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Reassessing Surgical Visualization with a Digital, 3D Heads-Up Display System

Digital viewing systems for retina surgery allow us to ask new questions about our surgical viewing preferences.

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Viewing retina surgery using heads-up, 3D technology is often described by new users as immersive. It is easy to understand why: the projection of the inside of the eye onto a large 3D display creates a stunning and memorable viewing experience (Figure 1). I recall one of the first cases I performed using heads-up, 3D technology on the NGENUITY platform (Alcon). As I worked on a retinal detachment repair, I found myself craning my neck to look into the periphery, as though I were actually inside the eye and trying to look around the corner to find additional tears.

This subjective experience of the "wow effect" can actually be reinforced by data. The NGENUITY setup is comprised of two 1080p high dynamic range (HDR) cameras (HDR optimizes image quality by taking two images with different exposures in rapid succession and averaging the results); the resulting image is then displayed on an ultra high definition (UHD), 55-inch, 4K display with 8 million pixels of resolution (Figure 2). This particular display is an important improvement compared with the previous 1080p display (with 2 million pixels), as it provides an upgrade to 1920 x 2160 pixel resolution per eye (2,160 lines of resolution) compared with 1920 x 540 with the 1080p model.

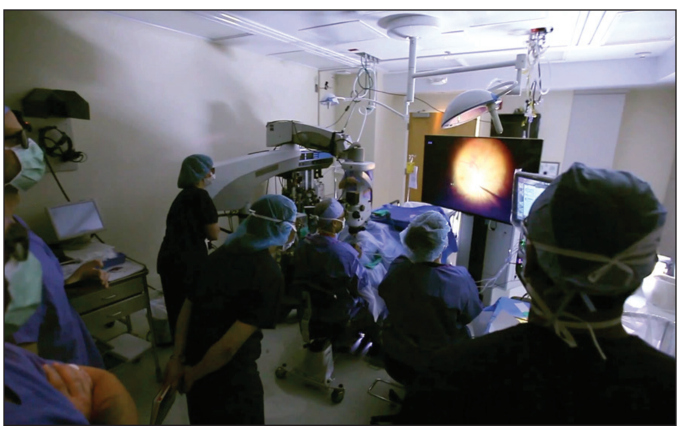

Figure 1. A retina specialist and team using the NGENUITY platform.

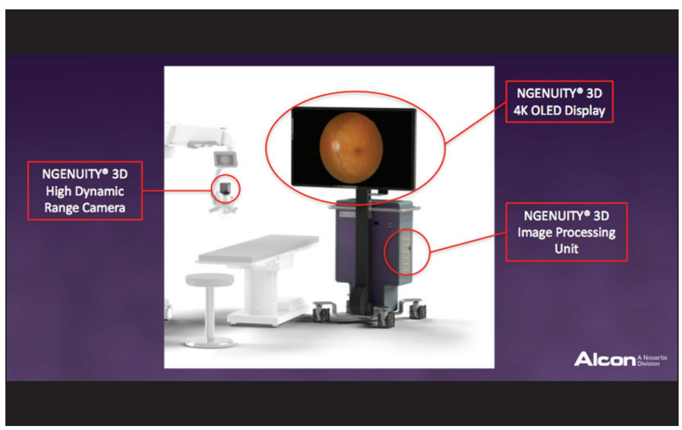

Figure 2. The NGENUITY 3D Visualization System.

However, the increased resolution is more than just a better picture, as it also translates to a higher degree of stereopsis. If one were to model the equivalent visual acuity of a 480i video display based on viewing geometry used for a standard surgical microscope, the result would be approximately 20/200 acuity; with 1080p high-definition video, the effective pixel density yields approximate visual acuity of about 20/40. With a 4K UHD display, the full resolution of the left and right camera are fully processed, thus increasing effective visual acuity to at least 20/20 after allowing for the ability to magnify the image.

But does a shift from analog to digital viewing also produce a latency that negates any potential gain in visual performance? In fact, any lag between what occurs inside the eye and when it is viewable on a display screen is negligible and perhaps imperceptible. The NGENUITY does have an approximate latency of around 80 ms. On the other hand, modeling of the human visual system using visual evoked potential reveals that perceptual latency, or the time between seeing a stimulus and reacting to it, is in the range of 200 to 350 ms.[1,2] The total perceptual latency, or the sum of the inherent latency of 3D, heads-up viewing and perceptual latency (80 + 200 ms), is within the range of total perceptual latency.

