Advanced Endoscopic Imaging: 3-D Laparoscopic Endoscopy

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Video imaging technology has significantly enhanced the performance of minimally invasive surgical procedures.[1-2] However, a major limiting factor for the endoscopic surgeon is to work in a 3-dimensional field while viewing a two-dimensional video image. Advances in electronic video imaging have resulted in satisfactory image quality[3] yet the lack of depth perception with standard 2-dimensional video system results in the surgeon having to rely on indirect evidence to assess the third dimension. To gauge depth, one may have to rely on touching the tissues with endoscopic instruments or estimate the relative movement of the instruments in relation to the intra-abdominal organs. These maneuvers result in a reduction in the speed of surgery and may cause unnecessary tissue trauma.

Recently a number of manufacturers have developed three-dimensional (3-D) video systems which significantly improve visualization and enhance the ability of the surgeon to perform delicate endoscopic dissection and suturing. These 3-D video systems may also improve the education of surgeons-in-training as they would have a better understanding of 3-dimensional anatomy during laparoscopic surgery.

We believe that 3-dimensional video imaging greatly facilitates the efficiency of endoscopic reconstructive procedures and is a valuable adjunct to performance of minimally invasive surgical procedures. In this monograph, we will provide an overview of stereo imaging, describe the basic components of 3-

dimensional video endoscopy and compare various 3-D systems in current use.

PRINCIPLES OF 3-DIMENSIONAL STEREOENDOSCOPY

In normal human vision, depth perception is a factor take for granted. Normally, the eyes will accommodate and converge in such a way that there is intersection of the visual axes of both eyes. This intersection is know as the point of fixation. (Figure 1) When viewed by both eyes, lateral disparity causes the viewed object to be projected in slightly different orientations on the retina of the right and left eyes. The human brain interprets this disparity on a small region of the retinal fovea (called the panum region) as depth information. The brain then fuses these images to give the perception of depth and this effect is called stereopsis.[4]

Accommodation is the ability of the human eyes to clearly visualize objects which are both near and farther away. The eyes converge and the lens increases its dioptic strength so that the object is brought into sharp focus on the retina. The nearest an object can be to the eye and still be in focus is called the near point, while the farthest it can still be in focus is called the far point. The region of depth is the area between the near and far points. (Figure 1) This ability to accommodate is preserved when viewing objects with a 3-D video system.

As noted, when viewing a particular object with binocular vision, one normally would perceive that object in three dimensions. However, if one eye was closed, one might note a "flattening" of the image. However, due to the capability of the image center within the brain to capture and recall images, the viewed object may appear with somewhat limited depth (i.e., $2^1/2$ - D). This ability to visually process 2-dimensional flat images off a standard video screen and view them in a partial 3-dimensional manner may be a significant factor in the ability of experienced endoscopic surgeons to adequately perform surgical tasks. However, this innate ability to perceive standard flat video images in three dimensions is significantly reduced when the surgeon is confronted with a scene which has not been viewed before. Therefore, the introduction of 3-dimensional video systems should facilitate the performance of endoscopic surgical procedures, especially those which require intricate dissection or reconstructive

Name of Manufacturer	Type of Laparoscope	Size of Laparoscope	3-D Display	2 Head Stereo Camera
Richard Wolf Medical Inst. Inc.	Dual Lens System	10mm	Active Glasses	Yes
American Surgical Technologies	Dual Lens System	10mm	Passive Glasses	Yes
Carl Zeiss, Inc.	Single Lens system	10mm	Active glasses	Yes
International Telepresence Corp.	Standard endoscope (Universal Adaptor)	Any size	Active Glasses	Yes

Table 1.

