Ophthalmol Ther (2023) 12:625–631
https://doi.org/10.1007/s40123-022-00624-6

CASE SERIES

Use of a Novel Three-dimensional Head-mounted Digital Visualization Platform in Corneal Endothelial Transplantation

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Received: October 20, 2022 / Accepted: November 23, 2022 / Published online: December 12, 2022

ABSTRACT

Introduction: To report the first endothelial keratoplasty procedures performed using a 3D digital head-mounted ophthalmic exoscope.
Methods: Three patients underwent Descemet stripping automated endothelial keratoplasty (DSAEK) using a 3D digital ophthalmic exoscope (Beyeonics One, Beyeonics Vision, Haifa, Israel) at the Tel Aviv Sourasky Medical Center, Tel Aviv, Israel.
Results: All procedures were uneventful, leading to resolution of corneal edema and vision improvement. Surgeons reported excellent visualization and minimal lag, almost negligible, with the benefits of improved ergonomics and the use of head gestures to control zoom, focus, brightness, and panning. There were no postoperative complications.
Conclusion: The new 3D digital ophthalmic exoscope system can be successfully used in DSAEK surgery with potential advantages in ergonomics, picture quality, and image control. Further studies can compare this system with either standard operating microscopes or 3D heads-up display systems.

Keywords: Three-dimensional (3D); Visualization; Microscope; Surgery; Descemet stripping automated endothelial keratoplasty (DSAEK); Corneal endothelial transplantation; Heads-up; Head-mounted display (HMD); Head gesture; Exoscope

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40123-022-00624-6.

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Key Summary Points

Why carry out this study?

This article presents the new Beyeonics One 3D head-mounted imaging system for ophthalmic surgeries and presents its features and surgeon opinion.

This article describes the first corneal endothelial transplantations ever performed with this new imaging system and the results.

What was learned from the study?

Use of the Beyeonics One 3D head-mounted imaging system in DSAEK surgery is feasible.

Preliminary experience suggests good ergonomics, high picture quality, and advanced image and feature control.

DIGITAL FEATURES

This article is published with digital features, including a video to facilitate understanding of the article. To view digital features for this article go to https://doi.org/10.6084/m9.figshare.21603621.

INTRODUCTION

The ophthalmic microscope is essential for ocular surgery. The monocular and binocular ophthalmic surgical microscopes were introduced in 1921 and 1946, respectively [1]. Since then, microscope quality has continuously improved but the fundamental imaging technology has not dramatically changed. Over the past decade, technological advancement led to the development of several three-dimensional (3D) digital visualization platforms that replace the standard microscope. These systems allow the surgeon to view the 3D surgical field on a big screen [2–6]

Three-dimensional digital surgical visualization offers enhanced resolution, magnification, and depth of field. These systems improve surgeon comfort and ergonomics, and expand teaching possibilities [2, 4]. Despite their tremendous advantages, use of heads-up systems requires a straight-up sitting position to view the screen, a direct line of sight with the screen, and constant wearing of polarizing glasses. Also, they do not provide the same immersive visual field experience of a standard surgical microscope.

Recently, a new 3D fully digital ophthalmic exoscope with head-mounted surgical visualization was registered with the US Food and Drug Administration (FDA) for marketing in the USA (Beyeonics One, Beyeonics Vision, Haifa, Israel). The exoscope and its surgical head-mounted system provide a true binocular visual field similar to the one viewed using a standard optical microscope with the added benefits of digital enhancement, better ergonomics, and augmented reality features.

This paper describes the first endothelial keratoplasty procedures performed with the 3D head-mounted exoscope. To our knowledge, these are the first keratoplasty procedures performed with the system.

METHODS

Participants

Data were retrospectively extracted and collected from the electronic medical records of patients who underwent Descemet stripping automated endothelial keratoplasty (DSAEK) surgery using the Beyeonics One platform at the Tel Aviv Sourasky Medical Center (2022). This study was approved by the Institutional Review Board (IRB) of the Tel Aviv Medical Center, Tel Aviv, Israel (protocol no. 0269-22) and follows the tenets of the Helsinki Declaration of 1964 and its later amendments.

Patient Evaluation and Data Collection

Patients suffering from corneal edema secondary to endothelial decompensation were referred for a posterior lamellar corneal transplant and underwent preoperative evaluation, including slit-lamp examination and fundus examination, intraocular pressure (IOP) measurements, and visual acuity testing including corrected distance visual acuity (CDVA). Demographic data, ocular and general medical history were documented. Follow-up examinations were routinely performed at 1 day, 1 week, 1 month, and 3 months after surgery. Postoperative data included CDVA, IOP, slit-lamp examination, and documentation of any complications.

