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Three-Dimensional Microscopic Surgical Videos: A Novel and Low-cost System

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■ INTRODUCTION: Three-dimensional (3D) imaging and videos are a very useful tool in the neurosurgical training, although unfortunately the 3D systems available have a very high cost. The objective of this study is to describe a novel and low-cost 3D microsurgical video system.

■ METHODS: To obtain the 3D videos we use a surgical microscope, 2 video adapters, 2 cameras, and an HDMI cable. A video editor program is used for processing the videos. For the projection we use a computer with PowerPoint (Microsoft, Inc, Redmond, WA) software, a video splitter, DVI cables, 2 projectors, 2 polarization filters, and a "silver screen" with polarized glasses.

■ RESULTS: By using 2 equal cameras and video adaptors in each beam splitter port it was possible for us to obtain 2 videos that were equivalent to the images received by both surgeon's eyes. Using the video signal of both cameras during processing resulted in a 3D stereoscopic recording with Final Cut (Apple, Inc, Cupertino, CA) software. The polarized 3D format provided the best projection conditions. It does not alter the original colors of the videos and its prolonged visualization was more comfortable. The main advantage of this method is the ability to show in a realistic way the spatial relationships and the depth of the structures captured with the microscope.

■ CONCLUSIONS: This paper presents in a clear and detailed way how to create and use a low-cost 3D surgical video system.

INTRODUCTION

Three-dimensional (3D) imaging and videos are a useful tool in neurosurgical training.[1] Unfortunately, available 3D systems have a very high cost. They also work with sophisticated expensive technology. These 2 factors represent a difficult expenditure to face for an educational institution. If we extrapolate this to developing countries, it is easy to think that future neurosurgeons will be educated without 3D microsurgical videos.

Our team in Argentina believes that a neurosurgeon must be trained with standards of excellence, regardless of the economic condition of their context. For this purpose, we devised a low-cost system to obtain, process, and project high-quality microsurgical 3D videos.

The aim of this paper is to describe this novel and low-cost 3D microsurgical video system.

METHODS

To create the 3D microsurgical video system we use, according to each stage:

1) Acquisition technique: OPMI surgical microscope (Carl Zeiss, Oberkochen, Germany), 2 video adapters with a focal length of 125 mm, 2 Micro Cinema cameras: 1920 x 1080, 1080p24 fps (Blackmagic Design, Port Melbourne, Australia) and an HDMI cable.

Each camera is connected to 2 equal arms of the microscope and these are connected laterally in each of the 2 inputs of the beam splitter.

2) Processing technique: Final Cut Pro X program (FCPX; Apple Inc, Cupertino, CA). This editing software is used for

Key words
- Microsurgery
- Neurosurgical teaching
- Surgical anatomy
- Three-dimensional videos

Abbreviations and Acronyms
3D: Three-dimensional
FCPX: Final Cut Pro X
TV: Television

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correcting the alignment and degree of video rotation, in addition to allowing the 2 videos to play synchronously.

3) Projection technique: MacBook Pro (Apple, Inc); PowerPoint software (Microsoft, Redmond, WA); Digital DualHead2Go card (Matrox, Harefield, UK), 2 separated DVI cables, 2 projectors (1024× 768, 4500 lumens, 4:3; Vivitek D945VX, Delta Electronics, Zandsteen, The Netherlands), polarization filters, "silver screens", and polarized glasses.

For the polarized projection technique, we connect the computer to a splitter and each video is projected simultaneously, filtered and superimposed. We use linear polarized filters and passive low-cost lenses to receive the 3D image.
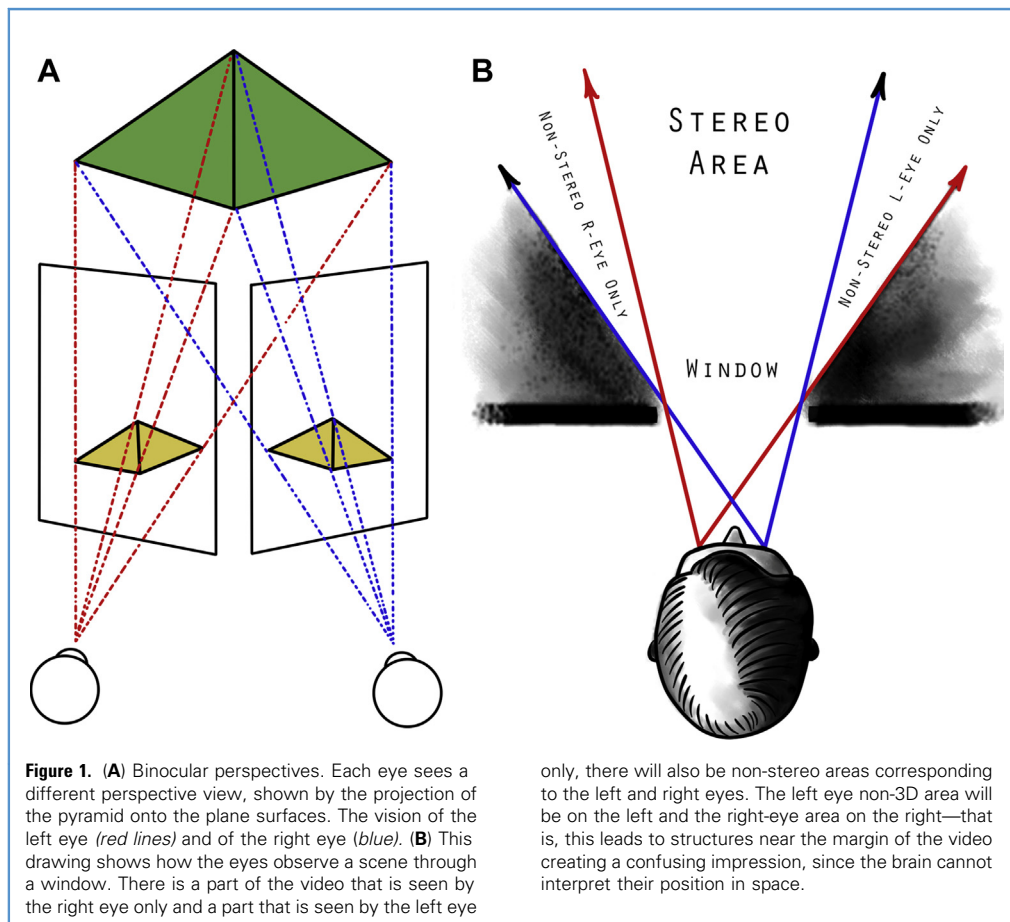
RESULTS

