Incorporating computer animation

into the study of veterinary anatomy and physiology:

Bovine upper gastrointestinal tract

by

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1. INTRODUCTION

1.1 Motivation

Using the computer as a canvas, an animator can create three dimensional models of biological systems that can be used to convey the functionality of the system from mass muscle movement down to the smallest chemical reaction. Computer animation is currently used for many applications including television and movie effects, court room litigation, and teaching anatomy and physiology. The work presented in this thesis is an application using three dimensional computer animations to communicate complex concepts of the science of ruminant digestion.

Computer animation can be used to narrow the gap between traditional teaching tools and animal teaching laboratories. Traditionally, instructors have relied upon drawings, models, photographs, and cadavers to convey spatial and functional information to their students. Drawings and photographs can only convey information in two dimensions. Models and cadavers are stationary and cannot demonstrate the functionality of a biological system.

The use of animated three dimensional models allows the student to change viewing perspective, view the normal motion of an organ or structure, or change input parameters and view the consequences of the change, time after time at the student's own pace. If the student is unfamiliar with the anatomy, labels for the structures can be displayed.

1.2 Research objectives

The stated objective of the proposal written to support this research was, "... to create agricultural science instructional materials explaining anatomy and physiology of food producing animals. The tangible outcome of the initiative is threefold:

- a 3-Dimensional database, RUMINANT 2004, will illustrate the ruminant digestive tract using geometric models;
- interactive computer animations of the database will be placed on videotape, laser disks, and CD-ROM;
- database and animations will be disseminated to local and national veterinary medical and agricultural science institutions."[1]

The work done for this thesis consists of:

- background research;
- creation of geometric models;
- computer animation of stomach motility;
- development of demonstrational video tapes.

1.3 Materials and methods

The production of the work presented in this thesis utilized a wide array of software and hardware. The main hardware platform was the Silicon Graphics, Inc. (SGI) graphics workstation. The modeling, animating, and rendering chores were done on an SGI Reality Engine™ running the IRIX 5.2™ operating system. Other machines used were SGI INDY™ workstations and a Power Mac 8100™.

The software used for the animations and rendering was VisLab™ by Engineering Animation, Inc. (EAI), of Ames, Iowa. Gigit was used for geometry generation. Gigit was written by Terran Boylan for use at the Visulization Laboratory in Black Engineering at Iowa State University, as well as VModel™, an updated version of Gigit, and VisModel™, a solid modelling software package, by EAI. Some of the texture manipulations were accomplished using Adobe Photoshop™.

Animations were rendered to an Abekas A60™ and then written to videodisc on a Sony™ LVR3000AN laser videodisk recorder. The videodisk player was controlled by Presentation Manager, a DOS program that cues segments on the videodisc. VCR tapes for demonstrations were recorded from the videodisc on a JVC™ BR-S811U editing recorder.

The geometry representing the exterior of the cow is a modified version of the PowerFlip cow supplied as a demo for the SGI computers. The tissue samples used for the textures of the stomach were gained through dissection of a perfused, adult sheep. The photographs taken during the dissection also supplied spatial information concerning the location of the stomach within the animal.

2. ANATOMICAL STRUCTURES OF THE RUMINANT STOMACH

The information in the following section was obtained, where not explicitly referenced, from Dukes' Physiology of Domestic Animals [9, 10] and is intended to give the reader a brief introduction to the upper gastrointestinal tract of the ruminant animal.

2.1 Anatomy

The ruminant stomach consists of four distinct parts. Three of these, the rumen, reticulum, and omasum, are considered forestomachs. The fourth, the abomasum, is considered the true stomach. The forestomachs have the responsibility of breaking down the dietary intake into a form that can be digested in the abomasum and absorbed in the intestines.

The esophagus enters into the reticulum. The reticulum communicates with the rumen and also with the omasum through the reticulo-omasal orifice. There is a fold between the reticulum and the rumen which serves to separate the rumen from the reticulum. The rumen and the reticulum share an opening and are considered to be one functional member of the ruminant stomach (Figure 1).

The reticulo-rumen (RR) sac is a fermenting vat in which the digesta is broken down by a concentrated microbial population. The rumen consists of five major compartments, the anterior blind sac, the dorsal and dorsal blind sacs, and the ventral and ventral blind sacs. The sacs are separated by the following muscular pillars: the cranial pillar, the longitudinal pillar, and the ventral coronary pillar, respectively. The compartments and pillars are shown in Figure 1. The coordinated muscular contractions of the RR are such that the digesta is constantly

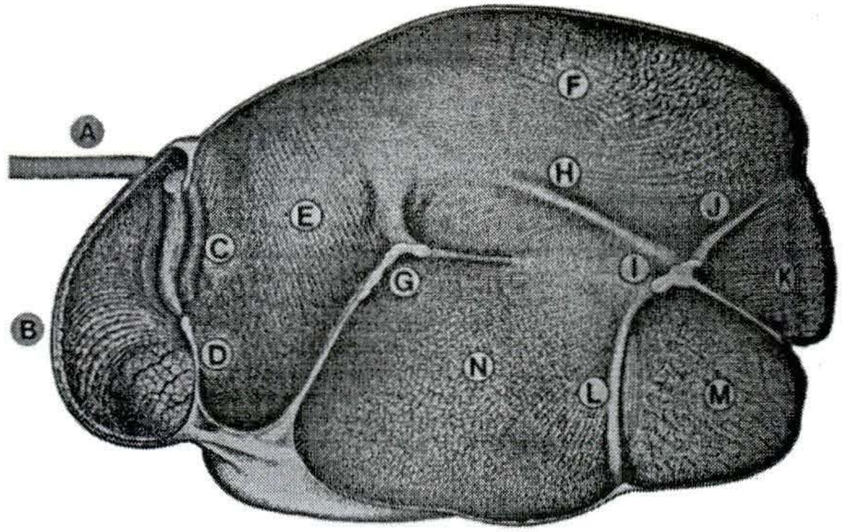


Figure 1. A photograph of the reticulum and rumen of the sheep sectioned in the vertical plane to expose the internal structures. A, esophagus; B, reticulum; C, esophageal groove; D, reticolruminal fold; E, anterior rumen sac; F, dorsal rumen sac; G, anterior pillar; H, longitudinal pillar; I, posterior pillar;K, dorsal blind sac; L, ventral coronary pillar; M, ventral blind sac; N, ventral rumen sac. (Drawing by J. R. Fuller, based on R.E. Hungate, *The Rumen and its Microbes*, Academic Press, New York, 1966.) [18]

moving from compartment to compartment.

The omasum (Figures 2 and 3) is a roughly spherical compartment that communicates with the reticulum and the abomasum (It should be noted that the omasum of the bovine is proportionally much larger than that of the sheep.) The omasum has many muscular inner folds, or septa (Figure 3), that squeeze water from the ingesta before it reaches the abomasum. The reticular groove (Figures 1 and 4) runs from the esophagus to the opening of the omasum. Liquid coming from the esophagus runs along the groove and into the omasum. In calves, milk will bypass the rumen completely by running through the reticular groove. This is because the rumen of a calve has no micro-organisms to break down solid food.

The abomasum (Figures 2 and 5) is the compartment of the ruminant digestive system that most closely resembles the stomachs found in monogastric animals (humans, dogs, etc.). In this compartment the digesta is attacked by gastric juices to break down the food particles before they are passed on to the duodenum of the small intestine.

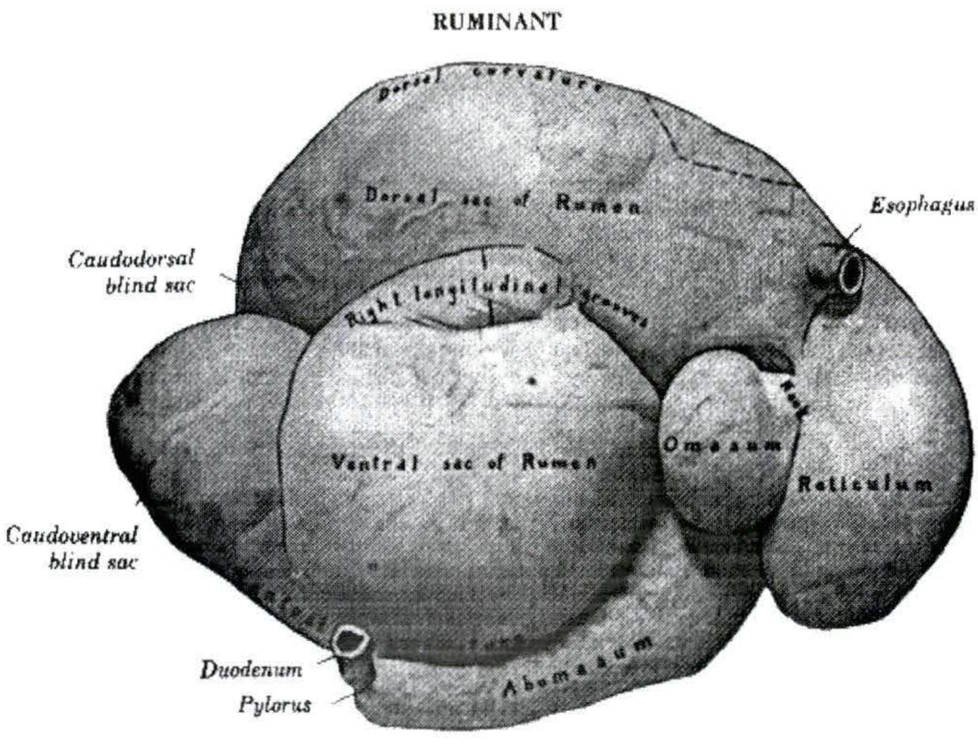


Figure 2. Stomach of sheep; right side. From a photograph of a specimen fixed *in situ*. Dotted line indicates position of spleen.[18]

Figure 3. Photograph of a cross section of the omasum of ox. 1-5, Laminae of various orders; 6, reticulo-omasal orifice in the neck of omasum.[18]

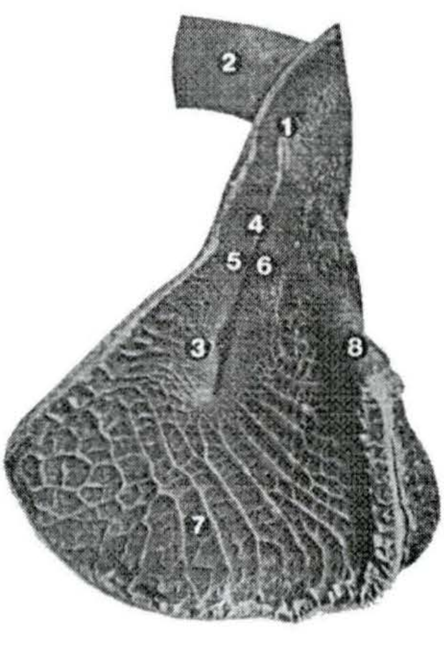


Figure 4. A photograph of the reticulum with the esophageal groove. 1) The opening of the esophagus; 2) the esophagus; 3) the reticulo-omasal orifice; 4) the groove; 5) and 6) muscular lips; 7 the ventral surface of the reticulum; 8) reticuloruminal fold. [18]

Figure 5. Photograph of the interior of the abomasum of ox. F, Body of the abomasum with abomasal folds; P, pyloric part; D, duodenum; 1 pylorus; 2, torus pyloricus.[18]

2.2 Stomach wall

The inner surface of the rumen varies greatly from the ventral cranial to the dorsal caudal end. At the cranial end the rumen lining is covered with dense tongue shaped papillae. The papillae decrease in density and size towards the caudal end where they are sparse and nodular. Figure 6 shows this progression of the papillae along the wall. The images in figures 6 and 7 were obtained from dissection of the stomach of another ruminant animal, a sheep.

