Digitally Assisted Vitreoretinal Surgery: A New Perspective

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**Intra-operative Vitreoretinal Visualization**

Vitreoretinal surgical procedures address eye disorders involving the vitreous humor, peripheral retina, and macula. Such disorders may or may not be secondary to complications of systemic illnesses, and include vitreous hemorrhage, macular hole, retinal detachment, and advanced stages of proliferative or neo-vascular diabetic retinopathy.

Because both the vitreous cavity and the retina are deep to more anterior tissues like the cornea and the lens, effective surgical visualization requires their penetration. Simultaneously, excellent visualization of microscopic structures is required particularly for retinal anatomy. Currently, the analog microscope aids ophthalmic surgeons in a wide variety of procedures targeting the anterior or posterior pole of the eye. The microscope is an established and standard tool of visualization for more than five decades. Over its history, numerous advances were made in context of optical quality, lighting, and depth of field. However, significant limitations persist including dependence on oculars, limited performance in high-magnification, prolonged exposure of photoreceptors to excess illumination, requirement for chemical dyes to highlight certain structures, and limited ability to merge images from ancillary imaging devices (i.e. OCT). These limitations inspired innovative approaches utilizing advances in high-resolution digital technology that offer improvements in the method of visualization for vitreoretinal surgical procedures. (Table 1)

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<th>Challenges with Analogue Microscope</th>
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<tr>
<td>• Dependence on oculars</td>
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<td>• Potential for prolonged exposure of photoreceptors to excess illumination</td>
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<td>• Inability to display vitrectomy machine setting parameters through the oculars</td>
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*Table 1: Existing Challenges with Analogue Microscopes*

**Technological Foundation for Digitally Assisted Vitreoretinal Surgery (DAVS)**

Digitally Assisted Vitreoretinal Surgery or DAVS (Figure 1) refers to real-time digital image guidance of vitreoretinal surgery, contemporarily utilizing an ultra-high-definition 3D flat-panel display. An example of such a system is NGENUITY® from Alcon. This device enables image capture using a twin sensor, high dynamic range camera, proprietary image processing technology, and projection of the image to an advanced 3D 4K OLED 55-inch surgical display. Displayed images are viewed through a pair of passive, circular polarized glasses.
The 3D High Dynamic Range (HDR) Camera that replaces the oculars on the microscope is a 5th Generation ICM5 3D Surgical Camera that optimizes image exposure through 3D HDR technology (85 to 90 dB). This camera, which can be coupled with any ophthalmic analog microscope with removable oculars, has two full HD (1920 x 1080) sensors that preclude the need for alignment, focus, or synchronization. It captures 60 frames per second per eye (combined 120 fps) with an adjustable stereoscopic aperture.2

The images captured by the ICM5 3D Surgical Camera is then sent to a proprietary ultra-high-speed 3D image processor, which optimizes 3D HDR images in real-time. Whilst images viewed by the surgeon are in 3D, the processor simultaneously streams 2D and 3D HDR images, and is capable of recording over 100 hours of 3D HD surgical videos at 1080p at 60 fps per eye.2

After the images are optimized, they are displayed on an advanced 3D 4K OLED 55-inch display, which generates a three-dimensional immersive surgical image. The 4K resolution translates to 3840 x 2160p or 8.3 million pixels. (Figure 2)
Figure 2: Example of an image captured from a DAVS system showing high image resolution and color contrast.

Organic Light Emitting Diode (OLED) technology adds a white sub-pixel to the usual red, green, and blue array which:

1. results in more natural colors,
2. displays pure black, which increases contrast,
3. has high contrast ratio, which produces more vibrant images, and
4. works without a back-light, which produces colors that are true to those of the object.

The image on the display screen is then viewed by the surgeon and others in the operating theater using a pair of passive, circular polarized 3D glasses, which do not require a power supply.²
DAVS and Practical Applications in Vitreoretinal Surgery

The technological elements described in the previous section enables vitreoretinal surgeons to optimize their workflow and technique through improved visualization experience compared with and analog microscope.

Ocular-free Viewing

With the use of 3D glasses to view images on the OLED screen, the need for oculars is obviated. Without these oculars, the surgeon's eyes are not required to be in close proximity to the microscope head, thereby relieving the cervical spine of fatigue from maintaining a bent position during the procedure.