Our report is divided into 3 parts to describe the technique: (1) acquisition, (2) processing, and (3) projecting of 3D microsurgical videos.

Acquisition Technique

For a 3D video we must present 2 videos with different perspective viewpoints,[2] destined to the left and right eyes of the viewer, just as the viewer sees the visual world (Figures 1A, 1B). From these 2 slightly different views, the eye—brain synthesizes an image of the world with stereoscopic depth.[3] An option to obtain 3D images is to take a picture of each side using a bar where the camera slides, but this is not possible for videos because they are dynamic sequences.

Fortunately, the surgical microscope is an optical instrument that provides the surgeon a stereoscopic magnified image with high quality and lighting. The basic components of a microscope are: a lens called *objective* where the surgical image enters, a magnification chamber that provides the magnification of the image, and a binocular head that directs and focus the image towards the surgeon's eyes. Before the image reaches the surgeon's binocular there is a circular piece called a *beam splitter*. This structure takes a sample of the images going to the eyes of the surgeon, dividing the vision of the surgical field into a right and left angle. The beam splitter has 2 lateral entrances (Figure 2). One of these entries is generally used to place an assistant surgeon's viewer and the other to install a photo camera or video camera. Only the eyepiece of the surgeon obtains a binocular 3D stereo vision, since the assistant surgeon or the camera only observes the right or left image. Each of these separate images are not binocular. No matter the interpupillary distance of each
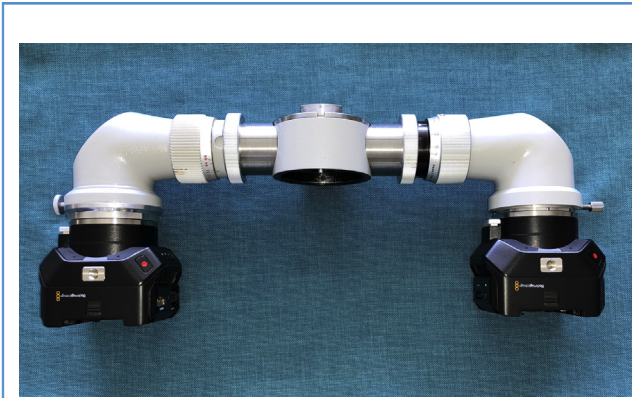

Figure 1. (**A**) Binocular perspectives. Each eye sees a different perspective view, shown by the projection of the pyramid onto the plane surfaces. The vision of the left eye *(red lines)* and of the right eye *(blue)*. (**B**) This drawing shows how the eyes observe a scene through a window. There is a part of the video that is seen by the right eye only and a part that is seen by the left eye only, there will also be non-stereo areas corresponding to the left and right eyes. The left eye non-3D area will be on the left and the right-eye area on the right—that is, this leads to structures near the margin of the video creating a confusing impression, since the brain cannot interpret their position in space.

Figure 2. The main components of the system for obtaining and recording 3D microsurgical videos. It is composed in the center by an Carl Ziess 50T surgical microscope beam image splitter, laterally 2 equal arms Carl Zeiss F 137 adapted each to Blackmagic micro cinema camera.
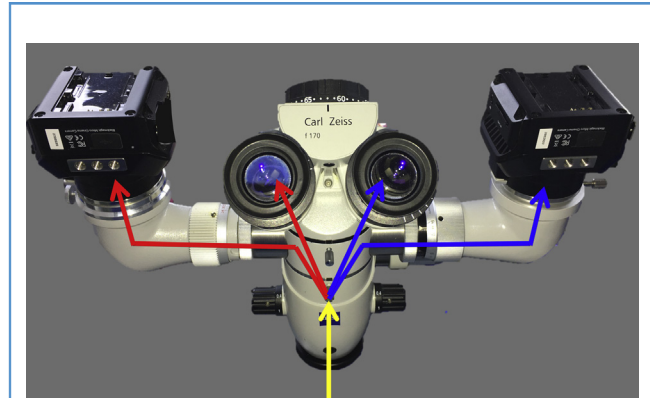

Figure 3. Microsurgical video recording system in 3 dimensions on the microscope. The *yellow arrow* represents the entrance of the image that reaches the image splitter, it is there that this image acquires 3-dimensionality when offered to the right and left eye from a different angle of vision. In this way the vision from a left angle (*red arrows*) is recorded with the left camera and the surgical video that is observed with the right eye (*blue arrows*) is recorded with the right camera.

surgeon, the stereoscopic 3D perception is the same as it only depends on the distance of the path of the left and right images.