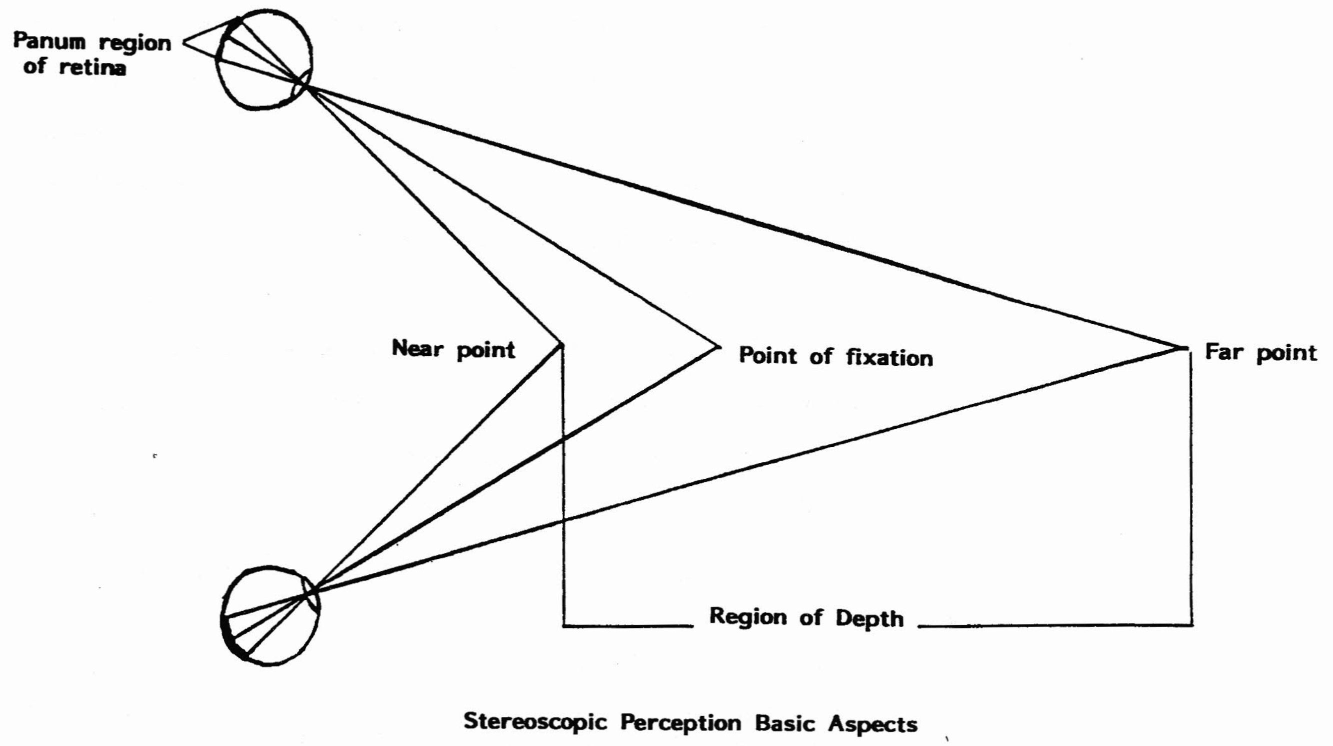

Figure 1. The basic aspects of stereoscopic vision in humans. The region of depth is defined as the distance between the near and far points of focus.

techniques.

To mimic normal 3-D vision, a 3-dimensional video system must therefore convey separate off-set images to each eye. The figure is captured in a slightly different orientation by the stereoendoscope and after image processing by the brain, it appears as a 3-dimensional object. (Figure 2) Any 3-D video system must therefore incorporate the principles of stereopsis.[4-5] One potential limiting factor of 3-D endoscopic systems is that the normal interpupillary distance for human vision is approximately 60 mm, while the maximum separation of 2 objective lenses in a 10 mm laparoscope is approximately 8 mm. However, various endoscopic designs have accounted for this disparity, still allowing for adequate capture and display of 3-dimensional images.

STEREOENDOSCOPIC IMAGE PROCESSING

Most of the 3-dimensional stereoendoscopic video systems currently available in the United States have four basic principles of stereoendoscopic image processing in common: image capture, conversion of 60 Hertz (Hz) to 120 Hz images; presentation of left and right images on a single monitor; and separation of the left and right eye images. While the components of the various 3-D video systems may differ slightly, they each contain the same basic principles. The following sections will describe in more detail current stereoendoscopic equipment utilized for 3-dimensional endoscopic surgery. (Table 1)

Stereo Laparoscope

Stereo laparoscopes are of two basic designs: a two-lens optical system (American Surgical Technologies and Richard Wolf Medical Instruments, Inc.) or a single optical channel (Carl Zeiss, Inc.). (Figure 3) The duel-lens systems individually capture slightly different images of the operating field much like the right and left eye will capture slightly different views of a single image. The parallel optical channels then present the separate images to the left and right-eye camera systems. (Figure 4)

