoracic area this turns into a continuous sheet. The entire esophageal wall is rich in elastic tissue, it increases in quantity whenever there is a thickening of the wall or a constriction of the lumen (Trautman and Fieber 1952).

Esophageal Phase -- In the resting state, the upper end of the esophagus is shut by a mechanism which is air-tight but will yield to variable pressure changes. This mechanism is the upper esophageal sphincter (Ingelfinger 1958). Stevens and Sellers (1960) state the esophagus is "guarded" by the contraction of the sphincter.

At rest, the esophagus is relaxed and may contain air or other material (Keele and Neil 1971). According to Ingelfinger (1958), if there is nothing in the esophagus, like food, air or gas, it will be collapsed. He says "the esophagus offers a potential lumen which may or may not be realized, depending on the circumstances of the moment." The cardial sphincter is also closed while in its resting state.

Peristalsis can be divided into two types according to the method of elicitation. Primary peristalsis is initiated by the swallow reflex, whereas secondary peristalsis is initiated in response to a local stimulus in the esophagus.

Ingelfinger (1958) has divided primary peristalsis into three waves. Manometric records show the first wave to be brief and negative. It is signaled by mylohyoid contraction and/or elevation of the soft palate. One mechanism which has been postulated to explain this is the stretching of the esophagus. Since the lower end is presumably anchored at the cardia and the upper end is elevated by the ascending hyoid-larynx-pharynx column, it is possible the pressure could fall.

The second wave is characterized by a positive, abrupt upward swing. The amplitude of this wave is related to the size and nature of the bolus. This wave, however, does not develop with a dry swallow.

The dominant wave of the esophageal swallow pattern is the third wave. This third wave is the actual peristaltic phenomenon.

The general view is that peristalsis sweeps down the entire esophagus without interruption. There is radiologic and manometric evidence to show the peristaltic wave starts in the pharyngeal constrictors and passes through the upper esophageal sphincter and the esophagus without interruption (Inglefinger 1958). Ramsey et al. (1955) refer to the pharyngeal constrictors contraction as the "stripping wave." They agree with the continuity of the peristaltic wave but they contend this stripping wave fades out at the upper esophageal sphincter then re-emerges as the peristaltic wave. They believe the "stripping wave, which begins in the mouth and passes through the different levels of the pharynx and upper esophagus, is the major propulsive force in all normal swallowing of semi-liquid and solid material."

It is thought that although peristalsis is not interrupted, it does, however, slow down. The peristaltic wave is more rapid in the cervical area than it is in the thoracic area in man.

Further information is needed to determine if there is actually a varying rate of peristalsis and if the consistency of the bolus affects the rate of passage down the esophagus.

Secondary peristalsis is the response of the esophagus to local stimulation. The stimulation for secondary peristalsis is usually esophageal distension (Ingelfinger 1958). Longhi and Jordon (1971) showed that the initiation of the secondary peristalsis is dependent upon the presence of a bolus.

Peristalsis consists of a lumen obliterating contraction which moves aborally (Keele and Neil 1971). It is produced by the integrated action of the outer and inner muscle layers of the esophagus.

The swallowing of fluids is slightly different from swallowing solids. Due to the buccopharyngeal pressure, thin liquids are squirted into the esophagus for variable distances (Ingelfinger 1958). Also, according to Ramsey et al. (1955) and Ingelfinger (1958), gravity plays an accessory role in swallowing fluids.

The ventral part of the esophagus is fairly rigid, compared to the dorsal or lateral parts. This is to protect the larynx and trachea.

The esophagus is motor inervated by branches of the vagus nerves (Dougherty 1971). According to Keele and Neil (1971) passage of peristaltic waves down the esophagus depend upon the continuity of the preganglionic vagal nerve supply, but not on the integrity of the muscle coat.

The thoracic area of the esophagus contains many vagal mechanoreceptors. These mechanoreceptors are stimulated by mechanical pressures or distortion, such as the expansion and contraction of the esophagus. These mechanoreceptors are connected with small myelinated fibers and have a low threshhold to mechanical stimuli (Falempin 1978). Keele and Neil (1971) again say, "oesophageal peristalsis depends on the integrity of the efferents and on the local reflexes involving Auerbachs plexus."