By using 2 equal cameras and video adaptors in each beam splitter port, it is possible to obtain 2 images equivalent to those received by both eyes of the surgeon. Using the video signal of both cameras, it is possible to process them to obtain a 3D stereoscopic recording (Figure 2).

Our setup was implemented on a OPMI surgical microscope with a 50% beam splitter, 2 video adapters with a focal length of 125 mm, and 2 Blackmagic cameras.

The complete system is illustrated in Figures 3 and 4, showing with arrows the path of the image as it enters the system up to the image splitter, where it is divided and captured by each camera.

When the system is ready in the operating room, the first step is to connect one of the cameras to a television with the HDMI cable. You must place an object under the lens and manually focus until you see a perfect image on the television (TV) screen. Without moving the microscope, an adequate image must be obtained in each lens of the surgeon's binocular vision. Both cameras must have the same exact setup, so that both videos have the same light, brightness, and contrast. This is achieved by establishing the codec, dynamic range, frame range, ISO, and shutter angle equally in both Blackmagic cameras. The arm of each camera also has a part for the control of the diaphragm, allowing the user to increase or decrease the entrance of the light externally. The 2 diaphragms must be set to the same aperture, because any variation results in a difference in brightness between the videos that will need to be corrected in post-production.
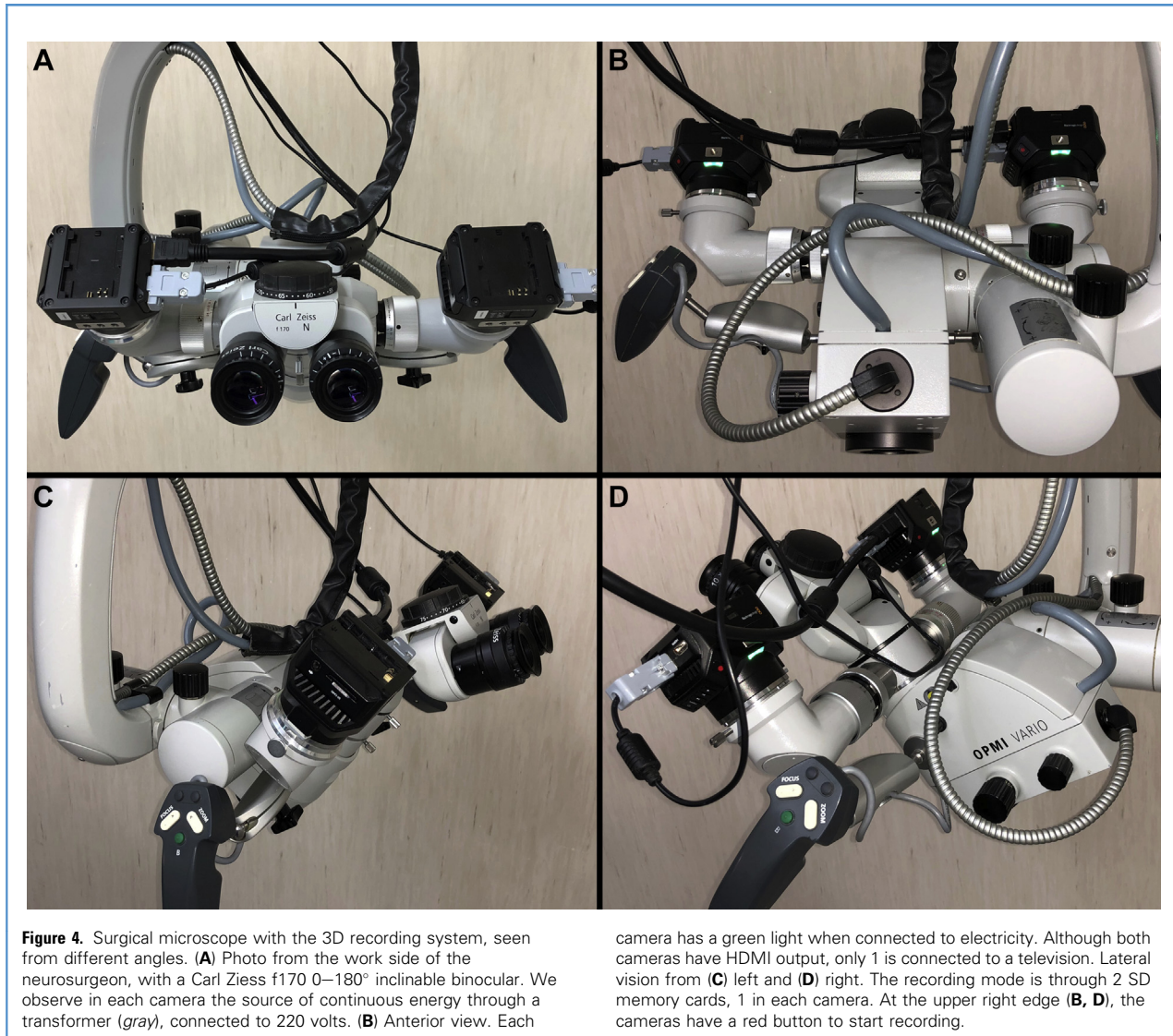
It is important to note that the alignment of both cameras is essential for easy editing. There are 3 basic ways to achieve this. The first is by means of equipment called a 3D multiplexer. These systems are rare and expensive. To use a 3D multiplexer it is also required to have a 3D TV inside the operating room. These systems merge the images of the 2 cameras and convert them into a 3D image to be seen on a regular 3D TV. The second option is to use multiplexer software. This software can be installed in any computer. The 2 images have to be digitized and captured into the

computer. The multiplexer software will create a 3D video that can be anaglyph, which in turn can be seen with regular blue/red glasses. The final low-cost option, and easy to replicate, is to draw a grid on transparent paper, cellophane, or acetate and then stick the paper over the TV. The first camera can be aligned with the paper and then the other camera can be connected to the TV and aligned.