In contrast, the single optical channel design captures the image with a single objective lens at the distal end of the endoscope. (Figure 3) At the proximal end of the endoscope, adjacent to the stereo camera, the image is split into separate left and right eye images. One advantage of this single optical channel

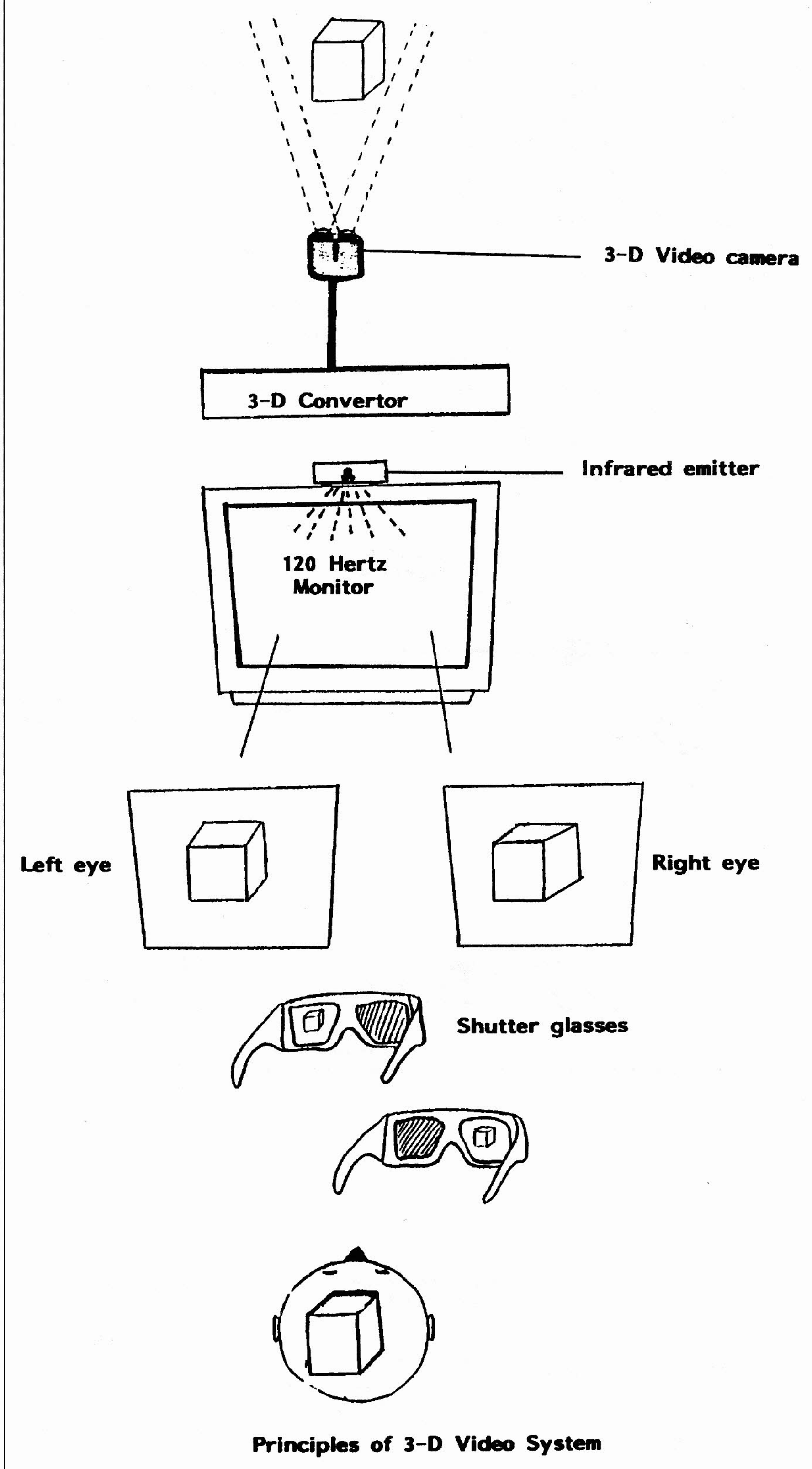

Figure 2. Demonstration of stereoendoscopic image processing after image capture by a 2 head camera. The image is "seen" in slightly different orientations by the left and right eye cameras. The different views are displayed alternately on the 3-dimensional video monitor after passing through the 3-D conversion processor. When viewed with "active" shutter glasses, the left eye receives information from the left camera and the right eye image is seen by the right eye. The image center of the brain processes this information as depth perception.

design may be higher resolution and more light for the 3-dimensional video image than presented by the smaller optical systems contained in the duel optical channel endoscopes.