Surgical Technique

A DSAEK procedure was performed in all three cases. DSAEK grafts were prepared using a Moria ALTK microkeratome (Moria, Antony, France) and an artificial anterior chamber. The graft was then marked using a surgical marking pen (arrow mark) to enable confirmation of correct graft orientation and punch trephine was used to cut the partial thickness graft. At the beginning of surgery, Descemetorhexis was performed, a continuous anterior chamber flow was used, and the DSAEK grafts were pulled into the anterior chamber from a Busin glide through a 4.5 mm limbal incision. Then, the graft was pulled into the anterior chamber using intraocular microforceps (MST, Redmond, WA, USA). An air bubble was introduced to unfold and attach the donor lamella to the posterior stromal surface with centration of the graft performed by external horizontal strokes over the corneal surface. The correct orientation of the graft was confirmed via the stromal ink mark [7]. The main incision was sealed using a single 10–0 nylon suture. The anterior chamber was then fully filled with air under high pressure for 10 min and residual interface fluid was removed via surface sweeping. Following 10 min under high pressure, some of the air was removed to avoid the pupillary block.

The 3D digital head-mounted ophthalmic exoscope includes several main components:

1. Head-mounted unit—providing surgical view with 3D surgical field imaging. The unit offers a quick size adjustment to the surgeon's head and contains motion sensors which track head motions and gestures, allowing accurate motion-activated head control of the image and its different features (Fig. 1). The system supports two head units for the main surgeon and for an assistant/observer who can view the surgery using the second unit with the same 3D quality viewed by the surgeon itself. Addition of supplemental high-definition screens is possible to enable others to observe the procedure.
2. The main suite—the main microscope which contains two high-definition cameras (resolution of 8192×4384 pixels, Fig. 2), a semi-robotic arm unit (Fig. 3), and the main processing unit with a 24-inch touchscreen serving both as a surgical display and as a user control interface.
3. Foot pedal—with programmable buttons and standard microscope controls (in addition to the previously mentioned head-motion controls).

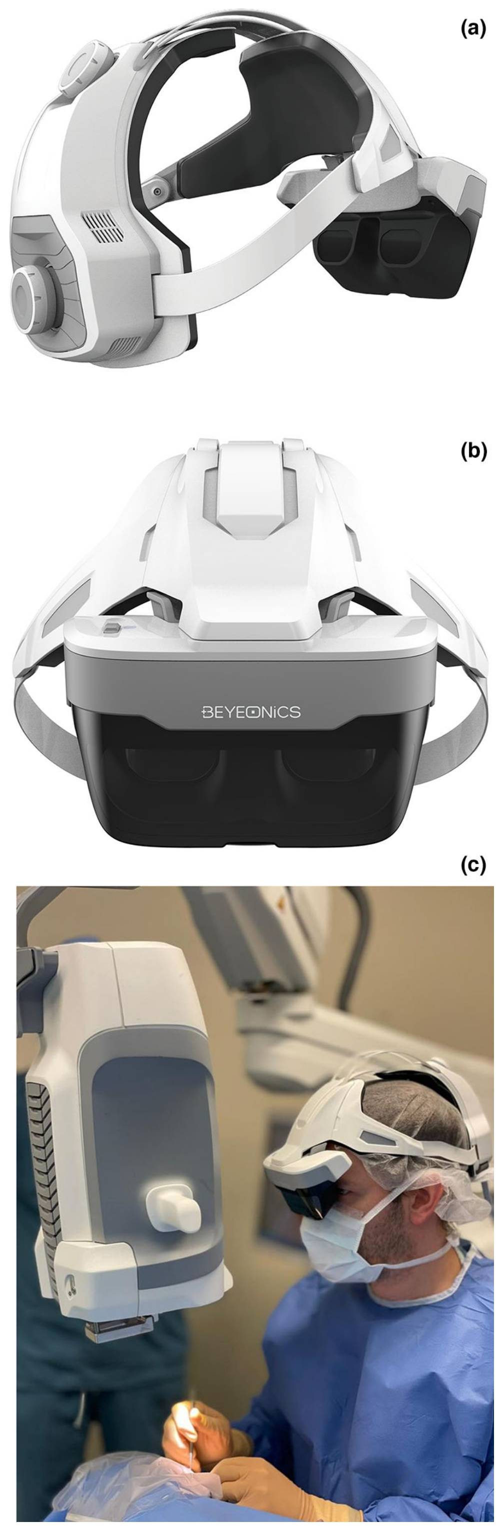

Fig. 1 Side view (**a**) and front view (**b**) of the three-dimensional head-mounted display, and the head-mounted display being used in DSAEK surgery (**c**)