OPERATING WITH LOWER ILLUMINATION

Colleagues have commented that latency may not be noticeable while working inside the eye, but that it may be more important with elements of surgery performed on the exterior of the globe. I have personally not found that to be the case. A recent surgery in which I did a chandelier scleral buckle for a retinal detachment using the NGENUITY as the only viewing system comes to mind. I learned two important things from this case: not only was there no latency, but in addition, the ability to magnify a crystal clear image on a 55-inch display helped compensate for some of the loss of accommodation in my own vision. The ability to magnify the image also becomes relevant when peeling a membrane or performing delicate work around the macula. I think it would be hard to argue that a highly magnified, high-resolution image on NGENUITY is not a better view for peeling a membrane than the traditional microscope view.

Yet, high magnification ability is only one aspect of working with digital visualization that becomes relevant for retina surgery. For instance, the HDR camera used by the NGENUITY system is able to amplify the image onto the display while providing excellent image quality even when the power of the light source is turned down. With traditional microscope viewing on the Constellation Vision System (Alcon) using a 23-gauge light pipe, the default output is about 35%, which equates to about 6.8 to 7.0 lumens of light. With that level of light, a surgeon is able to operate inside the eye for about 13 minutes and 45 seconds — a value referred to as the theoretic retinal threshold time.[3]

Most surgeons have reported being able to use the NGENUITY system at around 10% illumination or less.[4] It is feasible to go even lower than this by adding gain, although this will induce signal noise. Nevertheless, 10% illumination on a 23-gauge light pipe translates to only about 1.5 lumens, which yields a five-fold increase in the theoretic retina threshold time. From a historical perspective, many surgeons may remember that the release of 25-gauge technologies were limited by the perceived lack of illumination with 25-gauge light pipes on halogen and metal halide light sources. Interestingly, these 25-gauge light pipes had an output of ~4 lumens on these light sources, and because this was considered clinically inadequate, xenon light sources were developed to address this problem. The fact that we can now operate effectively at 10% illumination with 1.5 lumens of light only serves to demonstrate how effectively the NGENUITY boosts the output to provide a pleasant viewing environment on the display — and instead of 13 minutes and 45 seconds of safe operating time,[3] the surgeon can safely work in the back of the eye for up to 1 hour and 11 minutes, a crucial difference in the presence of complicated pathology.

DEPTH OF FIELD AND DEPTH RESOLUTION

The ability to work with lower light levels while using NGENUITY could contribute to a safer working environment, as lower light levels in the eye equate to less phototoxicity potential (retinal threshold time).[4] As mentioned earlier, the ability to use a heads-up display immerses the surgeon inside the eye — and the benefits for training and teaching become obvious when everyone in the OR can view the case on a large display. Yet, while these benefits of the NGENUITY system are important and impressive, the most vital components of any surgical viewing system are how much it lets the surgeon see and how well it permits the surgeon to visualize the relevant anatomy.

These latter two facets — increased ability to see and the clarity with which images are viewable at given depths of magnification — are a function of depth of field and depth resolution, each of which is, in turn, dependent on a number of interrelated variables. Conceptually, it is easy to appreciate that when compared to analog viewing, digital viewing systems, such as NGENUITY, should offer greater ability to zoom to higher magnification, as well as a greater facility to clearly display images at any level of magnification. Anyone who has ever looked at a digital display screen will easily recognize that ever improving technology will eventually result in crystal clear images of even microscopic detail (if it has not done so already).

But can the effects of depth of field and depth resolution be quantified? I have recently been involved in mathematical

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modeling comparing digital and analog viewing systems.[3] Through a series of complex analyses, we discerned differences that may have important clinical consequences.

Depth of Field

We compared two viewing environments in our research: analog viewing using a Zeiss Lumera 700 operating microscope with a 200 mm objective lens, Resight viewing system, and a 60D macular contact lens; and digital viewing using the NGENUITY camera at what are supposed to be baseline settings (30% aperture and the display placed at 1.5 meters). The depth of field calculation was the sum of three elements: a wave optics component, a geometric optics component, and an accommodation component (which varies according to the visual system of the operator). It is important to note that depth of field can be affected by a set of additional variables, namely the camera aperture, the focal length of the objective lens, power of magnification, and two elements that change according to who is viewing the image: depth perception and accommodation.

What we found is that NGENUITY had roughly three times the depth of field than the microscope setup. However, there is an important caveat — the degree of difference is positively correlated with the amplitude of accommodation loss in the operator's viewing system. That is, the gain in depth of field is disproportionately higher for individuals with higher degree of accommodation loss — any operator will gain depth of field with NGENUITY, but older surgeons with presbyopia will appreciate a greater difference.