One final design uses a standard single channel endoscope but provides a "universal optical converter" to produce a 3-dimensional video image (International Telepresence Corporation). This design has the significant advantage of not requiring a stand-alone endoscope which must be used to capture 3-dimensional images, but can be utilized with any available endoscope, no matter what the scope diameter.[5] However, some question the true 3-dimensional nature of this 3-D video image.

Image Splitter

The single-channel 3-dimensional video systems utilize a device to split the images captured by the left and right half of the single lens endoscopes. In some systems, (Carl Zeiss, Inc.) the image splitter is incorporated into the proximal end of the single channel stereo endoscope. (Figure 5) However, as noted previously, the International Telepresence System utilizes a stand-alone image splitter which may be attached to any available endoscope.

Stereo Camera

Most 3-D video systems contain a stereo camera head which incorporates two separate CCD image sensors (usually 1/2 inch CCD chips) which capture the images from the stereo laparoscope. These images from the stereo laparoscope are viewed by the left and right eye cameras, just as two separate images are presented to the left and right eyes during normal binocular vision.

Three-Dimensional Image Processing

Most 3-dimensional video systems contain a 3-D conversion unit which processes the images obtained from the left and right eye cameras. These conversion systems allow the left and right eye images to be synchronized alternatively at 120 Hz (60 Hz for each eye). (Figure 6) If the images are presented slower than 120 Hz, one may notice substantial "flicker" on the video monitor. Moreover, slower speeds of video display may also cause vertigo.