Bolus

After the food has been taken into the mouth, the tip of the tongue segregates the bolus from the material to be swallowed later (Ramsey et al. 1955).

As far as the weight of the bolus is concerned, Bailey (1961) showed the dry weight of the food bolus increased with an increasing weight of consumption. Gill et al. (1965) noticed that boli at the beginning of the meal were considerably lighter in both wet and dry weights than at the end of the meal.

Bailey (1961) says feeding non-fibrous foods results in increased size and frequency of the bolus, whereas feeding fibrous foods results in a decrease in size and frequency. Bae et al. (1979) show that an increase in consumption of hay results in an increase in bolus size. They postulate that this might be due to increased pressure in the reticulo-rumen, stemming from an increased rumen fill. Gill et al. (1965) showed that there was a tendency for the size of the bolus to decrease at the very end of eating.

According to Gill et al. (1965), Bailey (1961) showed that the rate of swallowing food was related to the rate of saliva secretion. For more fibrous foods, such as hay, both Bailey (1961) and Gill et al. (1965) said that the amount of saliva added per unit of food decreased throughout the meal. But according to Bailey (1961) this did not hold true for non-fibrous foods. So, for hay, as the meal continues, the size and moisture content (conductivity) decreases.

Summary

Swallowing is divided into three stages: oro-pharyngeal, pharyngo-esophageal, and esophageal. In the oro-pharyngeal stage, the bolus is formed and passed into the pharynx. In the pharyngo-esophageal stage, peristalsis is initiated by the superior, middle, and inferior constrictors. In the esophageal stage, the peristalsis continues down the esophagus, presumably uninterrupted. The first phase of swallowing is voluntary, the last two stages are reflexive.

EXPERIMENTAL METHODS

To determine whether esophageal impedance is altered by swallowing different foods, representative species of the three classes of vegetation were chosen. Ryegrass (Lolium perenne) represented the grasses. Alfalfa (Medicago sativa) represented the forbs, and yaupon (Ilex vomitoria) represented the shrubs. Both the ryegrass and alfalfa were grown in 32 x 25 x 3 cm trays in controlled environment growth chambers. The temperature ranged from 65 to 81°F, the relative humidity was about 60 percent and there was approximately 10.5 hours of daylight per day. The trays were used to, as nearly as possible, simulate natural eating conditions. The yaupon was excavated in a field and transplanted into five-gallon pots, and fed that way.

Twenty-four trays were planted -- 12 each of alfalfa and ryegrass. They were planted in groups of four trays of each forage at two-week intervals in three separate plantings. This schedule was devised to give three different maturity levels at the time of feeding. Also, a sample plot of the vegetation was clipped at feeding and dried to determine the percent moisture content. This was done to determine if the moisture content and maturity level of the vegetation had any appreciable effect on the waveform pattern.

The feeding trials were conducted by setting the trays in front of the animal. The vegetation type and maturity level were recorded on the data tape. When the animal swallowed it was called out and also recorded on the tape. This gave an alternate method of determining the impedance pattern for a swallow of a specific type of vegetation.

The biotelemetry system consists of three major parts: (1) the implanted impedance detector-transmitter; (2) the neck collar repeater; and (3) the base station receiver-data recorder.

The implant circuit detects the impedance changes associated with swallowing. The electrodes are stainless steel helically wound myocardial pacemaker electrodes. The change in impedance results in a proportional voltage change, which is then amplified by a logarithmic amplifier. This resulting voltage change is further amplified by a linear amplifier. The voltage is applied to a voltage controlled oscillator (VCO), which changes the varying voltage into a varying frequency output. The VCO output then goes to a monostable multivibrator, then to a low-power Colpitts oscillator. The oscillator is joined to a ferrite rod antenna, which allows the signal to be transmitted through the animal's neck by inductive coupling to the neck collar repeater. The implant is turned on and off by a latching magnetic reed switch and an external magnet.