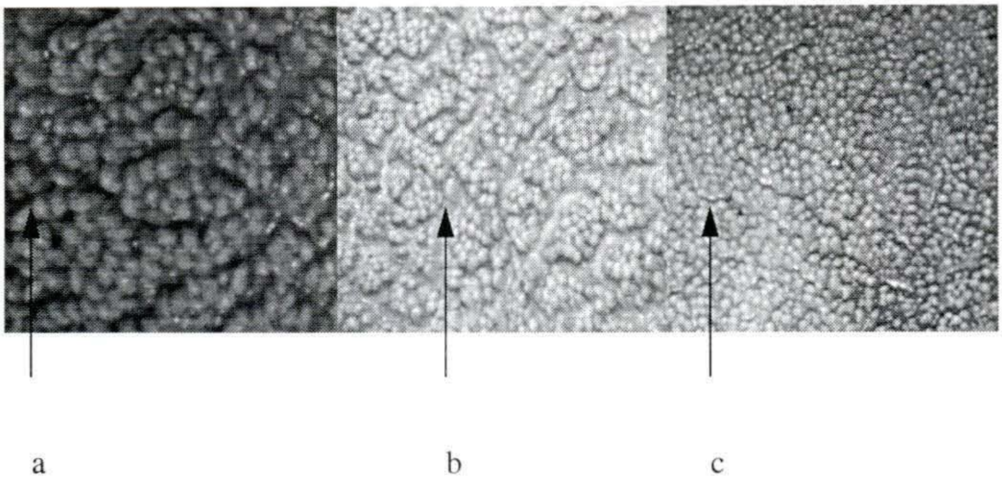


Figure 6. Photographs from a sheep of various locations of the rumenal wall to demonstrate the variations in rumen lining. a) Ventral cranial, b) middle, c) dorsal caudal ends. Note: the photographs in figures 6 and 7 are not necessarily the same scale and are intended only to be representative of the sur face of the parts of the stomach.

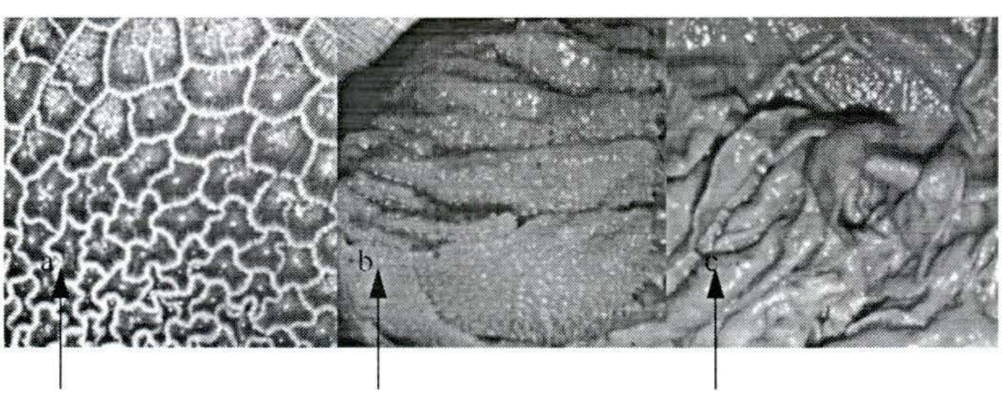


Figure 7. Photographs of the epithelial linings of the a) reticulum, b) omasum, and c) abomasum.

Figure 7 shows the surfaces of the reticulum, omasum and abomasum. The papillae of the reticulum have a characteristic honeycomb shape. The walls and septa of the omasum have sparsely distributed thorn-like papillae. The folds (rugae) of the abomasum have a smooth surface.

3. FLOW OF PARTICLES THROUGH THE STOMACH

The following chapter gives a general overview of the movement of food in and through the stomach of the ruminant. The information in this chapter, where not explicitly referenced, also comes from Dukes' Physiology of Domestic Animals [9, 10].

3.1 Background information

The flow of digesta through the stomach of the rumen is controlled by muscular contractions of the stomach. Food enters the stomach from the esophagus. Once in the stomach the particles are mixed with the rumenal contents. Through contractions of the rumen and the reticulum, the particles are either regurgitated to be remasticated or pushed into the omasum. Contractions of the walls of the omasum force the digesta into the abomasum. Peristaltic waves in the abomasum push the digesta out of the stomach, through the pyloric sphincter, and into the duodenum.

Movement of particles through the rumen varies considerably. Some of the factors affecting the motility of the ruminant stomach are: type of food being eaten, time of day, time of year, whether the cow is lactating or pregnant, and the climate. For instance, while the animal is eating, the contractions of the reticulum can range from 79-80 contractions per hour, but when the animal is resting, the range is 47-80, and while ruminating the range is 55-76 .

The timing of the contractions of the stomach can be obtained by measuring the changes in pressure in the different sacs of the stomach. The reticulum contracts, during feeding, at 35-45 second intervals, and the interval can be as much as 75 seconds while resting or ruminating. The reticulum has biphasic and triphasic contractions. Biphasic contractions are two contractions directly following each other. The second contraction of the reticulum pushes some of the dense material on the floor of the reticulum through the reticulo-omasal orifice and into the omasum, and it also signals the start of the contraction of the dorsal sac. Triphasic contractions are a series of three contractions where the third contraction corresponds to the introduction of rumenal contents into the esophagus during regurgitation .

Flow through the rumen can be calculated by surgically introducing electromagnetic flow probes. For studies that require measuring the components of the digesta, canulas can be introduced into the reticulum, the rumen, and near the pylorus [15]. Flow from the rumen can also be calculated by aspiration from the omasal canal through a tube passed through the reticulo-omasal orifice via a rumenal fistula [16]. Flow entering the proximal end of the duodenum, measured in a 420 Kg lactating cow with a diet of 10.5 Kg per day of hay and concentrates, was 175 Kg of digesta per day [17]. (The reason for the marked difference between comsumption and the amount leaving the abomasum is that the cow can produce between 90 and 180 L of saliva a day.) When marked particles are introduced into the rumen their concentration levels display a logarithmic decay.[3]

3.2 Particle flow through the upper gastrointestinal (GI) tract

The movement of food through the upper GI tract of the ruminant starts with mastication in the oral cavity. Here the food is mechanically broken down by chewing. Also in the mouth the ingesta is mixed with saliva which acts mainly as a lubricant, but also is an important buffer, and the pH of the ruminant's saliva is around 8.1. A bolus of food is forced to the back of the mouth by the tongue at which point it is conveyed down the esophagus by a peristaltic wave to the reticulum. The bolus enters either the reticulum or more commonly the rumen where it begins mixing with the rumo-reticular contents.

Coordinated contractions in the walls of the rumen and reticulum move the mixture through the RR. Rumination is a process that involves muscular contraction of the rumen, a triphasic contraction of the reticulum (section 3.3), and a reverse peristaltic wave of the esophagus (regurgitation). Regurgitation is an important process that results in the solid ruminal materials being broken down into finer (smaller) particles through remastication [15]. The animal swallows (deglutition) the juices from the regurgitated rumenal contents and this liquid runs down the reticular groove into the omasum.

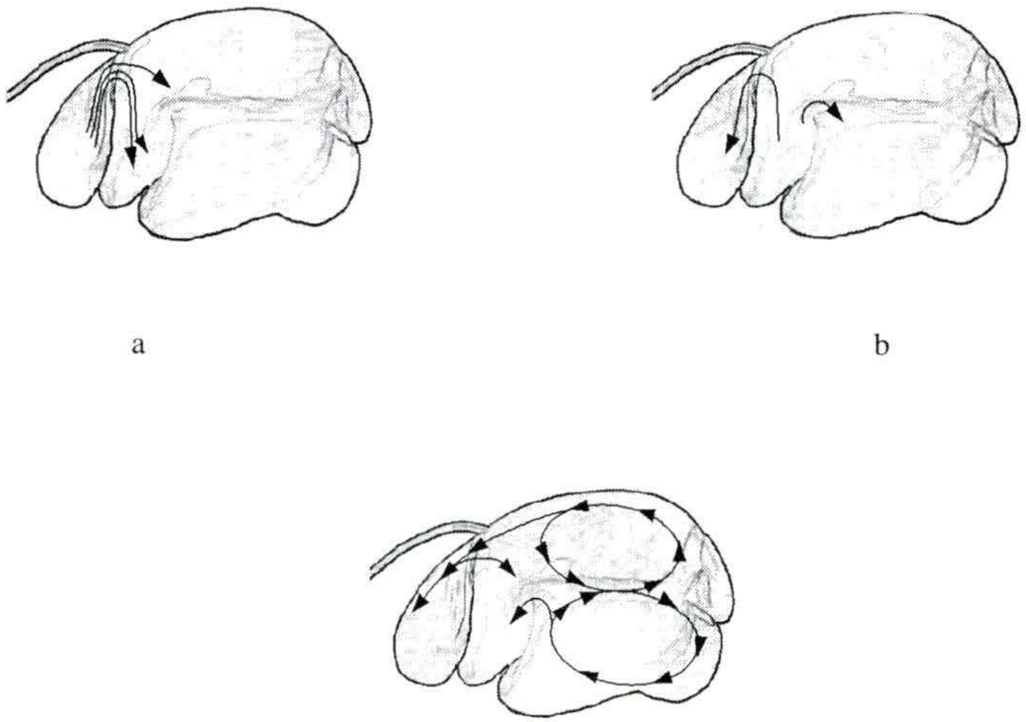
Once the liquid has reached the omasum, the muscular layers in the omasum contract to squeeze water from the digesta. Then some of the water, as well as some of the volatile fatty acids, is absorbed across the wall of the omasum while the rest is propelled into the abomasum. The contractions in the omasum are enhanced by the shifting of the abomasum and the reticulum. As the reticulum and/or the abomasum contract they will cause the omasum to twist.

3.3 Muscle movements of the rumen

Particle movement in the rumen is brought about by a complex chain of muscle contractions. This wave of contractions progresses both cranial to caudal, called forward progression, and caudal to cranial, referred to as backward progression. These wave progressions are not always constant. Sometimes the reverse follows the forward, or the forward can be present without the reverse. The progression of the forward wave is as follows (Figure 8 a-c):

1) Brisk double contraction of the reticulum
2) Relaxation of the reticulum and anterior blind sac
3) Contraction of the cranial pillars keeping particles from flowing back into the reticulum
4) Contraction of the anterior pillars, effectively cutting off the anterior sac
5) Contraction of the dorsal sac, dorsal blind sac, and dorsal coronary pillar
6) Dorsal blind sacs relax and the ventral sacs contract [4, 5].