When the microscope is already on the surgical field and covered by the sterile bag, the 2 record buttons of the cameras must be pressed at the same time. When starting the recording, the color of the upper light of the cameras changes from green to red—it is important to note this in both cameras because only one projects on the television. To facilitate the subsequent calibration of the 2 videos we clap our hands, which is recorded with a peak of sound in both recordings.

Processing Technique, or Post-Production

Generally the right and left videos do not always coincide in terms of the alignment and degree of rotation (cyclotorsion); they can be corrected directly with FCPX or any other editing software. In addition, although the surgeon turns on the recording in both cameras at the same time, the videos do not always coincide in synchrony. The first step is to import the right and left videos, then synchronize them with a specific function of the FCPX software. As mentioned earlier, at the beginning of the video we make a clapping noise near the cameras—this records a peak of sound at the same time. Once in the FCPX program, both videos must match the peaks of sounds to synchronize them. Another option to calibrate the videos is to look for a special point in a video, for example, the entry of a microscissor, and then look for the appearance in the other video. The next step in video editing is checking the correct alignment in the vertical and horizontal planes. For this, a grid of lines is used in both directions, having to move the videos up or down to achieve a perfect match (Figure 5). Generally, we use the coincidence of the edge of a

Figure 4. Surgical microscope with the 3D recording system, seen from different angles. (**A**) Photo from the work side of the neurosurgeon, with a Carl Ziess f170 0—180° inclinable binocular. We observe in each camera the source of continuous energy through a transformer (*gray*), connected to 220 volts. (**B**) Anterior view. Each camera has a green light when connected to electricity. Although both cameras have HDMI output, only 1 is connected to a television. Lateral vision from (**C**) left and (**D**) right. The recording mode is through 2 SD memory cards, 1 in each camera. At the upper right edge (**B, D**), the cameras have a red button to start recording.

nerve, an artery, or a suture point in each video for the alignment. Finally, we obtain a video where both (right and left) are joined and can be played as a single video (**Figure 6**).

Projection Technique
The most used methods to project stereoscopic pair of images are anaglyph and polarized methods. These are based on the same principle: projecting the picture or video considered as the left eye vision to be seen exclusively by the left eye and the same concept with the right eye.

For the projection of surgical videos in 3 dimensions we use 2 polarized modes depending on the system of emission of 3D images.

Anaglyph Method. This technique is based on the principle by which, when we use a filter of a color in a goggle eyepiece, we do not see that same color in the photographs. It nevertheless let you see its complementary colors. The most used glasses in this method are the classic blue—red (**Figure 7**). The main advantage of this technique is that it allows for the projection of images in any format—paper, computer screen, and conventional projection system—without the need for filters. The main drawback is that this method affects the quality of the images by altering their color and luminosity, causing discomfort and fatigue in prolonged visualization. This technique is not used for projection of 3D microsurgical videos because they have colors in red and blue tones.