Another advantage of ocular-free viewing is an enhanced educational environment for both surgeons in-training and operating room staff.1 Every person in the operating theater sees the same images of the vitreous and retina on a 3D 4K OLED 55-inch display screen. A less obvious advantage of ocular free-viewing, which was never available before DAVS, is the synchronized visualization of the surgeon and the surgical assistant. With the surgical assistant seeing the same images as the surgeon, while maintaining freedom of movement behind the mayo table and unencumbered by an ocular, the surgeon's next surgical steps are anticipated and the correct surgical instruments are handed over or prepared. Since surgery is considered by some as a coordinated dance between surgeon and assistant, DAVS can aid in the harmonious flow of movement leading to a more efficient workflow with benefits to surgeon performance and patient safety (e.g. a diathermy probe is immediately handed to surgeon when assistant sees bleeding without the surgeon asking).

Improved Images Under High-Magnification

Compared to an advanced analogue microscope, DAVS can provide 19% greater magnification and can further enhance stereopsis with a digital 3D 4K OLED 55-inch display.1,2 Furthermore, depth of field is improved 2.7 times and depth resolution is 19 per cent finer compared to an analogue microscope.2

Image clarity under high-magnification will aid the surgeon to visualize vitreous and retinal structures and surgical instruments accurately without losing fidelity from the actual image. Thus, surgeons will be able to appreciate the well-defined images and the edges of structures like the internal limiting membrane, epiretinal membranes, and retinal tears; aiding in their manipulation with confidence and a potentially superior completion of the surgical task than when performed under analogue microscopes. (Figure 3)

Figure 3: High Magnification Performance - 27+® Gauge Cutter Vitrectomy Probe
**Extended Depth of Field**

Depth of field is enhanced when the camera aperture is decreased. However, a decrease in aperture also entails a decrease in the amount of light reaching the camera's sensor, thus the images will appear dark. This is not an issue with DAVS since the camera used is very sensitive to light, enabling it to capture images, even when the camera aperture's opening is reduced. This is achieved while keeping the retina illuminated at an equivalent, or even reduced, levels.¹ (Figure 4)

The depth of field with DAVS can exceed that of the standard operating analog microscope by two to three times when camera aperture is reduced to 30%.¹

An extended depth of field at all magnification levels will allow surgical movements that require precision in the micron or millimeter level. Furthermore, because of ability of DAVS to simultaneously focus on more vitreous cavity structures at varying depths, the need for refocusing due to slight patient movement may not be necessary. (Figures 5, 6)

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**Figure 4:** A comparison of a photo showing extended depth of field (left) to one with a shallow depth of field (right).

**Extended Depth of Field**
Foreground and background are clear

**Shallow Depth of Field**
Foreground is clear, background is blurred

**Figure 5:** Images on the limbal plane are as clear as those on the vitreous cavity.
Digital Image Enhancement and Optimization of Surgeon Viewing Experience

Use of 3D High Dynamic Range (HDR) technology leads to optimization of 3D image exposure and contrast in real-time. This enables the surgeon to better visualize even transparent structures such as the vitreous.¹

With HDR, the brightest and the darkest objects are visualized equally such that lighting is optimized across a broad range of darkness and brightness. (Figure 7) Highlights are toned down while shadows are brightened. This attribute of DAVS enables the surgeon to visualize structures of varying brightness equally and may aid in more accurate movement of instruments and more accurate manipulation of tissue while working within the vitreous cavity.² (Figure 8)
Another feature that digital processing can provide is redshift viewing, which enables the surgeon to view retinal structures through vitreous hemorrhage and avoid delicate structures as the vitreous is removed.\footnote{1}

Although using a red-free filter is not new to retinal imaging, its use has been more akin to black and white fundus photography in order to improve contrast between retinal blood vessels and associated hemorrhages against other retinal structures. A similar technique is used in DAVS, to provide the surgeons with an enhanced visualization of vitreous hemorrhage and aid in the safer and faster removal of vitreous while maintaining clear sight of other structures in the vitreous cavity. In addition to this, tissue manipulation during membrane delamination becomes potentially safer. Redshift can also potentially improve surgeon proficiency since complete hemostasis of microvasculature becomes less important during tissue manipulation.\footnote{2}