The reverse wave of the rumen is associated with eructation. Eructation is another important result of muscular contractions of the rumen. During eructation, contractions of the reticulum and dorsal sac force gas produced by fermentation from the rumen into the esophagus. The rumen and reticulum contract with sufficient intensity to force the esophagus completely open [20]. The gas is pushed through the esophagus where some of it is directed into the lungs by a "trap door" in the nasopharynx. These gases are then breathed out the nose [2]. Eructation occurs approximately every two cycles of reticulo-rumenal contractions [10].



a b

c

Figure 8. Illustration of particle flow in the reticulum and rumen. The results of a) contraction of the reticulum, b) relaxation of the reticulum and contraction of the cranial and anterior pillars, c) movement caused by cyclical contraction and relaxation of the dorsal and ventral sacs.[5]

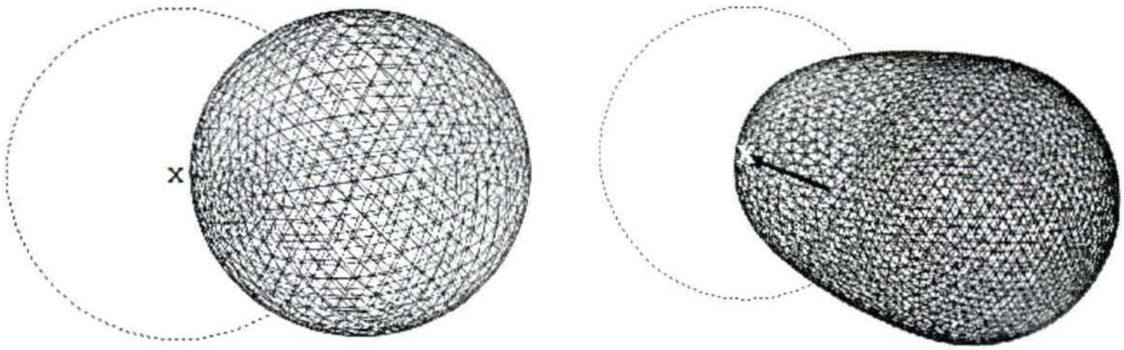
4. GEOMETRIC MODELLING OF THE UPPER GI TRACT

4.1 Geometric modelling

Modelling the stomach of the ruminant animal was accomplished by piecing together several individual geometric models to create a single system. Separate models were created for the rumen, reticulum, omasum, abomasum, and the esophagus. Once the models were created they were assembled and oriented in the commercial visualization package VisLab™, then the assembled pieces were written as a single object with five parts.

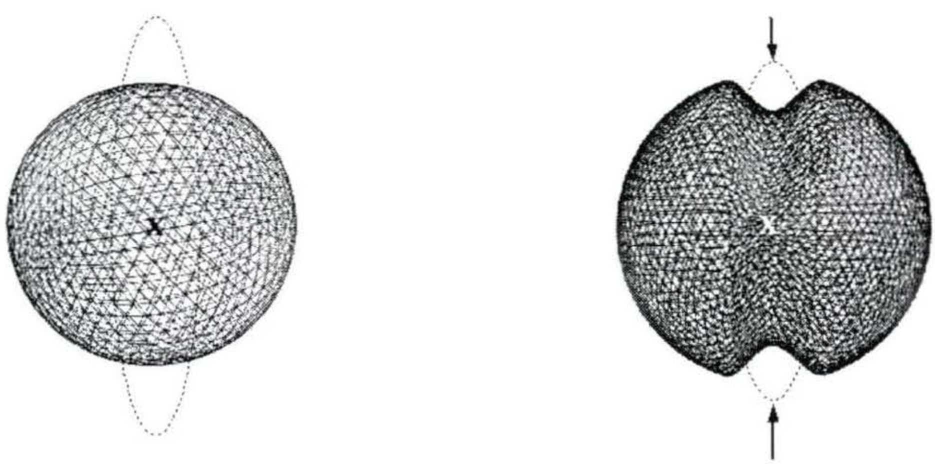
The models themselves were created by deforming spheres to match pictures of the part being modeled. Two types of deformations were used to create the geometry. One type of deformation is known as warping. Warping consists of defining a region that will be affected. Then, the affected volume can be pulled or pushed to create a new shape (Figure 9). The other type of deformation used is known as the pinch. A pinch also consists of defining a region, only this time the region affected is either expanded or contracted (Figure 10).

Matching the model to the picture consists of placing a picture of the item that is being modelled into the background of the computer's view volume. A sphere of triangular polygons is generated. The number of polygons in the sphere corresponds to the detail needed for the construction of the part (for example the oddly shaped rumen model has 5120 polygons, whereas the nearly spherical omasum model has only 2048). The sphere resides in the foreground of the view volume (Figure 11). The sphere is then deformed by defining a region of interest and pulling or pushing the polygons in this region to conform with the outline of the object in the background. This is more easily done when the spherical model is displayed as a



a b

Figure 9. An example of a warp deformation of a sphere. a) Defining a region to be deformed, b) creating the deformation



a b

Figure 10. An example of a pinch deformation of a sphere. a) Defining the region to be deformed, b) compressing the geometry

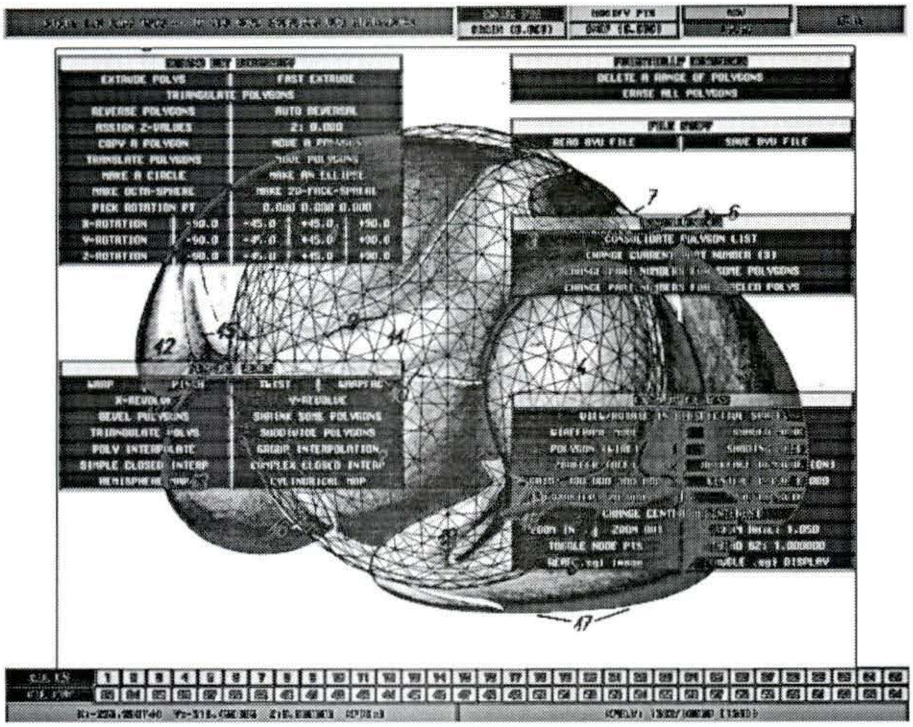


Figure 11. Gigit interface window. This view shows a deformable sphere overlaid on an illustration. The sphere is then deformed to approximate the view in the illustration.

wire frame. Once the model matches the picture, a new picture from a different angle is used. The model is rotated to match the new orientation and then is deformed to match the new view. This process continues until the model satisfactorily matches the 3-dimensionality of the intended part.

The esophagus was approximated by a constant cross sectional diameter tube. This was generated by a different method. To generate the esophagus, a spline was created that resembles the path of the esophagus through the body. A tube of triangular polygons following the direction of the spline was created with the cross section of the tube having the desired diameter.

4.2 Geometry manipulation

After the initial anatomical shapes had been created, the geometry needed to be smoothed, other anatomical structures such as the reticular groove had to be added, and the separate geometries had to be connected in the appropriate areas to complete the path from the esophagus to the pylorus. The following two sections detail the smoothing and the creation of geometrical transitions between the separate geometrical anatomical structures.

4.2.1 Smoothing the rough spots

Using spheres as the initial base for the anatomical structures gave edge free starting surface, i.e. there were no corners as there would have been if a cube had been used. Unfortunately the degree that the spheres had to be deformed created some areas where polygons were stretched far enough to leave visible defects, mainly sharp edges, that had to be removed.

To remove the defects the geometry had to be altered at the individual vertex level (each triangular polygon is defined by three vertices). To manipulate the vertices, hence the geometry, the software package VisModel was used. VisModel allows the user to select a single, or a group of vertices, normals (the normal vector is perpendicular to the face of the polygon), edges, faces, or parts. The selected item can then be manipulated to achieve the desired effect.

Two different operations were used to remove the roughness from the models. First a smoothing operation was used. According to the VisModel on-line help smoothing "compares the angle between the surface normals at each end of the selected edges to a specified minimum angle. If this angle is greater than the minimum angle, VisModel will add vertices and edges to the adjacent faces until the crease angle is equal to or less than the minimum angle." This operation added more polygons to the models which helped smooth some of the hard edges.

A tightening operation was used next. Tightening, according to the on-line help, is an operation that "computes an average position for the selected vertex from its neighboring vertices, then moves the selected vertex halfway toward that average position. VisModel will shorten some of the edges connected to the vertex and lengthen other edges to maintain the surface of your part." These operations took the roughness out of the geometry so that no geometrical defects were visible from either the inside or the outside.

4.2.2 Connecting the separate parts

In order to complete the geometry and make a continuous path through the upper GI tract the separate parts needed to be connected by the correct orifices. Three holes were needed in the reticulum to mark the openings from the esophagus, the opening into the rumen, and the reticulo-omasal orifice. A hole was needed in the rumen to connect the rumen and the reticulum. Two holes were needed in the omasum, and two in the abomasum.

The holes were created in Vmodel by selecting a group of polygons to delete. Since the holes in the different parts did not match, the vertices that comprised the edges of the hole were warped so that the edges of the corresponding holes in each of the parts matched. The resulting holes had edges with straight lines and sharp corners, so these defects now had to be removed.

To create a smoother transition between the parts, new geometrical transition pieces were created. These pieces were based on torus shaped geometry. The basic geometry was taken from SGI's Showcase geometry libraries. The geometry was in the form of an inventor file which was read into VisLab and written out as a .geo file (the .geo file is the format which is used in Vmodel). This geometry file was then read into Vmodel along with the stomach geometry and deformed to match the openings of the holes between the parts. Some of the polygons of the transitional geometry pieces were not visible when the piece were used in the models. These polygons were deleted.

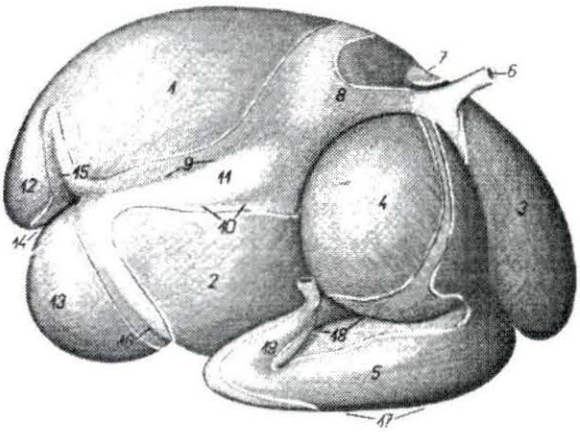
Once the transitional pieces were shaped and placed, they were separated into pieces. Some of the polygons became part of the anatomical structure on one side of the hole, others became part of the structure on the other side of the hole, while still others, the very inside edge of the torus, became a separate transitional part so that it could be textured separately.

When the transitional pieces were added to the original geometry, the normals did not match. The problem was that from the inside the camera saw the back side of the original geometry while it saw the outside, or front, of the torus geometry. Therefore, the normals of the torus geometry had to be reversed so that light would reflect equally from both surfaces. This was also done using Vmodel. The polygons that needed to be reversed were selected, and a normal reversing operator was used on these polygons.

