

Intraoperative optical coherence tomography using the RESCAN 700: preliminary results from the DISCOVER study

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ABSTRACT

Significant integrative advances are needed for intraoperative optical coherence tomography (iOCT) to achieve widespread use across ophthalmic surgery. A surgeon feedback system that provides microscope integration, heads-up display and foot pedal control of the OCT scan location represents a major interval advance in ophthalmic surgery. In this report, we describe the preliminary findings of the Determination of feasibility of Intraoperative Spectral domain microscope Combined/integrated OCT Visualisation during En face Retinal and ophthalmic surgery (DISCOVER) study, a multisurgeon investigational device study examining the role of microscope integrated iOCT systems with surgeon heads-up display feedback (eg, Carl Zeiss Meditec RESCAN 700, Cole Eye Institute iOCT prototype). During surgical manoeuvres in anterior segment and posterior segment surgery, this technology provides rapid visualisation of the area of interest and provides the surgeon with information regarding instrument–tissue interactions. This system represents a major advance in iterative technology for iOCT and may provide the first widely available platform for surgeons to seamlessly assimilate this technology into the operating room theatre.

INTRODUCTION

The widespread adoption of optical coherence tomography (OCT) across ophthalmology has transformed clinical care for ophthalmic diseases. Evidence continues to build regarding the utility of intraoperative OCT (iOCT).^{1–6} Reports have suggested surgical manoeuvres may significantly the microanatomy of the eye and that iOCT may provide the surgeon with information that is otherwise unavailable through the *en face* view of the microscope.^{1–4}

As clinical utility is established, iOCT systems will need to be developed that provide the surgeon with rapid feedback and minimal disruption to surgical flow. Many reports have documented use of portable SD-OCT systems used in a handheld or microscope-mounted fashion.^{2–6} Additionally, microscope integrated prototype iOCT systems have been described that allow for real-time visualisation of instrument–tissue interactions.^{5 7–9} To our knowledge, heads-up display systems and foot pedal surgeon control of the OCT scan system has not been described in human use.

In order to better understand the impact of a microscope integrated iOCT system with heads-up surgeon display of OCT feedback of the OCT scanner on ophthalmic surgery, we initiated the Determination of feasibility of Intraoperative

Spectral domain microscope Combined/integrated OCT Visualisation during En face Retinal and ophthalmic surgery (DISCOVER) study. The purpose of this report is to describe the early results of DISCOVER and describe one novel integrative iOCT system included in the study: the RESCAN 700 (Carl Zeiss Meditec, Germany).

METHODS

The DISCOVER study is an IRB-approved multi-surgeon investigational device study. The study adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants.

Intraoperative imaging for this portion of the DISCOVER study was performed using the RESCAN 700, a prototype microscope integrated iOCT system that includes a heads-up display system, external video display panel and foot pedal control of the OCT scanner (figure 1). The system is based on the Lumera 700 (Carl Zeiss Meditec) platform. Anterior segment imaging was achieved with the standard microscope viewing system. For posterior segment imaging, the RESIGHT lens system or a contact lens was used for surgical and iOCT visualisation. The RESCAN 700 includes Z-tracking and focus control for image stabilisation and quality control. Each surgeon underwent a lab-based training session with model eyes to provide foundational experience with the heads-up display system and foot pedal controls prior to human imaging.

iOCT scanning was performed during key milestones with continuous visualisation and motion. In addition, iOCT capture of volume and raster scans were also obtained. Surgeons could select the scan length, angle and location through either foot-pedal control or input through the video monitor display system.

RESULTS

iOCT images were successfully obtained in 10 of 10 cases. Both anterior segment and posterior segment imaging were obtained. Anterior segment images included iOCT evaluation of corneal incisions, scleral closure, phacoemulsification groove depth and intraocular lens position (figure 2, see online supplementary video 1). Posterior segment iOCT imaging included evaluation of hyaloid release with triamcinolone and completeness of peel in macular hole, epiretinal membrane and vitreomacular traction cases (figure 3). Contrast enhancement with triamcinolone and real-time capture of hyaloid release was achieved (figure 3A, see online supplementary video 2). Following



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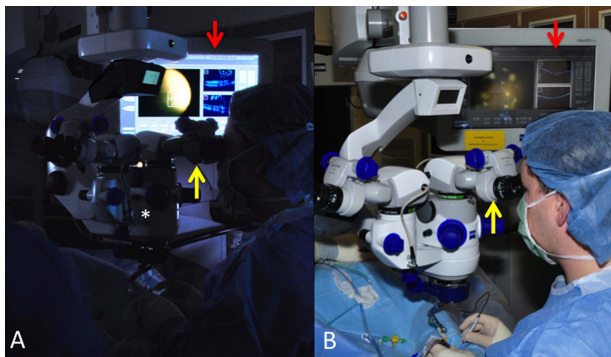