Polarized Method. The polarized 3D format has the best projection conditions. It does not alter the original colors of the photographs and its prolonged visualization is more comfortable and causes
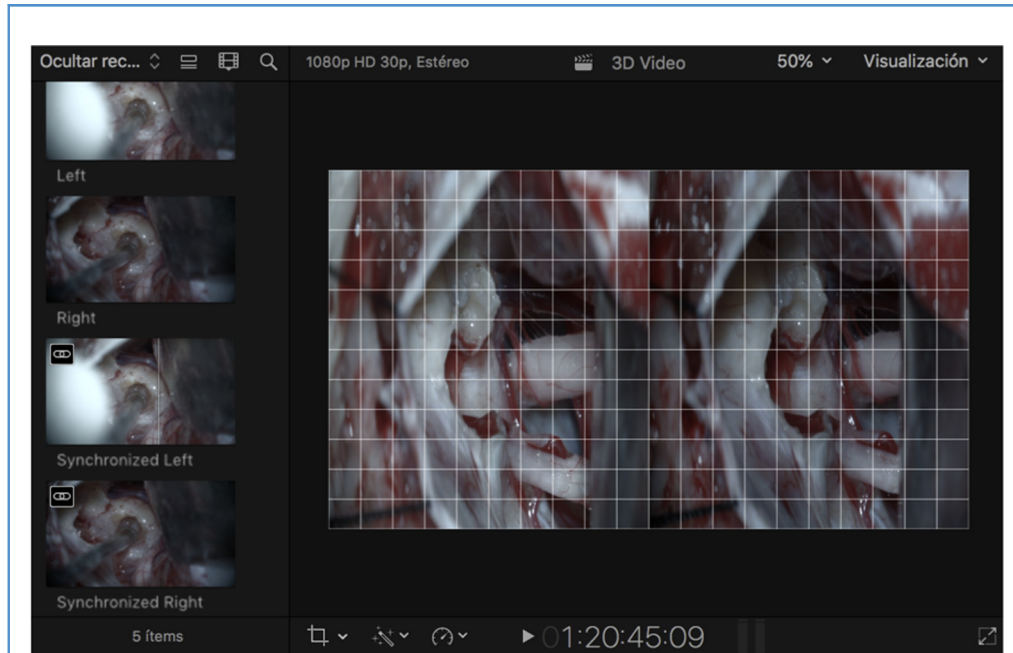
Figure 5. The processing of the videos in the Final Cut Pro X (FCPX) software is observed. The first step is to import the right and left videos, which are then synchronized with a specific function of FCPX. This maneuver allows both videos to be paired in the timeline, so that everything happens at the same time in both videos. An alignment grid then opens to move the videos vertically and horizontally for their perfect match, as can be seen in the picture.
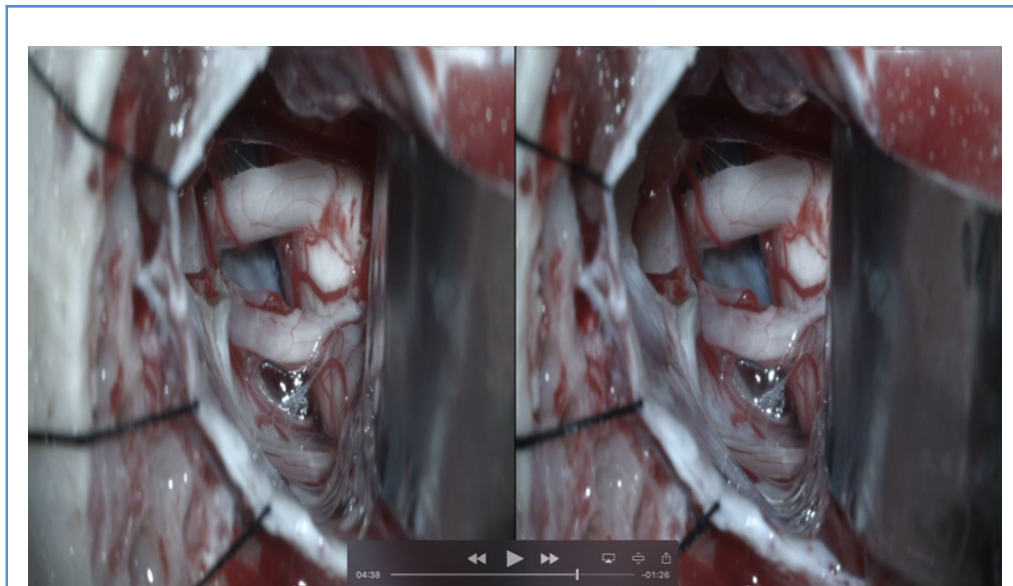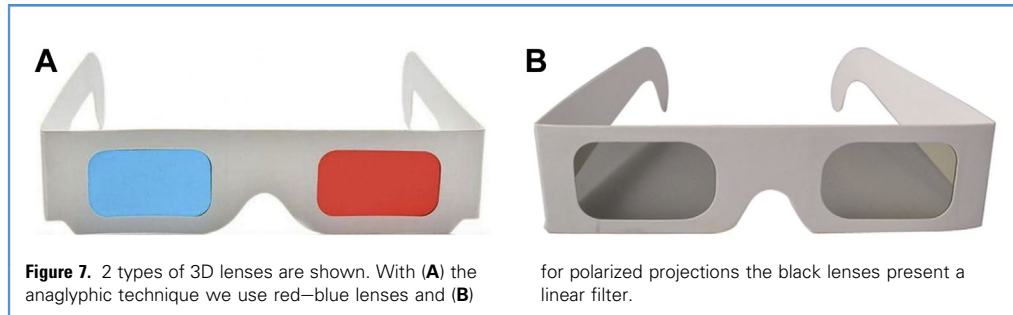

Figure 6. Once the alignment with the grid is completed, the video is exported in.mov format with a size of 1920 × 1080. As can be seen in the image after being synchronized in a single video, it is easier for its reproduction.