4.3 Anatomical verification

This section gives a comparison between the two dimensional drawings used to create the geometry and the results. The main differences between the pictures that were used for the creation and the resultant models are that the models can be viewed from any orientation, the models can be viewed from the outside or the inside, they can be viewed with or without the body of the cow, and with the correct motion or as a still image.

Figures 12.a and 13.a show the left and right views that were used for the creation of the corresponding models (Figures 12.b and 13.b). Figure 14 shows the third view of the stomach that was used to create the three dimensional models. The top edge of the stomach was defined by the geometry of the exterior of the cow model. Figure 15 shows a comparison of the internal structures and textures of the stomach of a sheep and the computer model.



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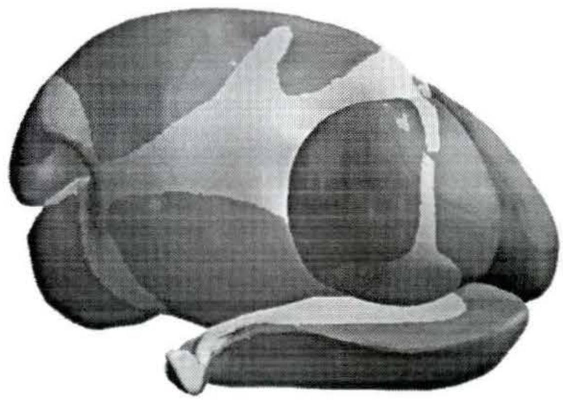
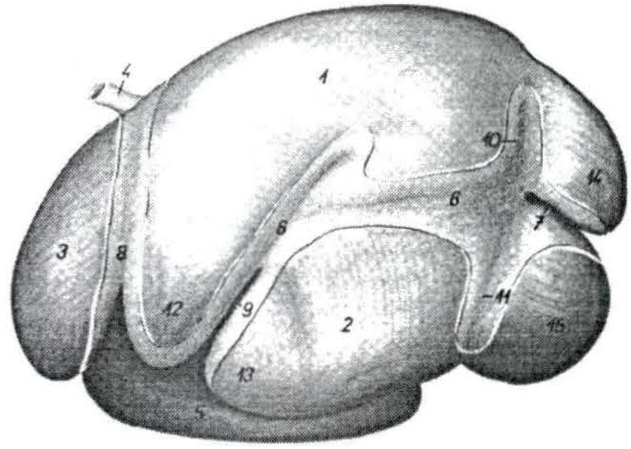


b

Figure 12. A comparison of the right side of the stomach. a) Figure 48 from Popesku[19], an illustration showing the stomach from the right side. b) Computer model showing the stomach from the right side. The geometry in b was created from the drawing in a.



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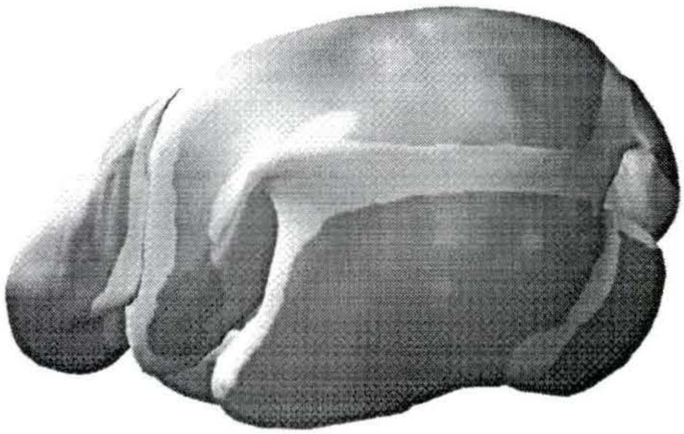
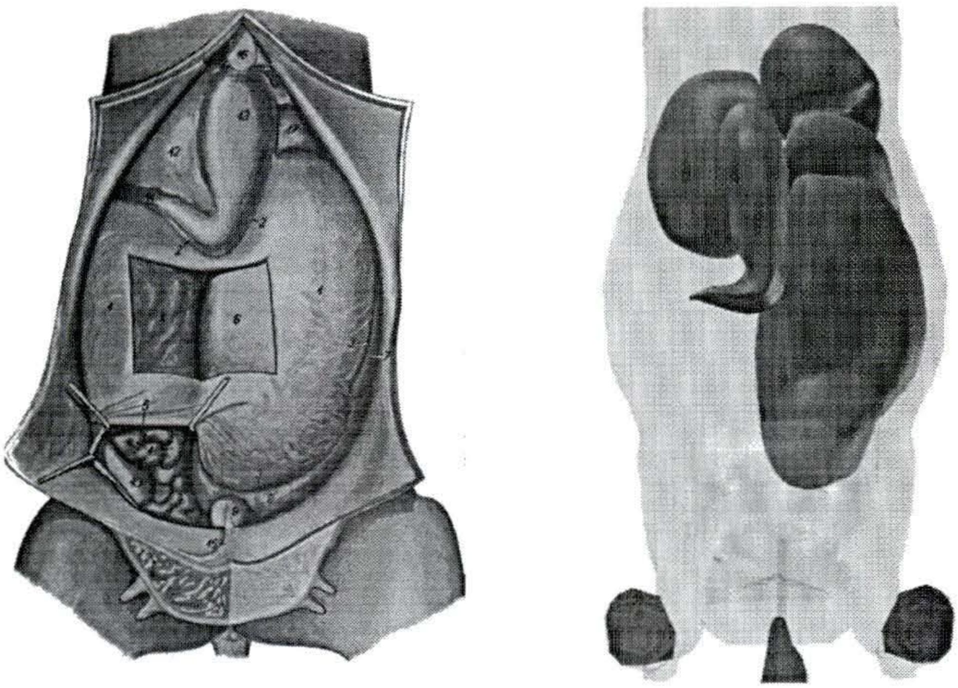


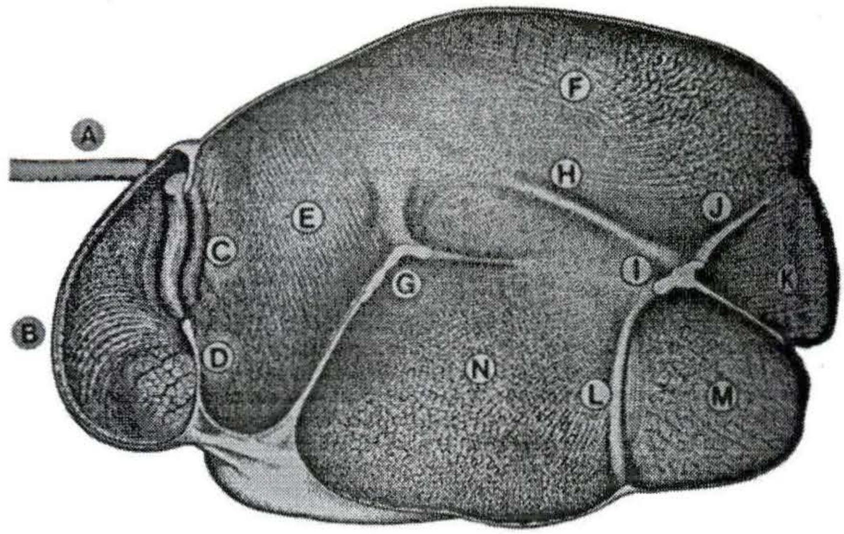
b

Figure 13. A comparison of the left side of the stomach. a) Figure 47 from Popesku[19], an illustration showing the stomach from the left side. b) Computer model showing the stomach from the left side. The geometry in b was created from the drawing in a.



a b

Figure 14. A view from the ventral portion of the cow. a) Figure 49 from Popesku[19], an illustration showing the underside of the cow to show the bottom of the rumen, abomasum, and intestines. b) Computer model viewed from the under side to show the placement and shapes of the rumen, omasum, and abomasum.



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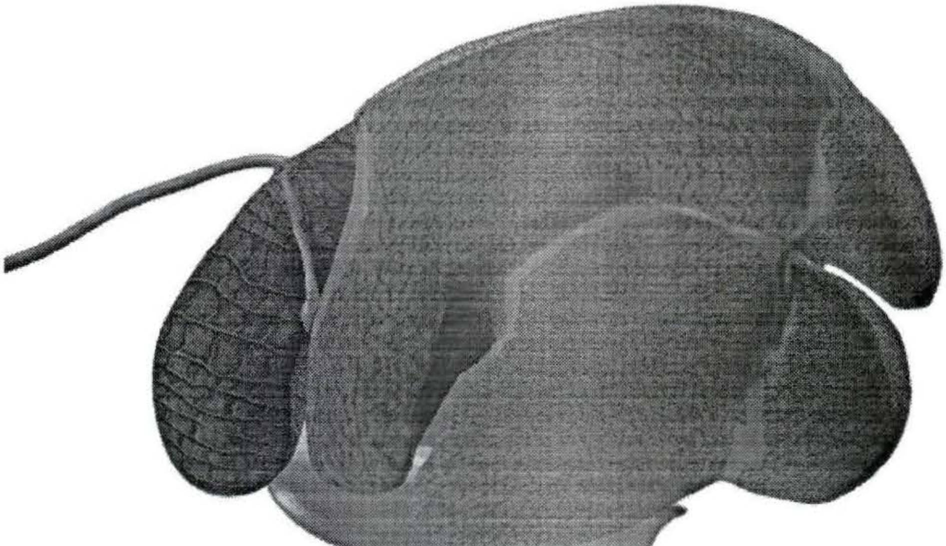


b

Figure 15. Comparison of the internal surfaces of the rumen and reticulum. a) a photograph of the reticulum and rumen of a sheep [18], b) textured model of the bovine reticulum and rumen.

5. ANIMATING THE UPPER GI TRACT

5.1 Animations

The animated sequences of this project were done using the VisLab™ package. VisLab™ incorporates a large variety of animation tools such as texture mapping, motion scripting, particles, animated deformations, and legend generation. The sequences rendered using this package were then stored on a laser disk for scripted playback. Still images from the animations can be found in the appendix.

5.1.1 Texture mapping

To give the models a more life-like appearance texture mapping was used for each part. Many of the texture maps used were acquired from a dissection of a sheep's upper gastrointestinal tract. The dissection was performed and pictures were taken of the various parts of the stomach. There were several pictures taken of the rumen to obtain examples of epithelial texture differences that exist from the dorsal to the ventral sides (Figure 6). Other texture maps were created by the artists at Engineering Animation, Inc. Copies of the texture maps used can be found in the appendix.

The textures created for the peritoneal covering of the stomach was developed from a photograph of the surface of the sheep's rumen. The original photograph was scanned into the computer using a UMAX UC1260 color scanner to be subsequently used as a texture. The picture was cropped to remove other items in the scene and leave only a small portion of the peritoneum. This texture was used as a background. To create sulci in which the blood supply to the muscular pillars is obtained, a grid was mapped to the models (Figure 16). The sulci were mapped onto the grid by digitally painting the corresponding areas. Following this procedure, the grid was removed from the picture to leave only the painted areas. The painted areas were then overlaid onto the background in Photoshop™ and then finally painted to resemble the actual sulci (Figure 17). This process was repeated for each of the forestomachs and the abomasum.

5.1.2 Deformations

Deformation of geometry is a technique used to make a single piece of geometry take on the appearance of another, or to make that geometry appear to be flexible. There are different methods of deformation. Objects can be deformed by use of control points acting on mathematically defined surfaces such as those defined by non-uniform rational B-splines (NURBS).