Through image processing, DAVS can provide edge enhancement, color space transformation, and brightness-contrast adjustment in real time without a significant increase in latency. Thus, surgeons may be able to visualize inner retinal and pre-retinal structures without the use of chemical dyes through image enhancement produced by digital processing and rendering in real time, without a noticeable increase in latency. It may be said that DAVS can provide surgeons a “virtual dye” without increasing patient risk to dye toxicity.\footnote{3}

Through Digital Illumination Modulation (D.I.M.), DAVS can enable the surgeon to operate at lower levels of illumination while excellent 3D images of vitreoretinal structures are maintained on the 55-inch OLED screen.\footnote{3} Although the surgeon may not notice the difference in the intensity of light (save for less glare when operating under air) since images viewed remain excellent, rod and cone photoreceptors are spared from prolonged high-intensity light exposure.

\textbf{Figure 8: Image showing equal clarity of structures with varying contrast.}
Vitrectomy Machine Surgical Settings Overlay

With the vitrectomy machine usually set-up on the periphery of the surgical field and the machine's user interface screen out of the surgeon's field of view, a development that DAVS offers is the ability to display relevant surgical settings on the same screen where retinal images are displayed. This feature constantly provides the surgeon information pertaining to surgical parameters such as infusion rate, cut rate, vacuum, and light intensity and will enable him/her to ask for a change in one of the parameters to a specific new setting. (Figure 9)

Photo courtesy of Dr. Steve Charles

Figure 9: Screen capture showing integrated display of vitrectomy machine settings with 3D retinal image.
Summary and Conclusion

Digitally Assisted Vitreoretinal Surgery (DAVS) is a new technique in performing vitreoretinal surgery with the aid of a 3D HDR ocular-free viewing system. With the technical advances that go into DAVS, vitreoretinal surgeons are given a new method of viewing the retina during surgery. (Table 2)

Using a 3D HDR Camera the surgeon views the retina on a 55-inch OLED display using polarized 3D glasses. This provides relief from the burden of having to view the surgery using oculars which can lead to neck strain. Furthermore, an ocular-free method of viewing allows others in the operating room to see exactly as the surgeon does and provides a more conducive environment for surgical education.

With the ability to highly magnify images while maintaining an non-pixelated image, as well as, improving depth of field and resolution, surgeons are able to discern and manipulate minuscule structures with confidence and complete a task with better quality compared to when doing surgeries under analogue microscopes.

Having a camera that has a very sensitive sensor allows for reduced aperture openings which result in an increased depth of viewing enabling the surgeon to visualize tissues flawlessly at various depths without having to adjust the focus while manipulating delicate retinal tissue.

Through digital image enhancement and optimization, DAVS provides surgeons three unique features not found in analogue microscopes: 1) 3D HDR which allows tissues of various brightness to be presented with equal intensity of brightness and can assist surgeons perform tasks in the vitreous cavity more accurately, 2) red shift viewing which enables surgeons to see through vitreous hemorrhage and also visualize membranes without the use of chemical dyes, and 3) digital illumination modulation which allows for excellent 3D images under lower levels of light settings and potentially decrease the exposure of photoreceptors from prolonged high-intensity light exposure.

Having the vitrectomy machine usually set-up with the user interface away from the surgeon's field of view, DAVS is able to keep the surgeon aware of current surgical settings constantly by having an overlay of the machines setting on the same medium which the surgeon is viewing the surgical field in which s/he is working. This obviates the need for the surgeon to ask what his/her settings are and lets him/her request for changes based on what s/he is seeing on the OLED screen.

To conclude, the features of DAVS enumerated above give the surgeon an enhanced view of the retina which can contribute to better performance of vitreoretinal surgeries and improved patient safety.

In contrast to the standard analogue operating microscope, DAVS provides the surgeon improved images under high-magnification, extended depth of field, and numerous options for digitally-enhancing images. The resultant viewing experience is one that is highly optimized in comparison to the one from analogue microscopes and can potentially lead to better surgeon performance and patient safety.
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<th><strong>Digitally Assisted Vitreoretinal Surgery</strong></th>
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<td>• Images which surgeons see through oculars are different from those displayed on usual 2D screens</td>
<td>• Allows surgeons and surgical team to simultaneously see the same images</td>
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<td>• Only on external 2D screen, but not through surgeons oculars</td>
<td>• On 3D screen and simultaneously viewed by surgeon and surgical team</td>
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**Table 2: Comparison between Features of Analogue Microscopes and DAVS**

**References**