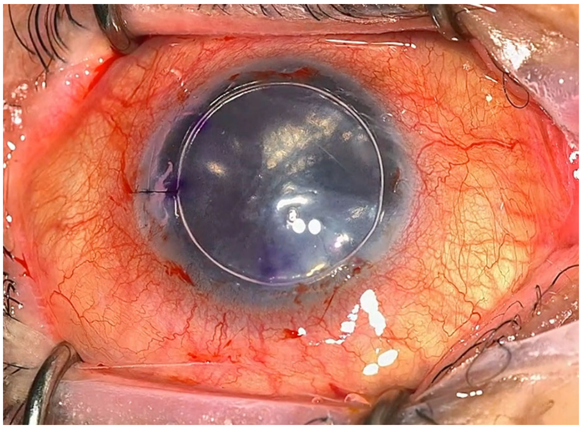

Fig. 2 Surgeon-view image during the final stages of a DSAEK procedure

Fig. 3 The main system suite, including the camera unit, the workstation unit and a semi-robotic arm carrying the camera unit

CASES

Case 1

An 83-year-old female patient with a history of bilateral primary open angle glaucoma, left-eye neovascular age-related macular degeneration (NV-AMD), bilateral cataract surgeries, and a right-eye trabeculotomy procedure. The patient was referred due to left-eye corneal decompensation with gradually worsening visual acuity. On examination, left-eye visual acuity was hand motion with severe corneal edema and an IOP of 12 mmHg. The patient was diagnosed with pseudophakic bullous keratopathy (PBK) and was referred for a corneal endothelial transplant in her left eye.

The patient underwent DSAEK surgery using the 3D digital head-mounted surgical visualization platform (see Supplemental Digital Content (SDC) video of DSAEK surgery using the Beyeonics One system). Surgery was uneventful with transplantation of a 7.5 mm corneal graft. Postoperatively, the corneal graft was well centered and attached with a clear cornea. Visual acuity 7 months after the procedure was 20/200 owing to NV-AMD changes.

Case 2

An 88-year-old female patient with a history of bilateral cataract surgeries and Fuchs' endothelial dystrophy who was referred because of right-eye corneal edema. On examination, right-eye visual acuity was 20/70 with moderate corneal edema and an IOP of 14 mmHg. The patient was diagnosed with right-eye endothelial decompensation and was referred for a corneal endothelial transplant. The patient underwent DSAEK surgery using the 3D digital head-mounted surgical visualization platform. Surgery was uneventful with transplantation of an 8.0 mm corneal graft. Postoperatively, the corneal graft was well centered, attached, and clear. Visual acuity 4 months after the procedure was 20/50.

Case 3

A 68-year-old female patient with a history of bilateral cataract surgeries who was referred because of right-eye corneal edema. On examination, right-eye visual acuity was 20/100 with severe corneal edema and an IOP of 11 mmHg. The patient was diagnosed with corneal decompensation and underwent DSAEK surgery using the 3D digital head-mounted surgical visualization platform. Surgery was uneventful with transplantation of an 8.0 mm corneal graft. Postoperatively, the corneal graft was well centered, attached, and clear. Visual acuity 3 months following the procedure was 20/40.

DISCUSSION

In this case series, we report our initial experience with DSAEK performed using the Beyeonics One 3D digital head-mounted visualization platform. To our knowledge, this is the first report of the system's use in corneal transplantation surgery. All surgeries were uneventful, leading to resolution of corneal edema and vision improvement. There were no postoperative complications.

Previous publications described n-DSAEK and Descemet membrane endothelial keratoplasty (DMEK) surgeries using heads-up surgery imaging systems. Mohamed et al. in 2017 published a case of non-DSAEK and described a successful and convenient procedure due to high magnification properties [8]. Galvis et al. reported in 2017 an uneventful DMEK surgery with 3D visualization system indicating especially the detailed vision, which is very useful in critical steps of the DMEK procedure [6].

Surgeons reported excellent visualization and minimal lag, almost negligible, with the benefits of improved ergonomics and head-gesture control. Our initial experience using the system in corneal transplantation suggests several advantages of using 3D head-mounted visualization. The first is image quality. The main unit includes two 8 K resolution, 3D cameras, providing a 3D image for both the main surgeon and an assistant. The high resolution enables surgical performance while imaging the smallest details.