Figure 7. 2 types of 3D lenses are shown. With (**A**) the anaglyphic technique we use red—blue lenses and (**B**) for polarized projections the black lenses present a linear filter.
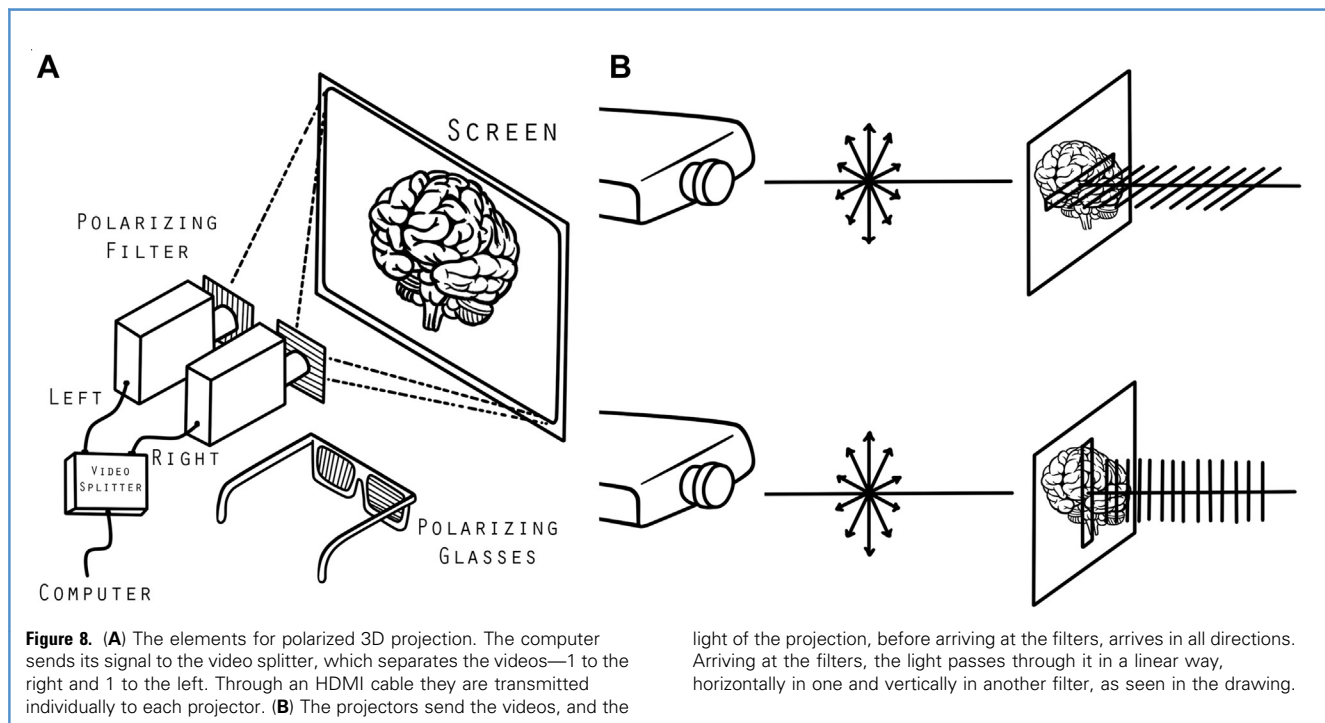
less fatigue than the anaglyph format. From the logistical point of view, however, this method is complex.

Before projecting, we need to prepare the video computer files. Our videos are usually projected in large rooms for educational purposes. The lectures where the videos are inserted are a combination of anatomical pictures and surgical videos. Therefore, we prefer to project all the images in the same slide presentation with PowerPoint. For this objective, the dimensions of the slides are wider than usual. In our lectures the proportion used is 22 × 8.25. This format allows us to load and adjust the 2 stereoscopic photographs side by side (to standardize, we place the left picture on the left and the right on the right). In the case of surgical videos, they are created as a single video but divided into 2 parts corresponding to both eyes. Similar to separated stereoscopic pictures, the video is adjusted to the size of the slide so that the midline of both the video and the slide are aligned.

Once the presentation is created in our computer, we must use a projection device. We commonly use 2 methods:

- 3D TV: In our case, frequently we use a 48-inch LG (Seoul, South Korea) screen. To project in this way, we only need to send the signal from the computer via a cable (preferably HDMI) to the TV. Applying the 3D mode of the TV, it will automatically emit the 2 images (left and right) of the slide so that they can be viewed with the passive 3D polarization glasses compatible with the TV. There are many types of TVs that project in 3D. The best quality is achieved with the active 3D TVs. However, the cost of the television itself and the special glasses they require is too high to project to a large audience.

- *Passive polarized projection system with 2 projectors*: This system has the advantage of allowing us to project the images on large screens for a large number of spectators. The projection system

Figure 8. (**A**) The elements for polarized 3D projection. The computer sends its signal to the video splitter, which separates the videos—1 to the right and 1 to the left. Through an HDMI cable they are transmitted individually to each projector. (**B**) The projectors send the videos, and the light of the projection, before arriving at the filters, arrives in all directions. Arriving at the filters, the light passes through it in a linear way, horizontally in one and vertically in another filter, as seen in the drawing.

is quite complex, however. To systematize its explanation, we will order its components in order from their emission to their visualization:

1. Computer: In our case we use a MacBook Pro laptop, although any computer can be used. We have previously created a presentation in Keynote or PowerPoint format with the aforementioned slide format (**Figures 8A, 9A**).

2. Graphic card or splitter: In our case we use the Digital DualHead2Go card (**Figures 8A, 9A, 9B**) that is connected to the laptop through a USB connection and another Video Graphics Array connection. It is a system that divides the image emitted by the computer screen in 2 halves. In this way, the image coming from each side of the slide can be projected independently.

3. Projectors: Each image divided by the splitter is emitted to the projectors by 2 separated DVI cables (**Figures 8,** and **9**).

The 2 projectors should be conventional—these are not 3D projectors. We recommend using two similar high-definition projectors with high luminosity (a property that is quantified in lumens). In our case, we use 2 projectors with these features: 1024×768, 4500 lumens, 4:3 Vivitek D945VX. One of the most delicate steps of the projection is the adjustment of both projectors. To achieve adequate 3-dimensionality on the screen, it is necessary that the images emitted by each projector fit exactly one over the other. To facilitate this, the first slide of all our lectures contains two parallel "dartboards". The adjustment requires us to put both projectors in a position that overlaps both dartboards. There are manufactured systems consisting of metallic structures that allow placement of the projectors one above the other with the ability to make precise adjustments to their position.