The neck collar repeater picks up the 100 kHz signal with a ferrite rod antenna and amplifies this signal. The signal is then passed through an envelope detector, then coupled to a comparator to give a 3-volt pulsed output. The fundamental frequency is 54 MHz and is tuned to the quadruple of 216 MHz and then fed to the antenna in the collar.

This pulsed signal is picked up by a yagi antenna. After going through several amplifications and filterings, the signal is processed by an envelope detector. The demodulated output from phase lock loop is filtered, resulting in the swallowing waveform. This waveform is displayed on both an oscilloscope and a stripchart recorder, and is recorded on an FM tape recorder for a permanent record.

A Spanish goat was anesthetized with Surital (Thiamylal Sodium) administered intravenously in the dosage of 5-8 mg/Kg. An endotracheal tube was inserted and anesthesia was maintained.

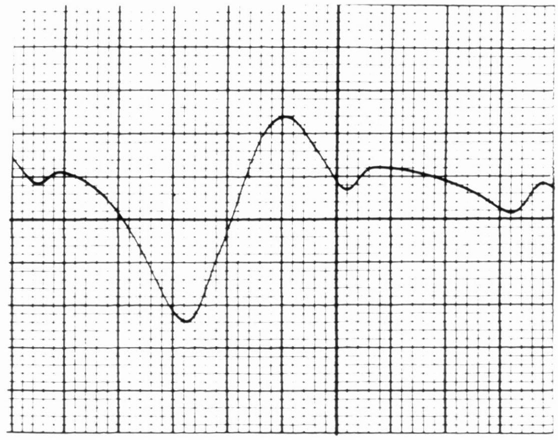
The first incision was made on the ventral side of the neck to the left of the midline. A stomach tube was inserted to facilitate locating the esophagus. The serosal layer of the esophagus was exposed by blunt dissection of the surrounding tissue layers and the pacemaker electrodes were screwed into the serosal layer of the esophagus on contralateral sides. Care was taken not to puncture the lumen, which could result in infection. The electrode leads were sutured close to each electode, using 4-0 mersilene suture in order to reduce strain on the serosal layer. The second incision, for the implant electronics package, was made on the lateral surface of the neck, just forward of the scapula. The skin was undermined to allow placement of the implant, which has been previously sterilized with ethylene oxide. The implant was secured by suturing it to the underlying tissue. A subcutaneous tunnel was formed between the two incisions to permit passage of the lead wires to the implant. Both incisions were then closed.

RESULTS

Two days following surgery, the system was first tested. Although swallowing waveform patterns were obtained that were similar to those recorded previously utilizing a hardwired system, there was much artifact due to head movement. By two weeks post-surgery the artifact had subsided greatly, but was still present during the feeding trials. After the data were gathered from the feeding trials for this monograph, the cause of the artifact was discovered. When the implant was installed, an excess of lead wire was left coiled in the neck in an attempt to provide a means of relieving some stress in the system. However, goats have an extremely mobile esophagus, and it was determined that when the goat moved its head, the excess lead created a pressure on the esophagus, resulting in a "false" geometrical change in the shape of the esophagus. This, in turn, gave erratic impedance change patterns.

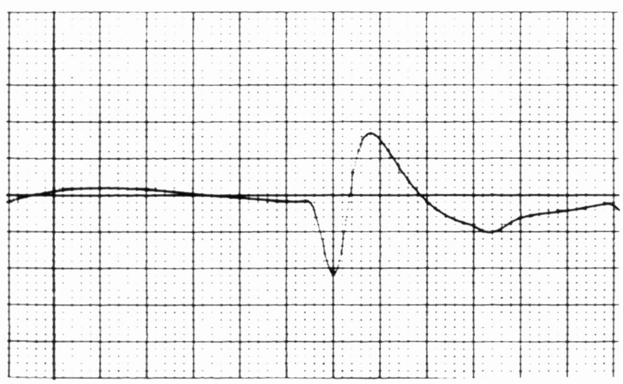
The four waveform patterns which were obtained in the feeding trials are shown in Figures 1-4. There were not readily distinguishable differences in waveform patterns, within a class of vegetation, resulting from variations in moisture content or maturity levels. There were, however, distinguishable waveform patterns for the four species of vegetation fed: the ryegrass, alfalfa, pinto bean, and yaupon. An off-line computer recognition system has been developed which is 85-90 percent effective in distinguishing these waveforms. An on-line pattern recognition system is now in the developmental stage.