The deformations used to create the muscular movements of the stomach were deformation of geometrical surfaces using an operator on a volume of interest. These deformations are the same type as those used to create the geometry. The animated deformations are time based according to a script. The degree and duration of the deformation can be varied as a function of time. Also, the position of the volume of interest can be varied with time by attaching the deformation to a moving part.

To create the peristaltic movements of both the esophagus and the RR, moving deformations were used. The type of deformation used to create the contractive motion of the RR was a pinch. In the case of the esophagus, moving pinches were used to create the secondary and tertiary waves, while an inverse pinch was used to create the moving bulge of the primary wave. Paths were defined by splines and invisible parts were set to follow those paths. The

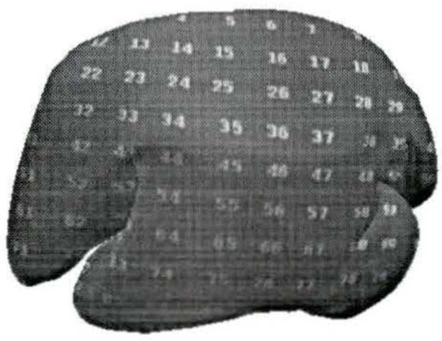
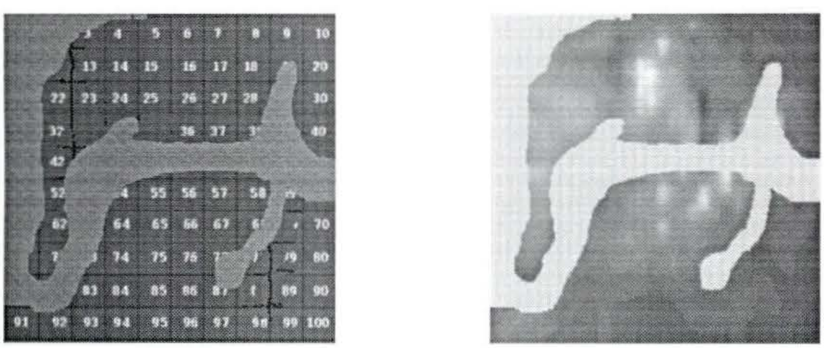


Figure 16. The computer rumen model showing grid used for painting textures.



a b

Figure 17. Creating the rumenal texture map. a) painted grid b) painted area placed on a background.

deformation patterns were attached to the moving parts and as a part of the model entered the volume of influence the model deformed to create a moving deformation.

Pinches were also used to create the muscle contractions in the rumen. For these contractions, stationary pinches were used. Several regions of the rumen were defined by using different volumes of interest. In order to make the different regions contract in the appropriate sequence each region was given its own schedule of when and how much to deform. The regions can be seen in Figure 18.

The deformation patterns and frequencies were timed to simulate the contractions described in sections 3.1 and 3.3. Once the deformation patterns for the different regions had been established, all of the deformations were linked together. One deformation calls another so that they all happen in sequence. The great benefit of using deformations based on spheres of influence is that different geometries will deform at the same rate so that adjacent surfaces remain adjacent.

Figure 19 shows an example of moving deformations. In this figure the dots represent and in fact are the moving parts. To create the effect of a continuous wave propagating down the length of the object, seven moving parts were all assigned deformations. There are four moving parts on the top and three on the bottom. The spheres of influence are shown for two of the deformations. The deformations used for this animation were offset warps. The center of the sphere of influence creates a reference point. Then the sphere is offset to create the deformation. In the figure the top spheres are offset downward to generate the trough of the wave, whereas the bottom spheres are offset to push up the crest of the wave. As the moving objects traverse the length of the geometry this motion generates a uniform wave motion.

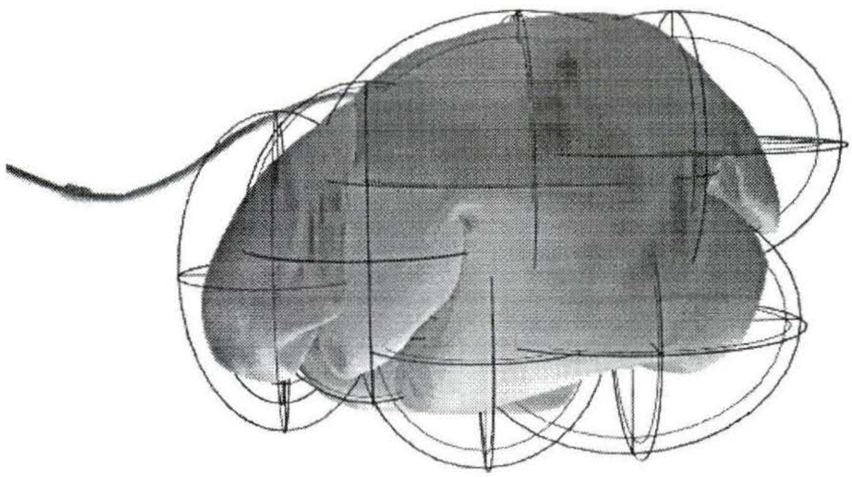


Figure 18. Spheres of influence (SOI) in the rumen and reticulum deformation models.

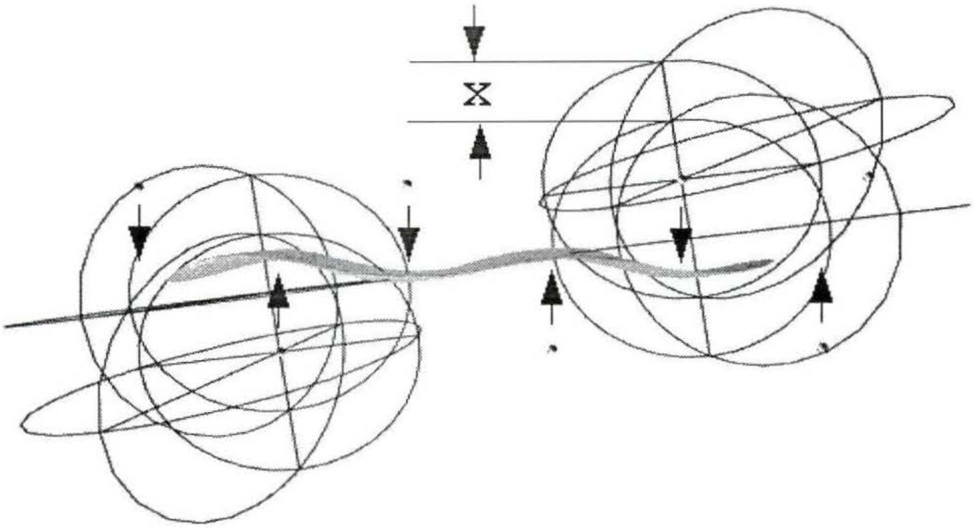


Figure 19. Producing a wave using offset warping. The dots are the moving objects to which the SOI are attached. The arrows show the direction of the deformation. The distance X is the offset of the SOI that creates the deformation.

The plots in figure 20 are graphs of pressure changes in the compartments of the rumen and reticulum during a cycle of rumination. The timing of the scripted deforamations was based on these graphs.

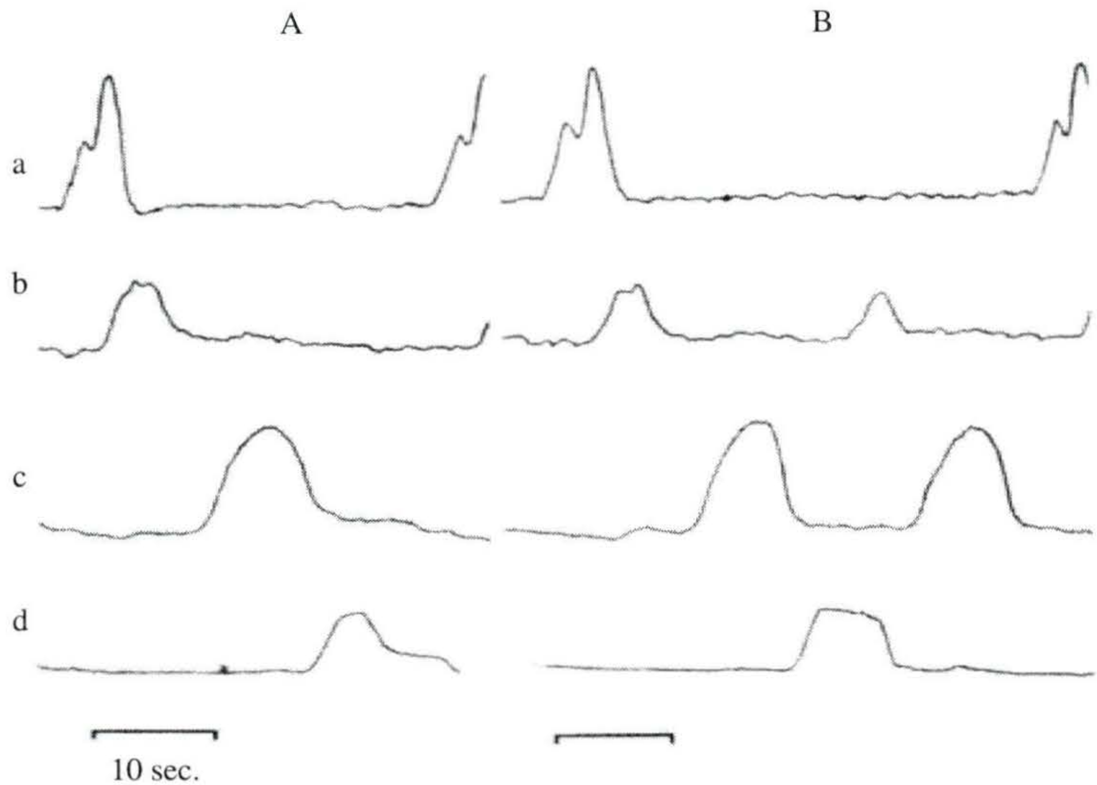


Figure 20. Frontal recording lever records, from exteriorizations. a) reticulum, b) dorsal rumen, c) main ventral rumen, d) posterior blind sac. The recordings in group A show a forward progression, whereas the recordings in group B show both a forward and a backward progression [5].

5.1.3 Particles

Particle systems were used to create several different effects in the animations. Particles were used for corn, trees, a bolus of food, and rumenal contents. The particles in the model are different shapes, have different sizes and different motions.

The motion for the particles is based on either a static part or a part traveling a path. A particle system is attached to a part that is traveling a path down the esophagus and through the stomach giving the appearance of mass flow through the upper GI tract. The motion of the particle can also be affected by deformations. If the center of the particle system falls in the volume of influence of a deformation the particle system is acted upon by the deformation. For example, the static particle systems that sit at the bottom of the blind sacs compress and expand with the deformation of the sacs. Figures 22 and 23 show the placement of the particle systems in the rumen, the boxes represent moving systems and the dots represent systems attached to static parts.

The size and shape of the particle system is determined by the scale of the part the particle is tied to and to the type of particle used. For example, to create the gas cap at the top of the rumen a set of particles is tied to a static part and is confined in a elliptical bounding box that encompasses the top of the rumen. This particle system is made of particles that are larger, more translucent, and have more internal space than the particles making up the fluid component of the stomach contents.