In addition, some 3-dimensional image processing units allow recording

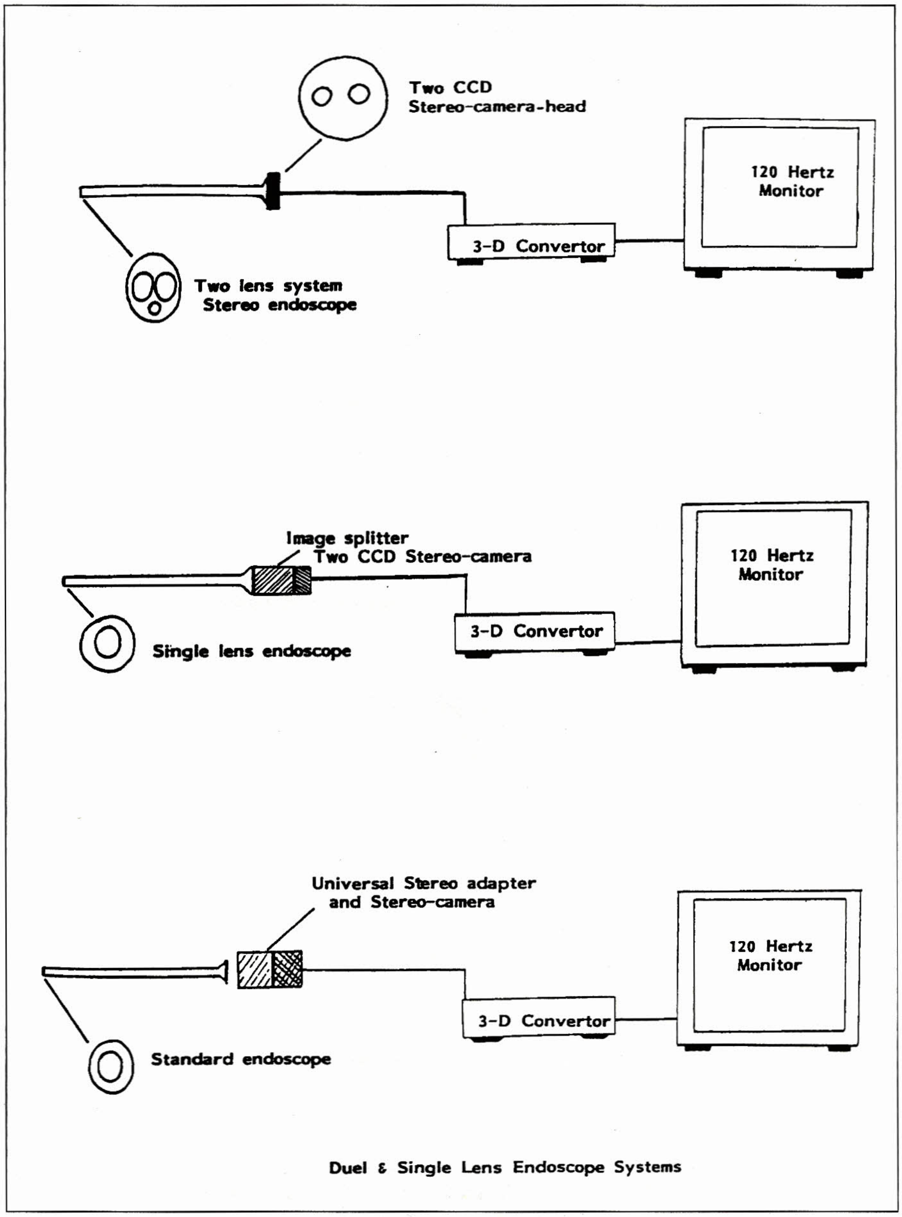

Figure 3. Three different designs of stereoendoscopic systems. The systems vary mainly with regards to the stereoendoscope: a 2 lens scope, a single channel scope with 3-dimensional conversion or a "universal" stereoadaptor which fits any standard endoscope.

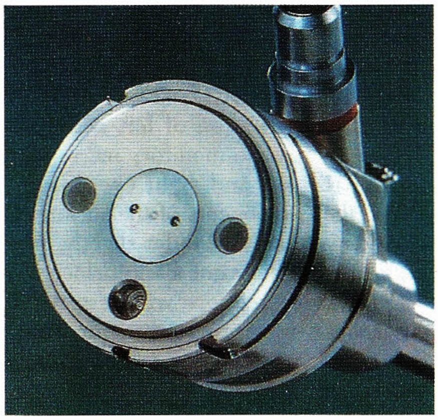

Figure 4. Close up view of proximal end of a 2 lens stereoendoscope. Note the two optical channels and single light channel. (Richard Wolf Medical Instruments, Vernon Hills, IL.)

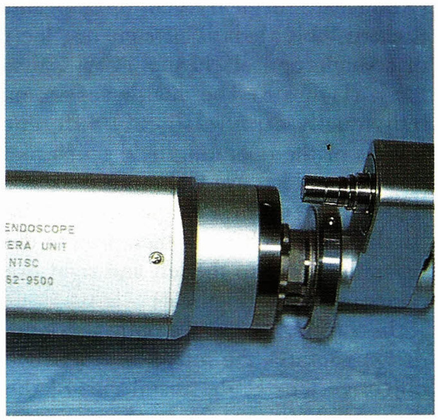

Figure 5. View of proximal end of stereoendoscope which contains an "image splitter." The left and right eye images are then coupled with the left and right eye CCD chips, in the stereo camera head. (Carl Zeiss, Inc., Thornwood, NY)

of 3-D video images on a single video tape (Richard Wolf Medical Instruments, Inc.). The left and right eye images are stored on a single "video frame" which greatly simplifies the recording, playback and editing of 3-dimensional endoscopic images. However, the image processing unit and standard 3-dimensional video monitor are both necessary to view the previously recorded endoscopic images.

The 3-D video conversion systems will allow viewing of live 3-dimensional procedures, recording of surgical cases in 3-dimensions with subsequent playback of these cases in 3-dimensions. While initial 3-D video systems recorded left and right eye images on separate video recorders, current systems can capture both the left and right images on a single video tape.