4. Polarization filters: The method to emit each image to each eye is based on light polarization. The light emitted by each
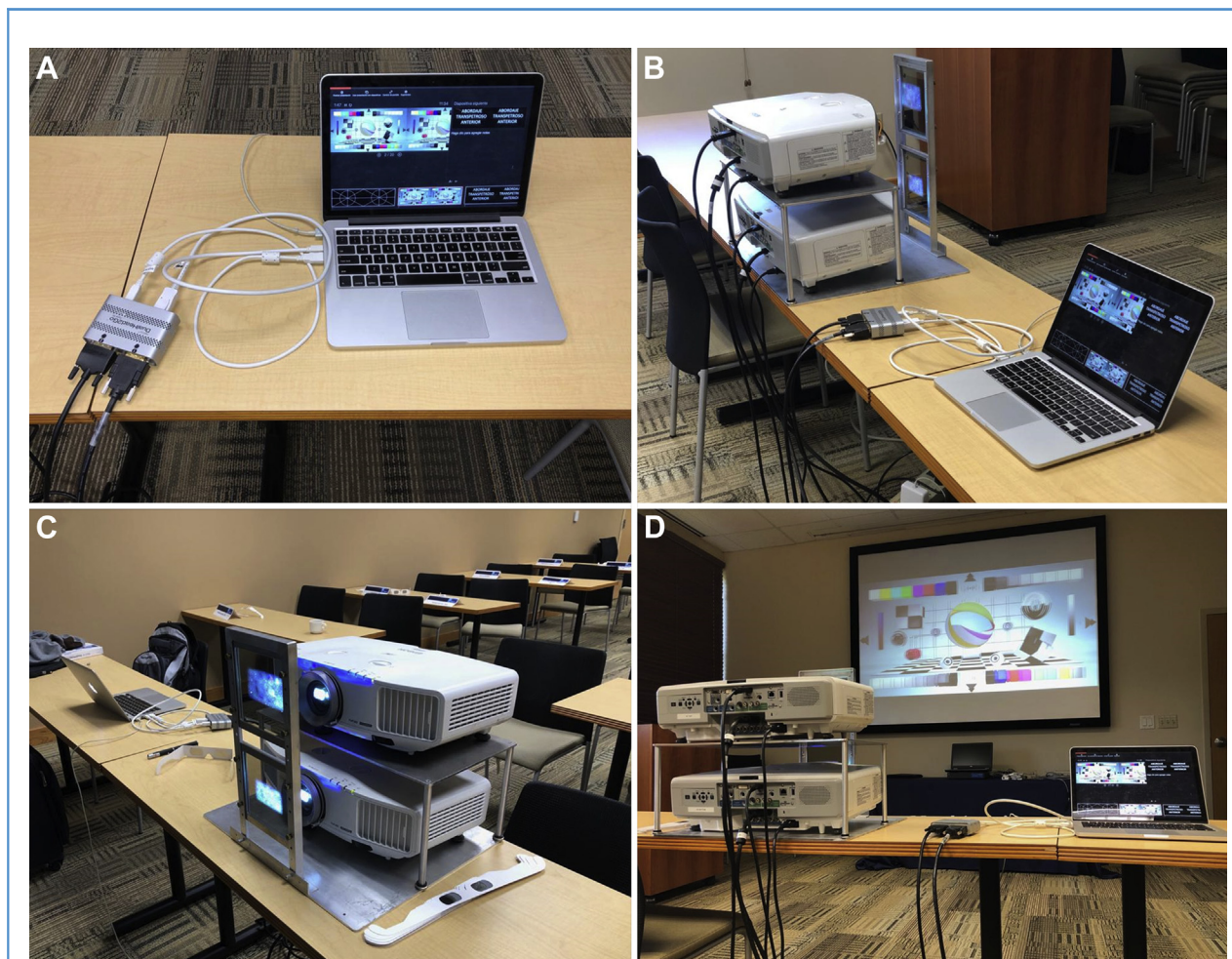

Figure 9. (**A**) We use a MacBook Pro laptop (Apple Inc, Cupertino, CA) connected to the video splitter through a USB connection and another Video Graphics Array connection. In our case, we use the Digital DualHead2Go card from Matrox (Harefield, UK). (**B**) Each video is divided by the splitter and emitted to a projector by 2 separated DVI cables. For the two similar high definition projectors, we use projectors with these features: 1024×768, 4500 lumens. (**C**) There are 2 linear polarization filters, placed on a metal support and at least 5 cm away from the projector to prevent the emitted heat from burning them. (**D**) The videos emitted must be projected onto a special screen covered by a metallic surface. These screens are usually called "silver screens" and enhance the polarization of the light emitted by the projectors.

projector is polarized by glass filters placed in front of the projectors. There are different types of filters depending on how they modify the light waves. In our case, we use linear polarization filters. In this phase, the light emitted by the projector acquires a wavelength different from that emitted by the other projector. Filters must be kept at a distance greater than 5 cm from the lens of the projectors to avoid burning them (**Figures 8,** and **9**).

5. Screen: The videos emitted must be projected onto a special screen covered by a metallic surface that enhances the polarization of the light emitted by the projectors. These screens are usually called "silver screens" (**Figure 9D**). One of the advantages of this projecting method is the use of large screens, like the 3D screens used in cinemas.