Particles were also used to provide backgrounds for the introduction of a demonstration video. Billboard particles, a flat particle that can be textured and that turns to face the camera,

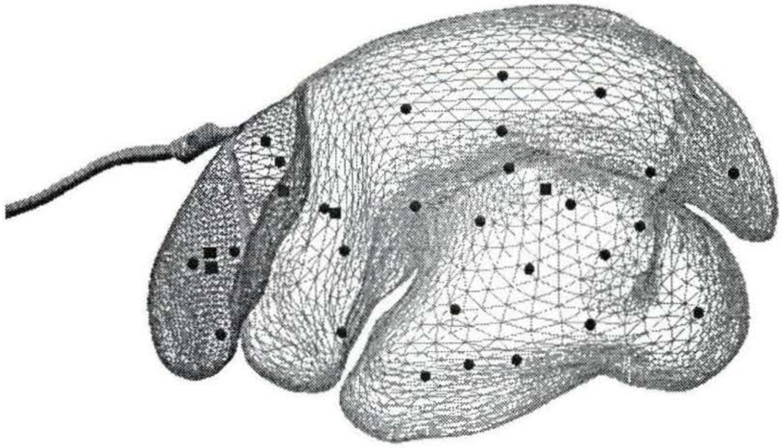


Figure 21. Computer model showing the location of the particle markers.

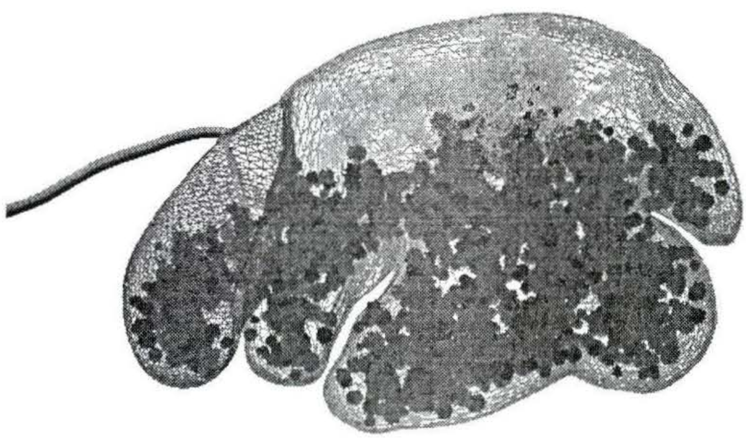


Figure 22. Computer model showing particles in the rumen. These particles were used to show stomach contents in motion during a fly through of the stomach.

were used for trees and corn. Another type of particle utilizing dynamic textures is used for red blood cells and micro-organisms. A dynamic texture is a small animation that can be played back on a billboard particle to give the illusion of independent motion of complex items. Dynamically textured particles are much less computationally expensive than using several geometric models all executing similar motions.

6. CONCLUSIONS

6.1 Continued work

From this point the continued work on this project will be concentrated on model and motion refinement. More functionality will be added to the simulations towards the goal of presenting a rudimentary working model of the physiological effects of microbial digestion. The animations will be stored as frames on laser disk and CD-ROM and distributed to schools for use in class rooms.

The work todate on this project is only the beginning in the overall scheme. This technology can be applied as text book augmentation for subjects such as the effects of changes in diet, drugs, developmental anatomy, motion studies, and surgical procedures. Using the computer as a study guide, the student will be able to see macro and micro movements of internal organs that otherwise could not be seen except through two dimensional radiographic studies or descriptions in a book.

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APPENDIX

The texture maps used in still images and animation

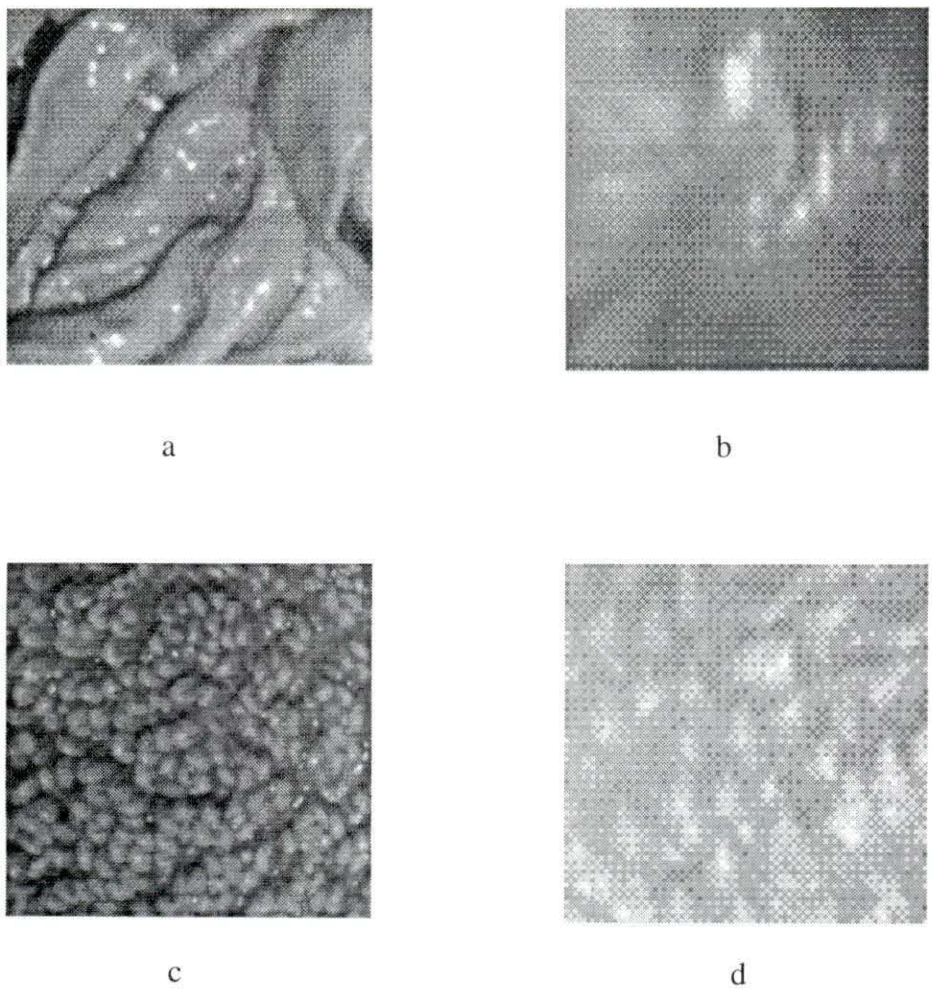
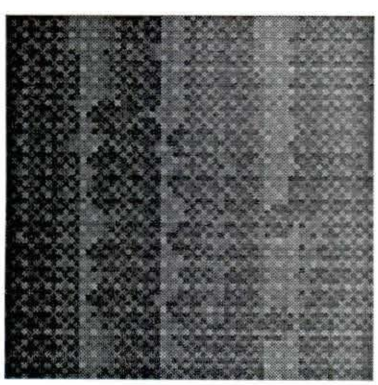
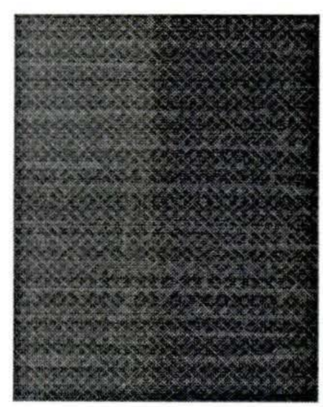


Figure 23. Photographs of the stomach wall of a sheep. a) the internal wall of the abomasum, b) the extenal wall of the rumen, c) the internal wall of the rumen, d) the internal wall of the omasum.

Figure 24. Texture used as the inside of the reticulum. Painted by Stephanie Chamberland at EAI and modified by John Walker at the Iowa State University Visulization Laboratory

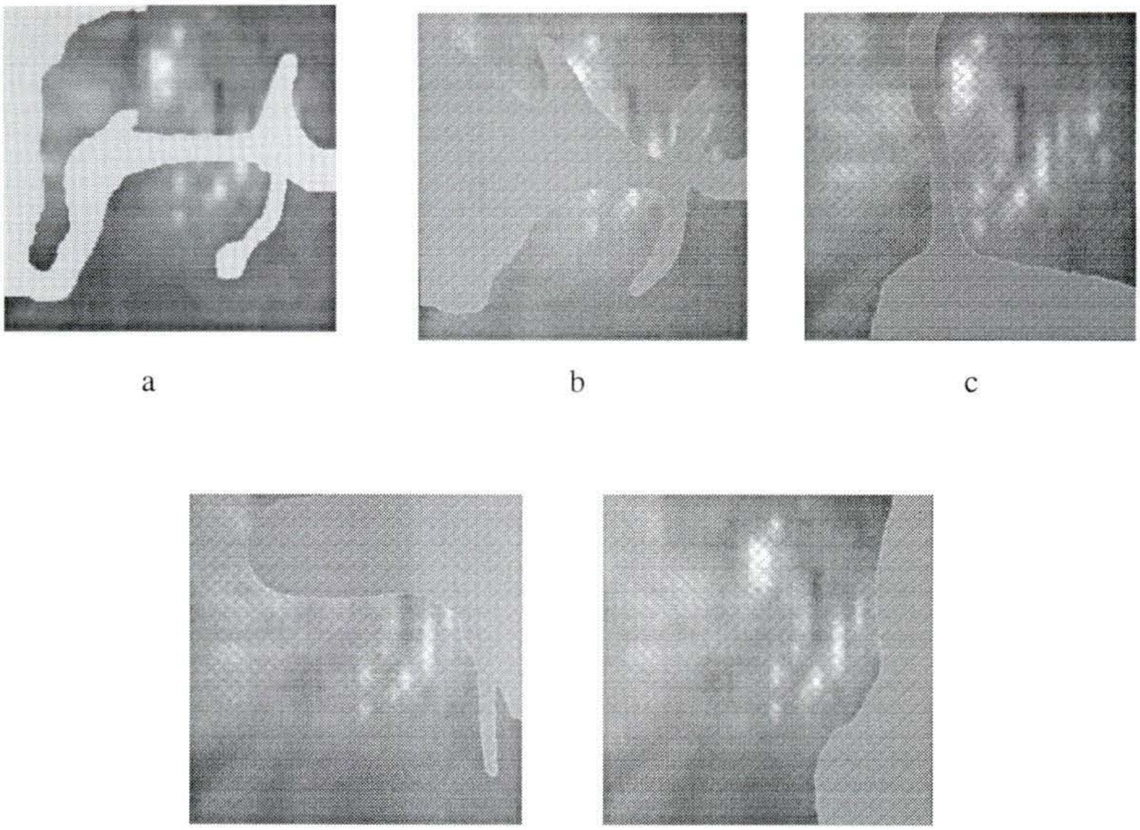


a



b

Figure 25. Texture a was used to give the tail a hair-like appearance. Texture b was used to give the hooves some character.



a b c d e

Figure 26. Textures used to create the outer surfaces of the stomach. a) Left side of the rumen, b) right side of the rumen, c) the omasum, d) the abomasum, e) the reticulum.