Three-Dimensional Display

The 3-dimensional conversion system will sequentially display the left and right eye images on the 120 Hz 3-D video monitor. However, in order to view the left and right eye images on a single monitor, the images must be separated. (Figure 7) One method involves "active" liquid crystal display (LCD) shutter glasses. These glasses are synchronized by an infrared emitter which is located on top of the video monitor. As the left-eye image is projected on the video screen, the emitter will control the shutter glasses so that the right eye is closed and left eye open. (Figure 8) Alternatively, when the right eye is open, the left side of the LCD glasses is blackened and the right eye image appears on the video screen. The advantage of this active system is that more light is projected to each eye and therefore the 3-D image appears brighter. However, the active LCD shutter glasses require a battery, are somewhat heavy and quite expensive (approximately $1,000.00).

Alternatively, "passive" polarized glasses may be worn to view the left and right eye images from the single video monitor. This type of system requires a special polarizing filter on the video screen which will "rotate" the left and right eye images in different directions thereby allowing viewing of the left and right images alternatively. (Figure 7) The passive polarized glasses have the advantage of significantly cheaper cost than the active LCD shutter glasses and are more comfortable to wear. (Figure 9) However, the polarizing glasses present a slightly darker 3-dimensional image than the active glasses.

ADVANTAGES OF 3-DIMENSIONAL VIDEOENDOSCOPY

The increased depth of field afforded by 3-dimensional endoscopic video systems facilitates intricate minimally invasive surgical procedures.[6-7] The increased depth of field allows better recognition of tissue layers and may facilitate complex maneuvers such as laparoscopic suturing or knot tying.[8] Indeed, skill tests performed assessing laparoscopic suturing and knot tying demonstrated a 25% increase in speed and accuracy of these laparoscopic tasks when utilizing a 3-dimensional video system as compared to a standard 2-dimensional endoscopic video system.[9] However, some investigators claim that 3-dimensional video systems only facilitate surgical tasks in inexperienced laparoscopic surgeons. It