Our research then compared the NGENUITY system to analog viewing with the Resight system, but this time without a macular contact lens. Similar to findings with the contact lens, the digital setup yielded greater depth of field compared with the non-contact lens. However, the increase in depth of field with NGENUITY over a contact lens viewing system was greater than the increase in depth of field over a non-contact lens. Overall, what this suggests is that a macular contact lens appears to provide more depth of field than a non-contact macular lens. The clinical implications of this finding are not fully known at this time.

We also studied the effect of increasing the amount of magnification and changing the viewing distance of the display with respect to differences between digital and analog viewing. The bottom line was as you increase magnification you gain better depth resolution, or the ability to resolve images at a given depth, but lose depth of field for both digital and analog systems. The total magnification of the NGENUITY system was found to be always 19% greater than an operating microscope. The loss of depth of field with increasing magnification was proportionally greater with the digital versus analog system, but at all magnifications tested the digital system still had more depth of field than the analog one. With respect to the viewing distance, we noted that by moving the display closer to the surgeon you increase the magnification and depth resolution but once again lose depth of field in the process. The amount of change in the depth of field or depth resolution with changing the display distance between 1-2m is on a much smaller scale than the changes which occur with altering magnification.

Depth Resolution

As mentioned earlier, depth resolution refers to the ability to resolve images along the z-axis. Conceptually, depth resolution can be understood by moving an object close to one's eye. The object stays the same size in reality but appears larger in the visual system; yet, the closer it is moved to the point of refraction, the harder it is for the eye to gain focus.

In our research, we found that NGENUITY again outperformed microscope viewing with respect to depth resolution. In fact, the difference between the digital and analog setup with a contact macular lens was 19%, the same difference observed in magnification power. Unlike our other mathematical modeling with depth of field, however, use of a non-contact macular lens provided greater depth resolution.

CONCLUSIONS

The mathematical modeling we performed yielded some intriguing findings. Namely, we found a suggestion that a contact lens system provided greater depth of field, whereas a non-contact system yielded better depth resolution. Moreover, depth of field was always better with the NGENUITY system compared with the microscope setup, although it is proportionally better for older surgeons or those with higher loss of near accommodation. The data suggested that NGENUITY was capable of 19% greater magnification power, which equated to 19% more depth resolution.

As with any study, translating this research to real-world clinical practice is difficult. The two variables that were studied in our modeling, depth of field and depth resolution, seem to change inversely with the variables we studied — magnification and viewing distance. The question is, as a surgeon, what should I care more about — depth of field or depth resolution? In my opinion, when we are performing a core or peripheral vitrectomy, depth of field may be the more relevant value — I want to know where my cutter is in as wide a depth of field as possible to ensure I am not bumping into a detached retina below or hitting the lens above. But as I move to high precision maneuvers, such as membrane or internal limiting membrane (ILM) peeling, in my opinion, depth resolution becomes more important. In these situations, I want to be able to resolve as precisely as possible in a z-axis how to peel a microns-thick ILM off of the underlying retina.

In practical terms, the easiest way a surgeon can control these variables is by altering the magnification of the system. For a core or peripheral vitrectomy where the surgeon may want to maximize depth of field, I would suggest zooming out and minimizing magnification. If the surgeon wants to change the depth of field in a subtler way, they can do this by pushing the display a bit further away. On the other hand, for macular work, I would suggest maximizing zoom to maximize depth resolution, and if more subtle changes are desired, pull the display closer to the surgeon. ■

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IMPORTANT PRODUCT INFORMATION

Caution: Federal (USA) law restricts this device to sale by, or on the order of, a physician.

Indication: The NGENUITY® 3D Visualization System consists of a 3D stereoscopic, high-definition digital video camera and workstation to provide magnified stereoscopic images of objects during micro-surgery. It acts as an adjunct to the surgical microscope during surgery displaying real-time images or images from recordings.

Warnings: The system is not suitable for use in the presence of flammable anesthetics mixture with air or oxygen. There are no known contraindications for use of this device.

Precautions: Do not touch any system component and the patient at the same time during a procedure to prevent electric shock. When operating in 3D, to ensure optimal image quality, use only approved passive-polarized glasses. Use of polarized prescription glasses will cause the 3D effect to be distorted. In case of emergency, keep the microscope oculars and mounting accessories in the cart top drawer. If there are any concerns regarding the continued safe use of the NGENUITY® 3D Visualization System, consider returning to using the microscope oculars.

ATTENTION: Refer to the User Manual for a complete list of appropriate uses, warnings and precautions.