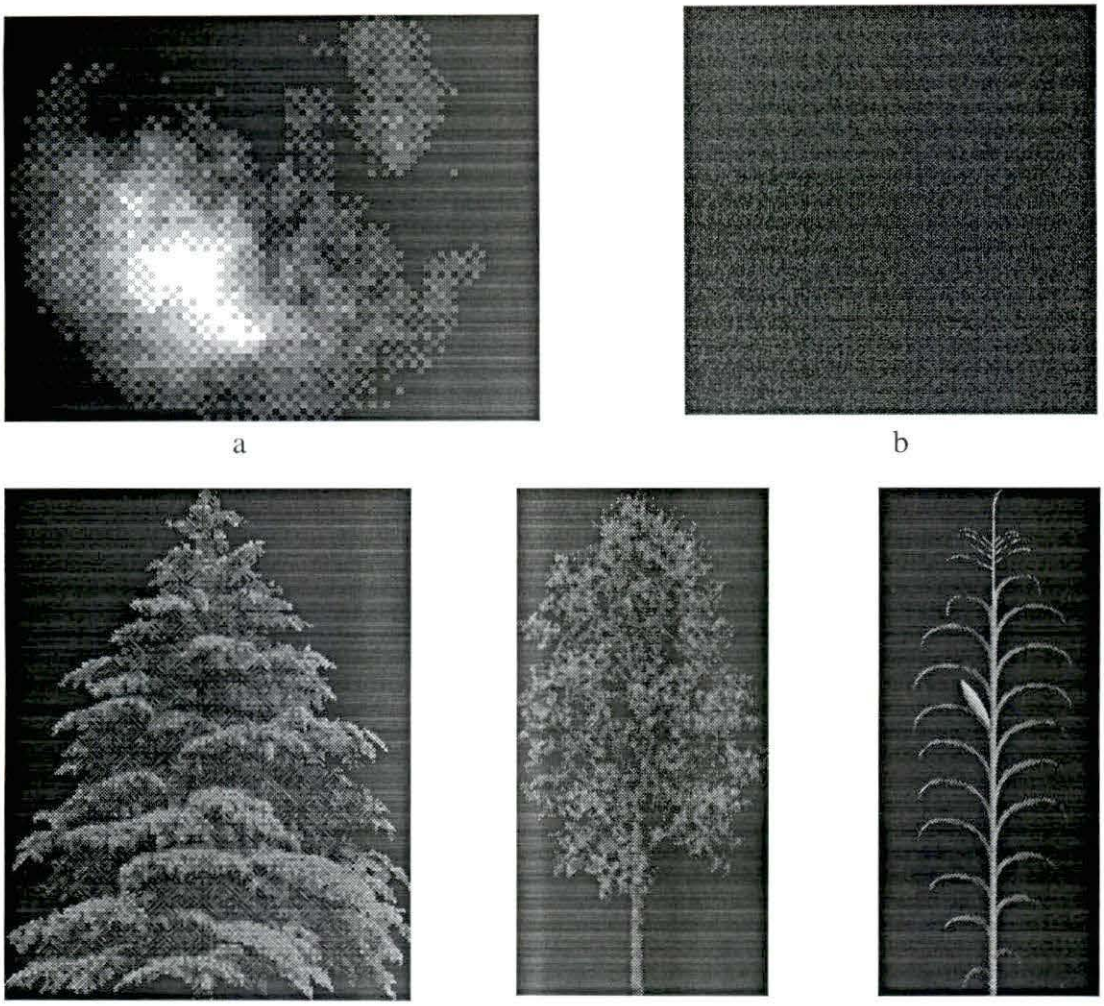


Figure 27. Environmental texture maps to a reallism to the introduction. a) Clouds, b) grass, c) pine trees, d) leafy tree, e) Jim Troy's corn plant.

Computer images detatiling the anatomical structures

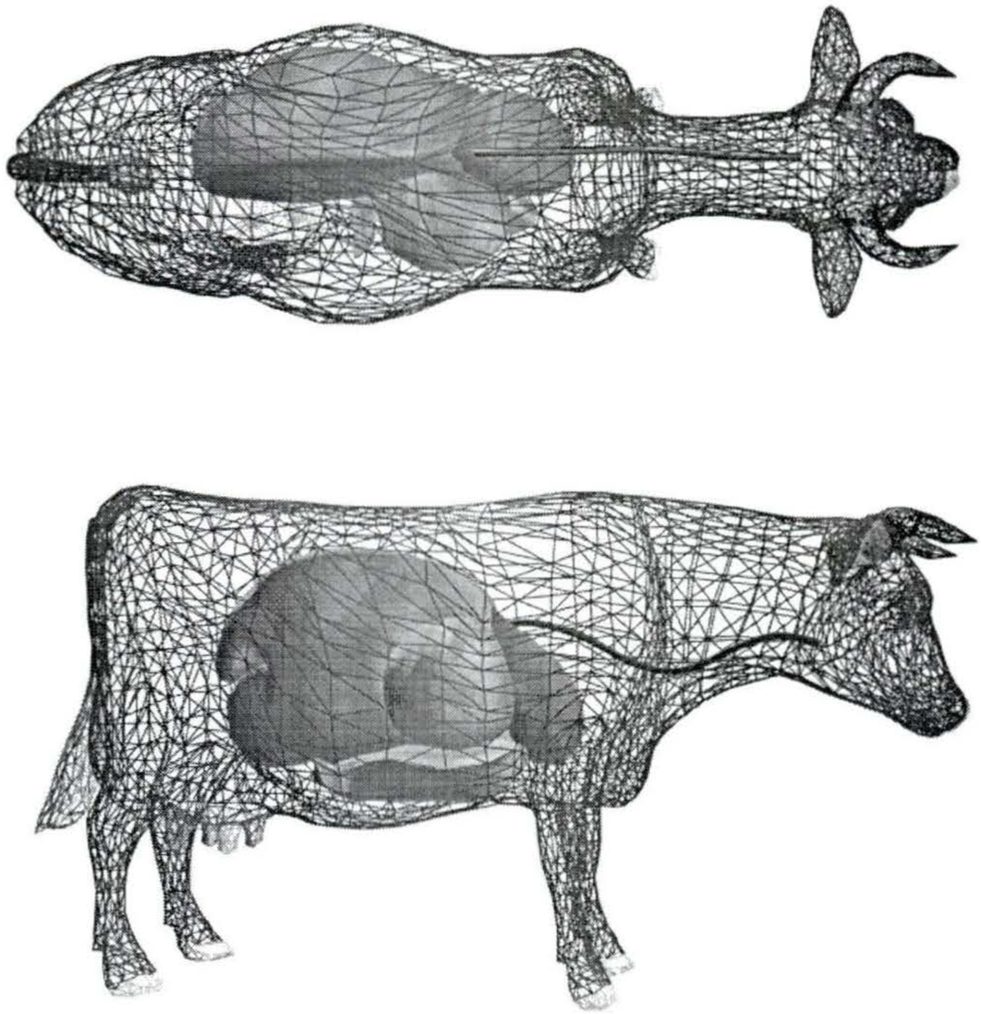
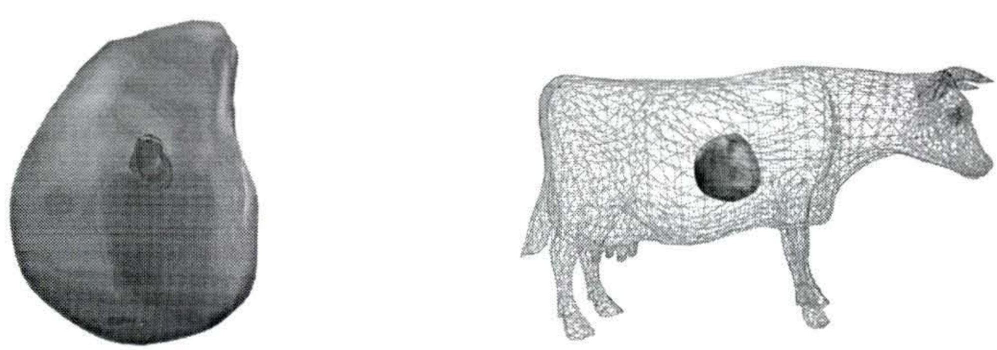


Figure 28. A view of the cow as a wireframe showing the stomach inside the body. The top picture is looking down, bottom picture is looking from the right side.

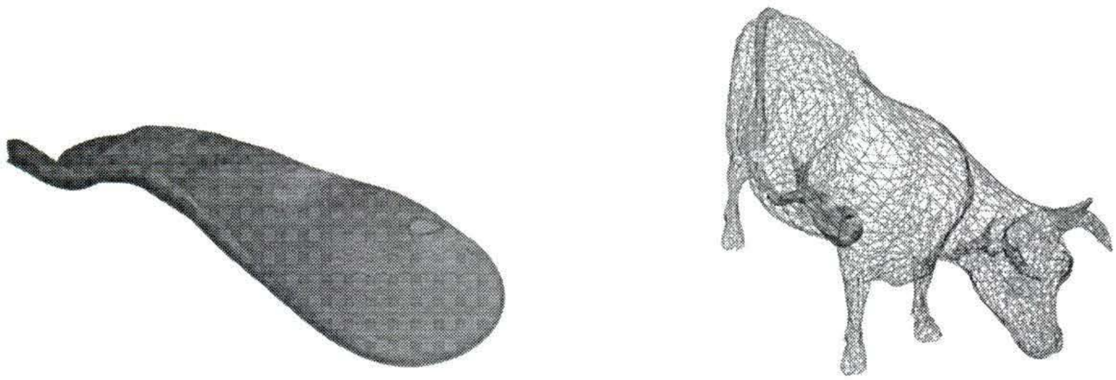
a b

Figure 29. Computer model of the reticulum. a) looking cranial to caudal along the esophagus, b) a wireframe view of the cow showing the position of the abomasum within the body



a b

Figure 30. Computer model of the omasum a) From the front, b) from the right side



a b

Figure 31. Computer model of the abomasum, a) from the front, b) isometric

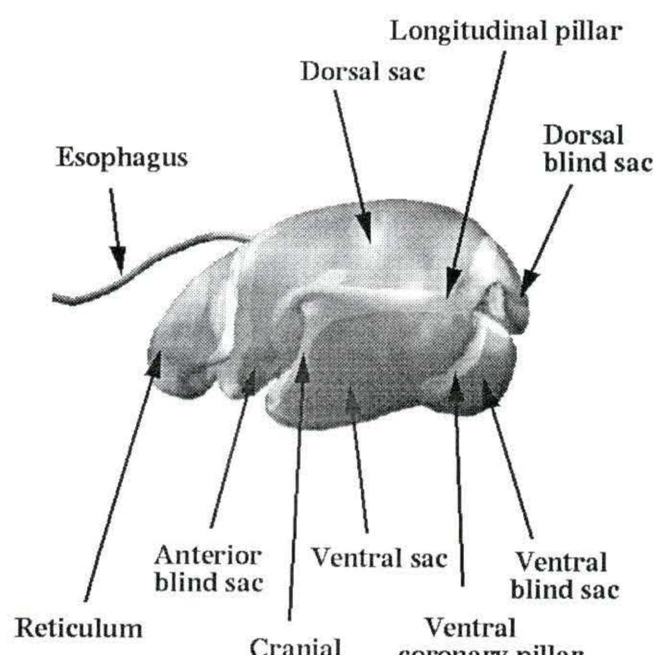


Figure 32. Computer model labeling the anatomical structures of the rumen and reticulum.