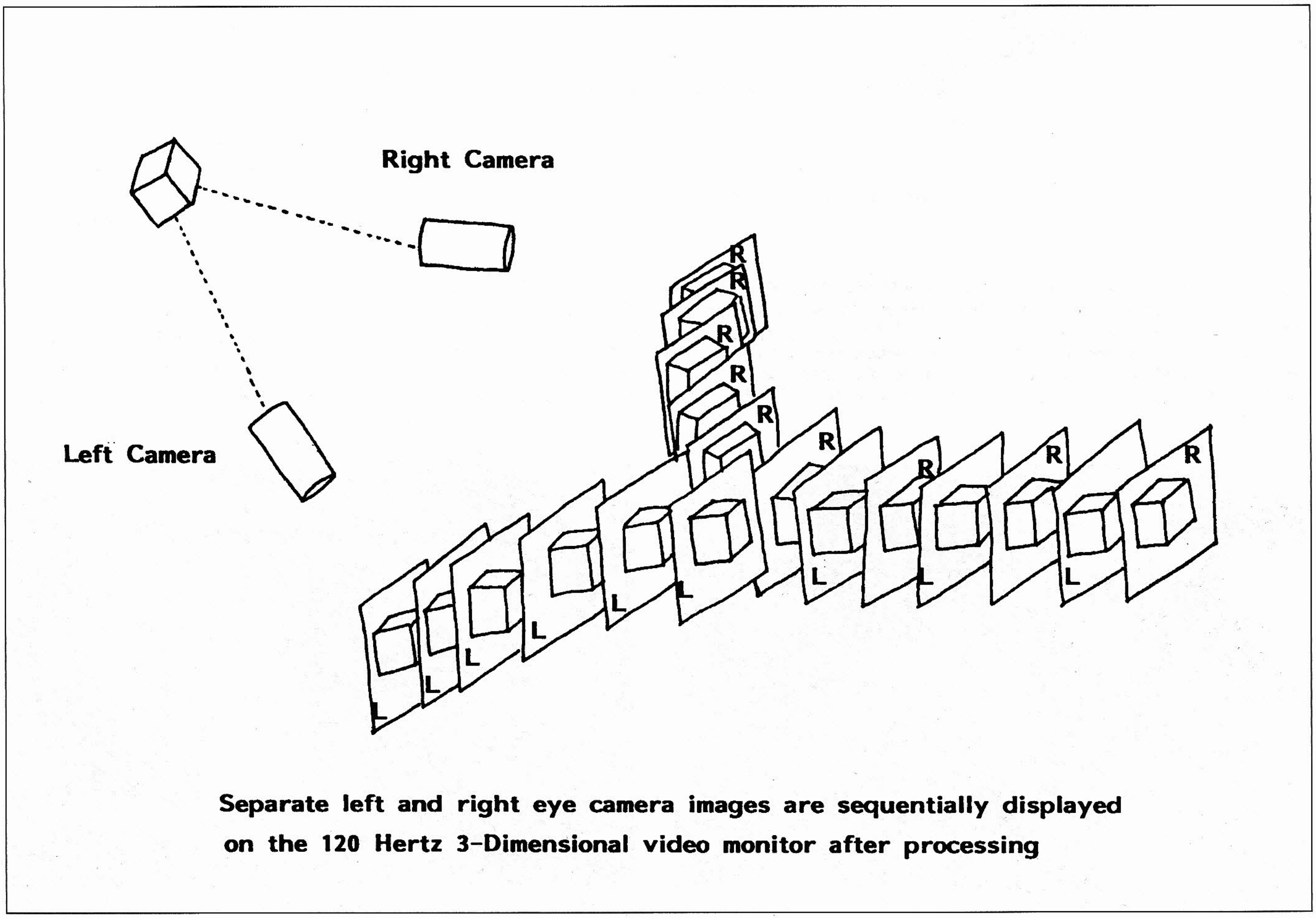

Figure 6. Graphic representation of 3-dimensional conversion unit which alternates the left and right eye images at 120 hertz on the 3-D video monitor.