6. Glasses: Finally, the signal emitted and reflected by the screens reaches the eyes. To see the videos in 3 dimensions we need to use polarized glasses (**Figure 7**). Each eyepiece of the eyeglass has a filter that allows light to enter that is similarly polarized and blocks the light polarized in the opposite direction. With those glasses, each eye perceives a different image, allowing each eye to selectively receive the light emitted by the corresponding projector. The image emitted by the projector of the right video will only go through the filter of the right eyepiece of the glasses and the video of the left projector will only go through the left eyepiece.

DISCUSSION

Previous Concepts for Understanding the 3D System

One of the main characteristics of humans is the anterior location of the eyes on the face, in the same coronal and axial plane. Binocular vision resulting from the aligned position of the eyes allows us to observe the same element from 2 different visual points. Three-dimensional vision is the ability we have to perceive the volume, distance, and depth in our visual field. When fixing the view on an object, the visual axes intersect—this is called *convergence*, greater convergence exists when the object is closest to the eyes separately.[4] The neurosurgeon has the ability of 3D vision through the surgical microscope, because it receives a different image to each eye through a beam splitter.

Stereoscopy is the production of the illusion of depth in a photograph, movie, or other 2-dimensional image, by the presentation of a slightly different image to each eye. The 2 images or videos are then combined in the brain to give the perception of depth.[5,6] Thus, to create artificial 3D perception of a surgical field we need to take 2 images of the same structure simulating the images seen by each eye. The final result of these 2 images is called a *stereoscopic image*.[7-9]

All available methods of producing 3D videos are based on a fundamental requirement: obtaining 2 slightly different videos of the microsurgical field.[6,10] These 2 videos differ because 1 shows the surgery as seen from the right eye of the surgeon and the other through the left eye.

3D Vision in Neurosurgery

The main advantage of this method is the ability to show in a realistic way the spatial relationships and the depth of the neurovascular structures captured with the microscope. The representation of anatomy that a neurosurgeon must learn should be as similar as possible to the real anatomy. The surgeon will need to move through deep spaces where they have to know the spatial relationship between nerves, vessels, cerebral parenchyma, or skull.[2] When we use the microscope to operate, we are using a device that allows us to see in 3 dimensions. Thus, if we want to show our surgical experience to our colleagues or students, the use of 3D stereoscopy is the optimal way.

Another advantage offered by stereoscopy is the ability of teaching form a real image of the anatomy without using a real cadaver in front of us. In this way, we avoid the inconveniences of cadaver use: lack of availability, economic cost of the specimens, discomfort, and the health risks associated with dealing with the toxic substances of preservation as well as the psychological impact of facing a deceased person.[11-13]

The increasing utility of virtual reality in the field of medicine and its teaching has been accompanied by the use of binocular vision in order to increase the sense of reality of the exposed structures.[14-16]

Other papers discuss the usefulness of stereoscopy in the reconstruction of radiologic images.[16-18]

What this paper provides as a novelty is the step-by-step description of the material and methods that we use to acquire stereoscopic images directly from a surgical microscope. Our technique is easily reproducible, since each surgical microscope has 2 equal arms and an image splitter—thus, we have only to implement the adaptation of the cameras as described in our technique. Other authors have described the techniques of acquisition of 3D imaging and its projection, although most of them have applied it on specimens exposed to a simple camera at a distance at which it is relatively easy to make stereoscopic photography.[2,14,19] In case of approaches to depth regions of the brain, the capture of 3D images with conventional cameras is difficult. These scenarios require very specific conditions to be captured, difficult to capture with conventional photography methods. The use of adequate lighting and objectives with a macro focus become fundamental. Using a simple camera to take pictures or record videos in the surgical field is not easy, however, and requires the operation to stop while moving the microscope. Thus, the theoretically simplest method to capture images of microsurgical approaches is the direct capture of an image through a microscope. Devices designed for stereoscopic capture from the head of microscopes are very expensive, however, and their availability very limited.[20]

Here, we provide a 3D capture method through a conventional microscope not previously described in the literature.

Our Experience in the Use of This 3D System

This video recording tool will be useful in the field of neurosurgery teaching because it allow us to see in a real way the anatomical structures with their real volume, color, and depth.

The surgical microscope provides real 3D perception to the surgeon during live operations. But the surgical videos recorded are usually in 2D format. Nowadays, some microscopes have their own 3D recorder devices. They record the image from each eyepiece, simulating real stereoscopic vision, creating directly a

simple video with the pair of synchronized stereoscopic videos (e.g., Trenion Zeiss, True Vision Leica Microsystem). The problem with these systems is the high cost. Analyzing the costs of 3D recording systems that are included in the latest generation microscopes, we find that they are up to 15 times more expensive than our setup.

Our system, on the other hand, is very affordable and versatile. The 2 images are projected superimposed onto a special silver screen through different polarizing filters. The use of a silver screen is important, because a regular screen will not refract the polarization, resulting in "ghosting" of the 3D images. The viewer wears low-cost 3D eyeglasses that contain a pair of different polarizing filters.

The 3D polarized system that we use for projection gives us the best projection quality. Unlike the anaglyph method (red and blue glasses), the original colors of the videos are not altered, allowing a comfortable visualization for a long time.

Our team has published 3D videos where you can appreciate the high quality of its definition.[21]

CONCLUSIONS

In this paper, we presented in a clear and detailed way how to create and use a low-cost 3D system. This allows us to obtain, process, and project high-quality images. This is a useful tool in the training of young neurosurgeons of the 21st century. This is an easily replicable system; in the near future it may be used by professionals of different surgical specialties from around the world.

ACKNOWLEDGMENTS

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