Still images from the animations

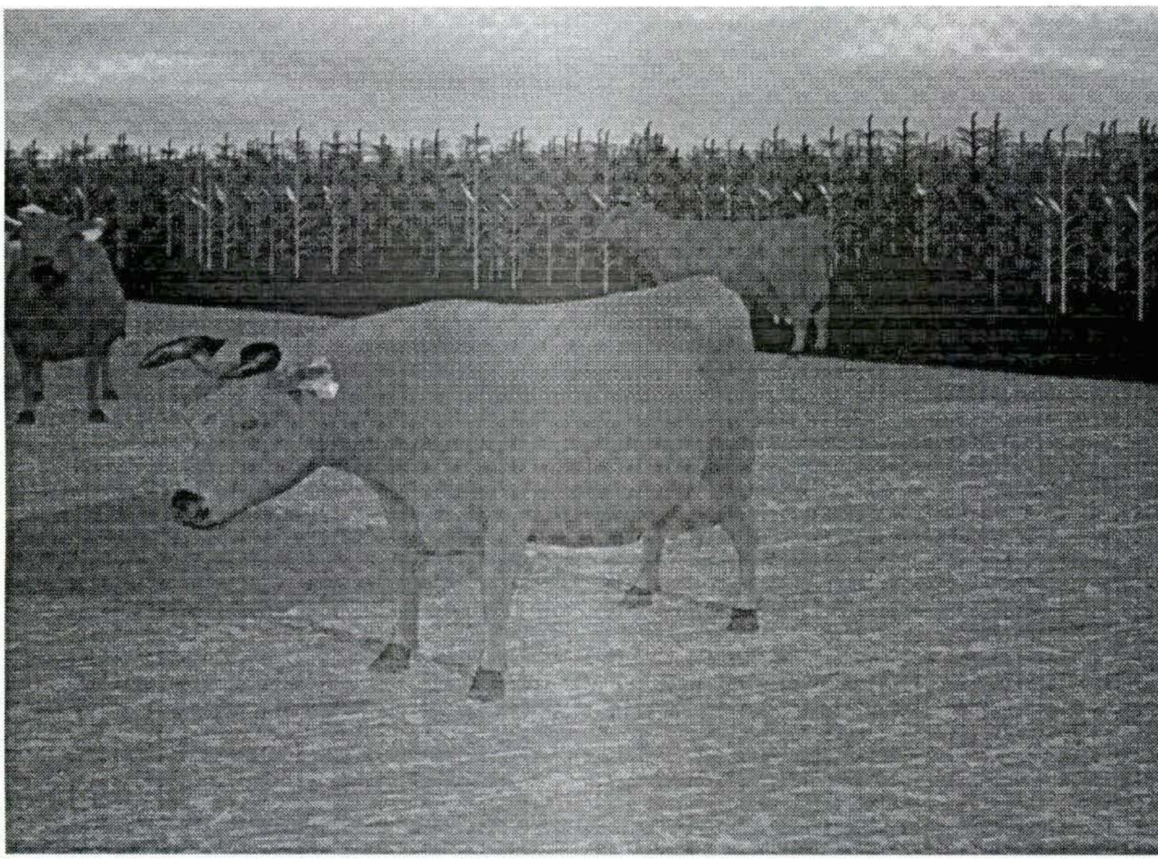


Figure 33. Computer image of the exterior of the cow during the introduction.

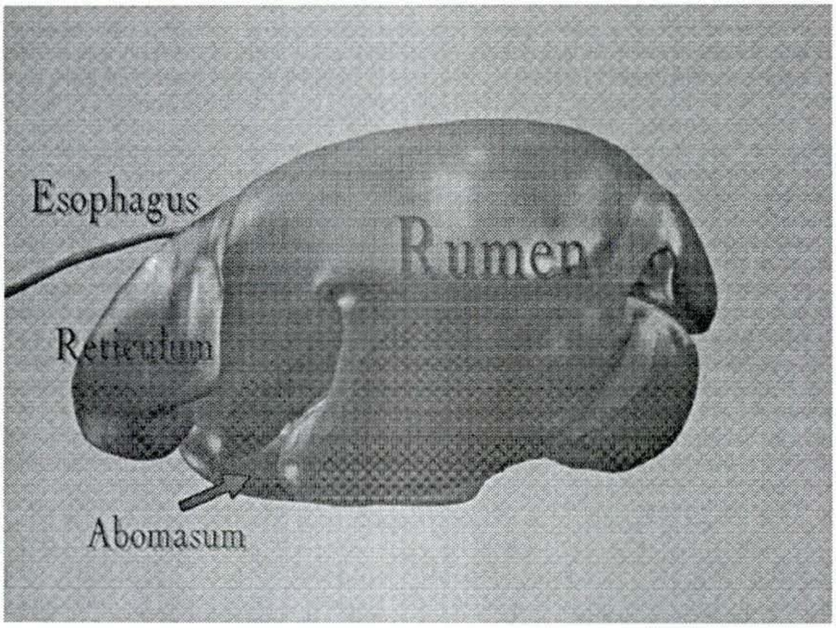


Figure 34. Computer image labeling the gross anatomy of the stomach.

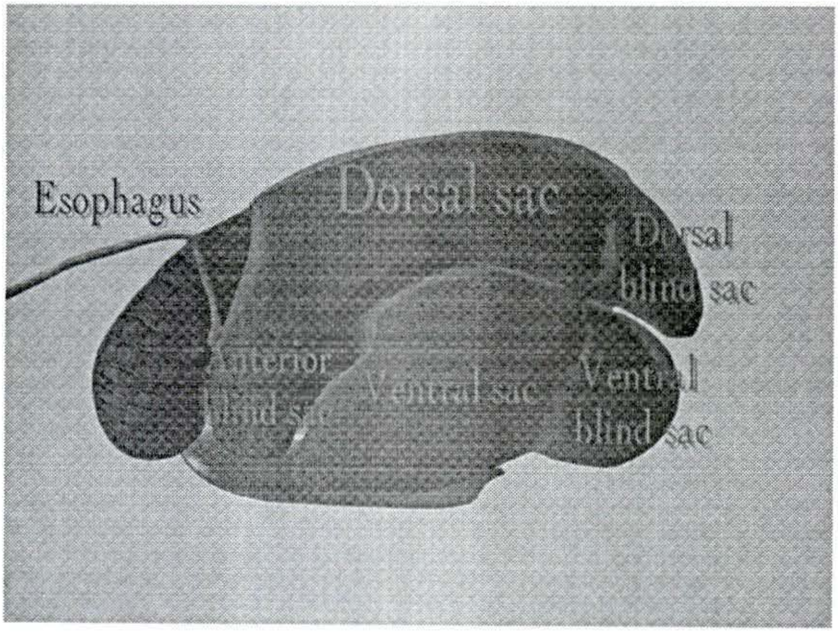


Figure 35. Computer image labeling the compartments of the stomach.

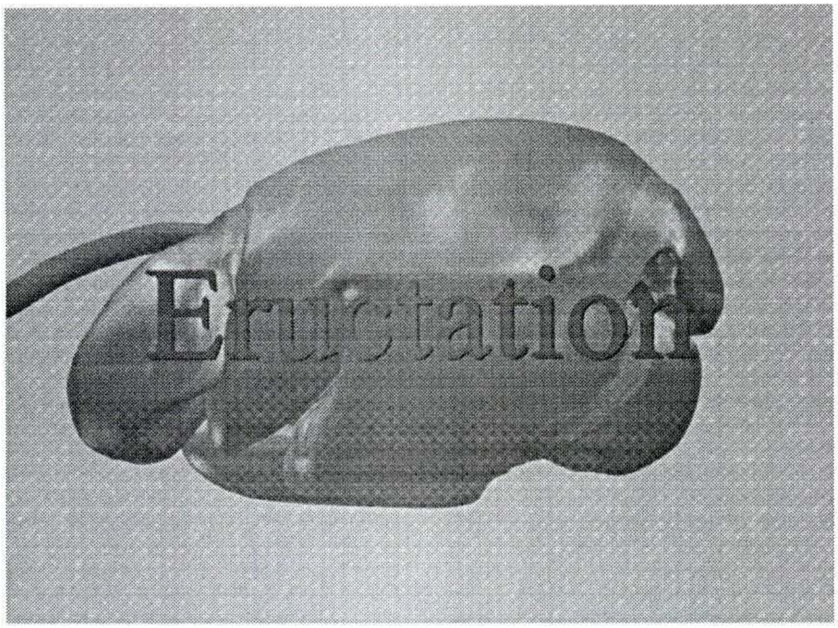


Figure 36. Scene from display of eructation showing the expansion of the esophagus.

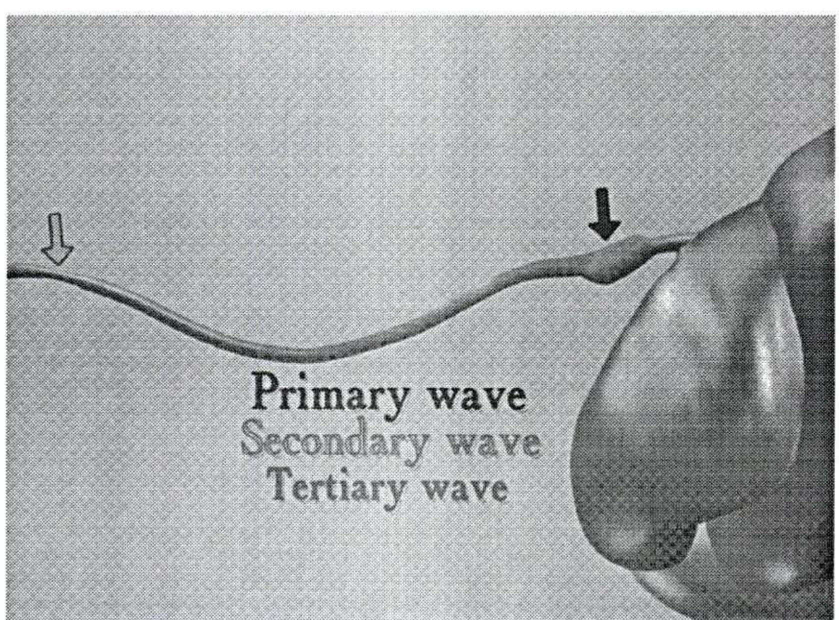


Figure 37. Scene from the explanation of peristalsys showing the primary and secondary waves.

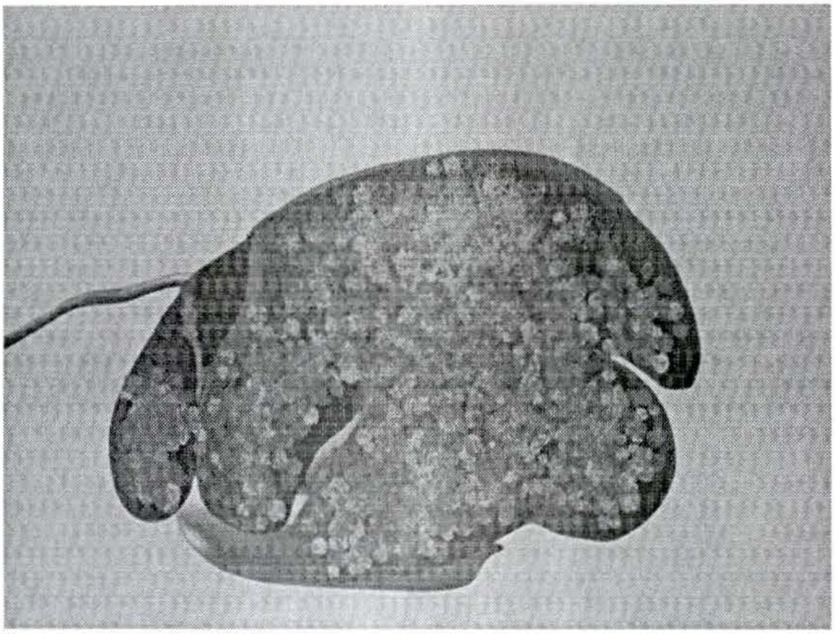


Figure 38. Computer image showing particles in the stomach.