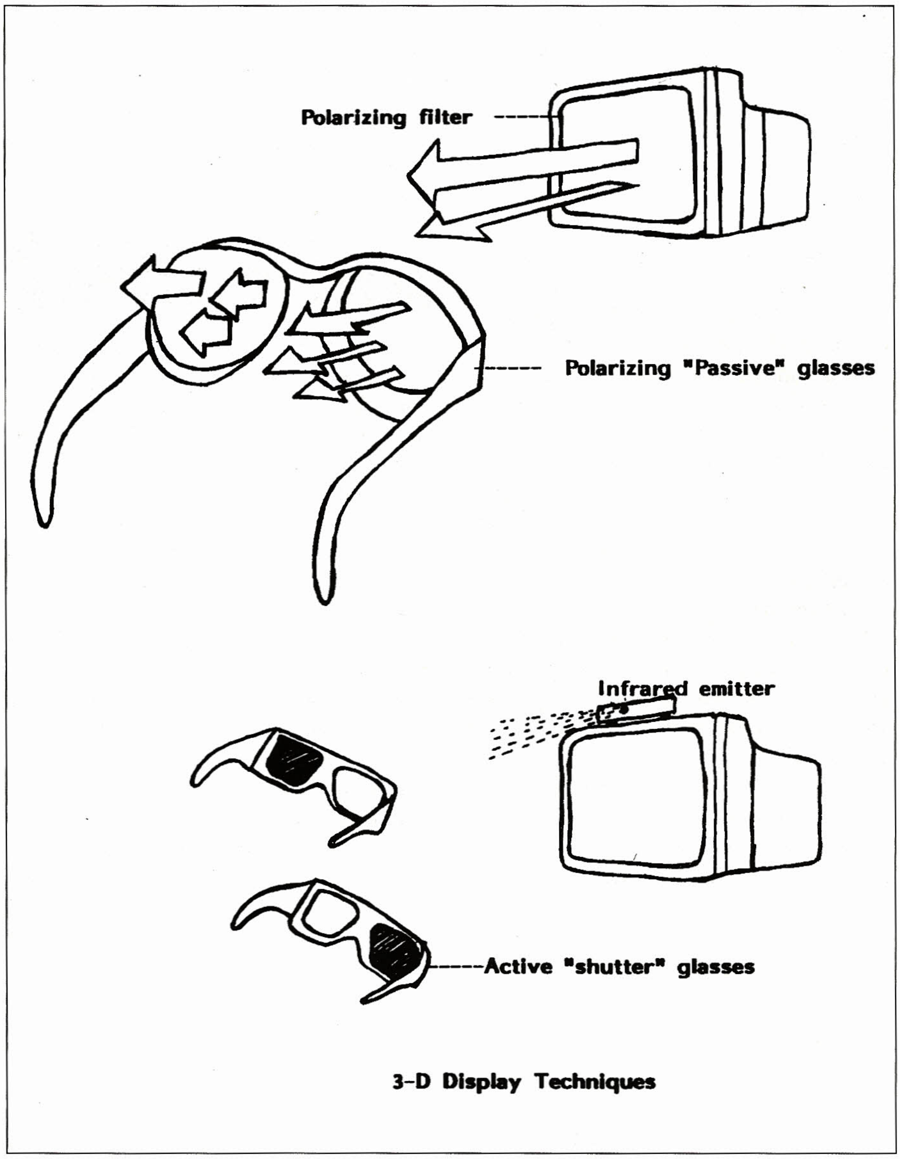

Figure 7. A. Three-dimensional video monitor with polarizing filter which splits the right and left eye images so that they have different polarity and can be viewed with passive (polarizing) glasses. The left eye receives the left camera information and the right eye receives the right camera image. B. An alternative display technique utilizes "active" shutter glasses which are synchronized by an infrared emitter. The right eye is blackened by the infrared emitter's command when left camera view is on display and one cannot see through the left eye lens when the right eye image is on the 3-D video monitor.

appears that the increased speed in performing various minimally invasive surgical procedures may be diminished in those individuals who have a large amount of experience utilizing standard 2-D video systems during endoscopic surgery.

LIMITATIONS OF 3-D IMAGING SYSTEMS

Current 3-D video endoscopic systems provide greatly improved 3-dimensional viewing of minimally invasive surgical procedures as compared to the initial 3-D components. Yet, current 3-D video systems still provide reduced resolution and lower light images as compared to standard single chip or 3-chip 2-dimensional video cameras. The decrease in image brightness and resolution is due to the fact that most 3-dimensional video systems utilize two optical channels which are significantly smaller than a single lens system in a standard 10 mm laparoscope. Moreover, since most 3-dimensional video systems incorporate two separate camera systems, the camera head is significantly larger than a single camera system and therefore more cumbersome to work with during minimally invasive surgical procedures.

Cost continues to be a limitation of 3-dimensional video endoscopy. Most 3-D video systems are 2-3 times more expensive than standard 2-dimensional endoscopic video cameras. Moreover, except for the International Telepresence System which utilizes a 3-dimensional endoscopic coupler, most 3-dimensional video systems are stand-alone units and therefore cannot be utilized with other endoscopic equipment.

Figure 8. Shutter glasses being used with an "active" 3-dimensional display system.

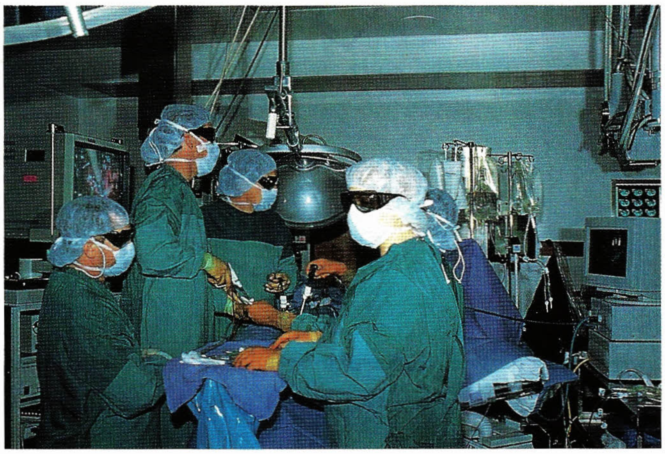

Figure 9. "Passive" polarized glasses may be used with systems that employ a polarizing filter on the video monitor.

CONCLUSIONS

While 3-dimensional video imaging systems are more costly than conventional 2 dimensional video equipment, the enhanced depth perception produced by 3-D endoscopes has been demonstrated to improve the performance of minimally invasive surgical procedures. Three-dimensional imaging also facilitates the training of minimally invasive surgery and may lessen the learning curve of these technically demanding procedures. It is anticipated that 3-dimensional video imaging will significantly improve the performance of current laparoscopic procedures as well as facilitate the development of more advanced minimally invasive surgical techniques. STI

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