One problem that was encountered when feeding yaupon was the large amount of artifact obtained. This problem was significant only with



RYE GRASS

Figure 1. Waveform pattern of swallowing ryegrass.



ALFALFA

Figure 2. Waveform pattern of swallowing alfalfa.

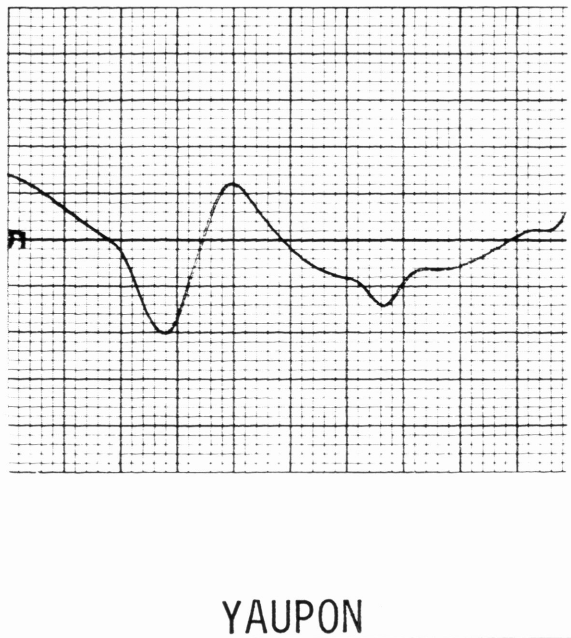


Figure 3. Waveform pattern of swallowing yaupon.

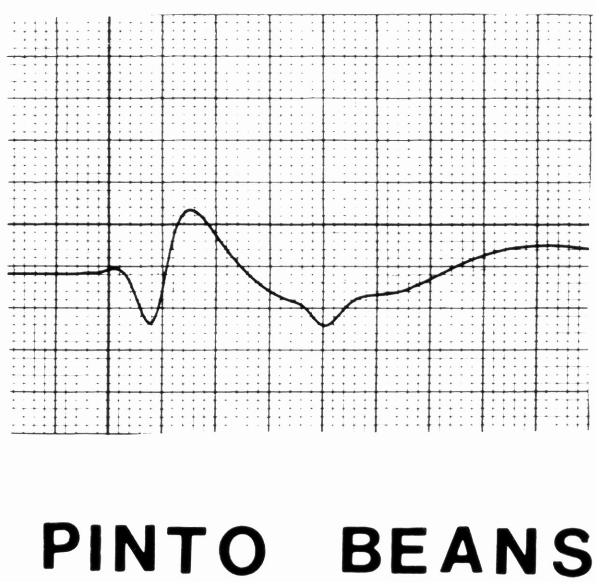


Figure 4. Waveform pattern of swallowing pinto bean plant.

yaupon because of the manner in which the goat ate it, which involved a considerable amount of head movement and neck stretching. When the leaves were hand-fed to the goat, the waveforms were relatively clean.

An unexpected result of this study was the detection of the heartbeat (Figure 5). When the goat's neck was stretched, the heartbeat was obtained through the impedance change in the carotid arteries, which run adjacent to the esophagus. Although this waveform was considered as artifact in this study, its presence opens a new avenue of research into other uses of impedance changes for detection of physiological events.