Second apparent advantage is the use of head gestures to control zoom, focus, brightness, and pan. Use of head-gesture control over foot pedal control appears to be more accurate since head motion is more refined than foot motion and since the IN and OUT motions are continuous and not operated via separate IN and OUT buttons. Additionally, the range of motion using head gestures is wide and can be customized for each surgeon. The system offers pan mode which enables panning across a large visual field using sideways head nodding even while the picture is zoomed in. Our impression is that the system has minimal video lag, almost negligible, and the images are true real time. This is an absolute necessity and a basic requirement for any surgical imaging system. Surgeons also reported good depth of focus which reduced the number of necessary focus adjustments during the procedure, as well as enhanced contrast which benefitted some stages of the procedure such as loading of the graft onto the glide and graft insertion, where enhanced contrast enabled recognition of the graft edge even when it was submerged in fluid.

The issue of surgeon ergonomics is at times underestimated by both surgeons and developers. The standard operating microscope can sometimes enforce an undesired sitting position during the procedure due to the constraint of the surgeon having to place their eyes right at the microscope eyepiece. A head-mount imaging unit enables the surgeon to assume any desired posture without the need to lean forward to reach the microscope. The system essentially disconnects the eyepieces from the microscope (or camera unit in this case) which in our opinion can become a significant advancement in surgeon ergonomics and health, especially so in keratoplasty procedures which can become lengthy. Previous publications have demonstrated the ergonomic superiority of 3D heads-up display systems (HUD, where the image is displayed on a flat screen in front of the surgeon) over the standard ophthalmic surgical microscopes where the majority of surgeons favored the HUD's ergonomics [2, 4, 9, 10]. Our clinical impression is that the head-mounted system could have superior ergonomics compared with the HUD systems since the surgeon is not confined to the flat screen. Rather, the surgical field is present directly in front of the surgeon's eyes no matter the position.

While using the system, the surgeon can easily look "out" of the head-mounted image to view the surgical bed, instrument tray, etc. This is performed in a manner similar to using bifocal glasses where looking down gives a near view. This is sometimes referred to as parallel environment awareness or "surgeon bifocality".

In the context of DSAEK surgery, we found this option extremely helpful during graft preparation since actions such as marking, trephining, and loading the graft often require both in-the-scope and out-of-the-scope view which can be simultaneous while using this system. Surgeons who find this option not sufficient for viewing the environment outside the microscope can use a feature of the system which enables one to temporarily switch off the displayed image via a foot-pedal switch, enabling the surgeon to view the environment outside the surgical field through the unit's visor. Parallel environment awareness also comes into play with the option of viewing patient imaging photos and documentation during surgery, in real time, within the surgeon's field of view.

Length of surgery was a controversial issue in studies evaluating 3D HUD imaging systems. Panthier et al. reported longer surgery times in DMEK surgery performed using a 3D HUD system compared with a standard microscope [11]. This report can be attributed to the learning curve which may impact every new technique. In our experience, DSAEK surgery time using the 3D head-mounted digital exoscope was not longer than that using a standard microscope. This should be further evaluated.

CONCLUSIONS

Initial use of the Beyeonics One 3D head-mounted imaging system in DSAEK surgery had good outcomes. Preliminary experience suggests good ergonomics, high picture quality, and advanced image and feature control. Further studies can compare this system with both the standard operating microscope and HUD systems.

ACKNOWLEDGEMENTS

Funding. No funding or sponsorship was received for this study or publication of this article. The Rapid Service Fee was funded by the authors.

Author Contributions. Nir Gomel—Concept, design, statistical analysis, writing, drafting, reviewing; Eliya Levinger—Concept, statistical analysis, drafting, reviewing; Polina Lankry—Design, writing, drafting, reviewing; Shai Cohen—Design, statistical analysis, reviewing; Shulamit Schwartz—Concept, design, drafting, reviewing; Adiel Barak—Concept, design, statistical analysis, writing, drafting, reviewing; Anat Loewenstein—Concept, design, statistical analysis, writing, drafting, reviewing; David Varssano—Concept, design, statistical analysis, drafting, reviewing; Nir Sorkin—Concept, design, statistical analysis, writing, drafting, reviewing.

Disclosures. Adiel Barak and Anat Loewenstein are consultants for Beyeonics Vision. Nir Sorkin received advisory board honoraria from Beyeonics Vision. Nir Gomel, Eliya Levinger, Polina Lankry, Shai Cohen, Shulamit Schwartz and David Varssano have nothing to disclose.

Compliance with Ethics Guidelines. The study has been approved by the IRB of the Tel Aviv Medical Center, Tel Aviv, Israel (protocol no. 0269-22) and follows the tenets of the Helsinki Declaration of 1964 and its later amendments.

Data Availability. The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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