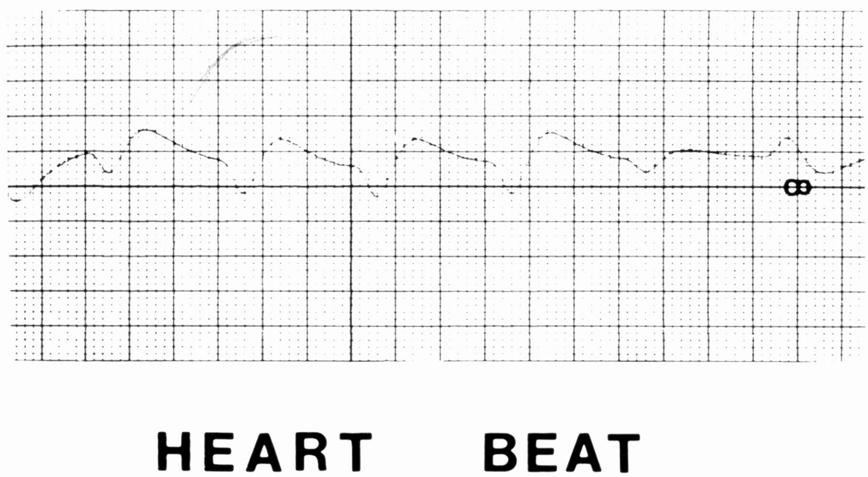


Figure 5. Waveform pattern of the heartbeat.

CONCLUSIONS

The four waveforms presented here (Figures 1-4) all have a characteristic downward swing as the first part of the swallowing waveform. Evidence indicates most swallows, with the exception of thin liquids, have this characteristic downward swing. As correlated with manometric studies, which are characterized first by a decrease in pressure or an expansion of the esophagus, followed by an increase in pressure or a contraction of the esophagus, the first downswing of the waveform should be the result of a change in impedance. Since impedance is influenced by a change in the geometrical shape of the esophagus or a change in the conductivity of the material within the esophagus, the initial expansion of the esophagus probably causes the change in impedance, which results in the first downward swing of the waveform pattern.

Following the initial expansion of the esophagus, there is a contraction which is characterized by an upswing of the graph. It must be remembered that this relaxation and contraction of the esophagus is occurring in one small segment of the esophagus at a time. The waveform pattern is, of course, due to the relaxation and contraction of the esophagus at the segment containing the two electrodes, but the pattern is continued down the esophagus, resulting in the peristaltic phenomenon.

According to this theory, the bolus size and/or weight should have a direct bearing on the amplitude of the waveform pattern. As presented previously, the size of the bolus can be influenced by the amount of fiber in the food, and also by the consumption of food. Theoretically, then, the amplitude of the waveform could be influenced by the fiber content and the amount of consumption of the food (degree of hunger).

As mentioned earlier, impedance is dependent also on the conductivity of the material being swallowed. Bailey (1961) has shown that the amount of saliva added throughout the meal decreased for fibrous foods but not for non-fibrous foods. Theoretically then, the amplitude of the waveform should, again, decrease toward the end of a meal, at least for fibrous foods.

So far, however, there are not enough data to prove or disprove these trends. It is the opinion of this author that in the light of facts presented here, the change in impedance which is responsible for subsequent waveform patterns is caused primarily by the change in geometrical shape of the esophagus. The amount of saliva added (i.e., conductivity) probably plays only an accessory role except when swallowing liquids. No explanation of the variance of waveforms of liquids from those of solid feeds will be offered here. It possibly should be the subject of further research.

Judging from the results of this study, it is deemed feasible to use the detection of impedance changes across the esophagus as a method of determining forage intake and grazing patterns. Additional research will need to be done in this area in order to develop the system for use in a definitive study. Also, before this system is used to any great extent, the operational efficiency of the implant needs to be improved in order to obtain cleaner and more consistent waveforms. Another major contingency factor is the on-line computer recognition program. To this author, this is a vital link that is missing in this program at present. Without it, determination of waveforms is done manually, which can be only haphazard at best. Although the system has problems which need to be solved, as does most new technology and technological applications, the feasibility is definitely there. And this opens up a whole new realm of possibilities for furthering research in the area of biotelemetry as applied to grazing management of both wild and domestic animals.

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