Figure 1 RESCAN 700. (A) Microscope integrated intraoperative optical coherence tomography (OCT) system, the RESCAN 700 (*) with simultaneous display monitor revealing OCT data stream (red arrow) and surgeon oculars with heads-up display (yellow arrow). (B) Similar image with full view of RESCAN 700 with the heads-up display in surgeon oculars (yellow arrow) and Callisto display monitor with OCT feedback (red arrow).

hyaloid elevation, formation of an occult full-thickness macular hole was identified with *i*OCT, resulting in a change in the surgical procedure (eg, internal limiting membrane peeling, gas tamponade), [figure 4A](#). The real-time imaging and heads-up

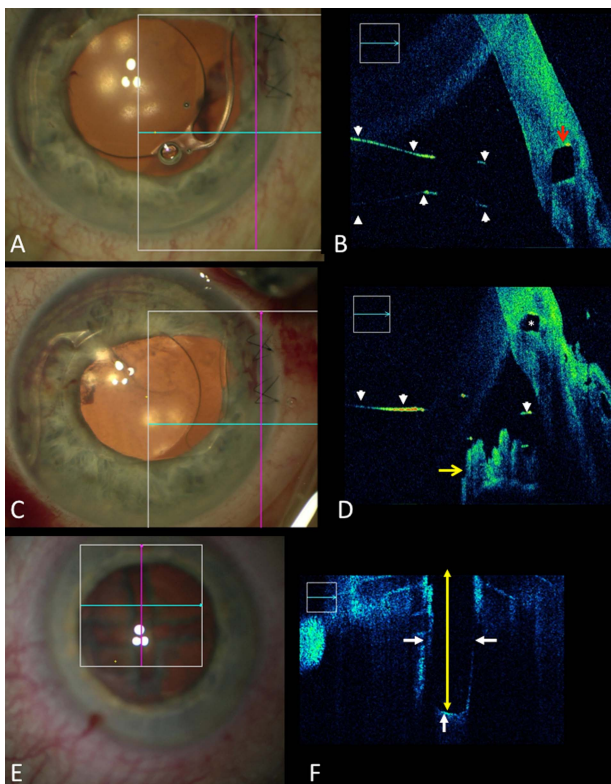


Figure 2 Anterior segment intraoperative optical coherence tomography (*i*OCT) with real-time feedback. (A) Surgical view of subluxed anterior chamber intraocular lens (ACIOL) with haptic trapped in corneal wound. (B) B-scan with *i*OCT feedback identifying elevated ACIOL (white arrowheads) and entrapment of haptic in corneal wound (red arrow). (C) Surgical view following ACIOL repositioning with B-scan crosshairs visible on display. (D) B-scan with *i*OCT feedback confirming optimal ACIOL position (white arrowheads) with haptic in the sulcus resting on the iris (yellow arrow). Residual corneal gap is present and identified (*). (E) Surgical view during phacoemulsification following groove formation. (F) B-scan of *i*OCT revealing groove depth (yellow arrow) and lens edge at groove (white arrows).

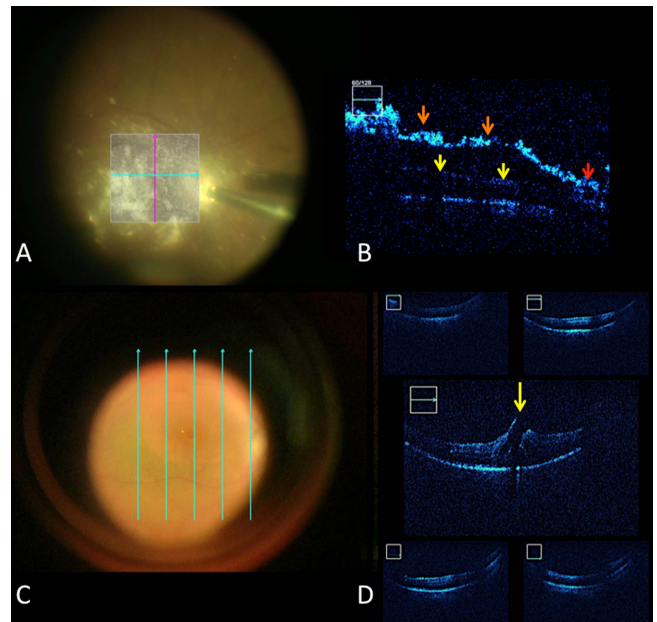


Figure 3 Posterior segment intraoperative optical coherence tomography (*i*OCT). (A) Surgical view following triamcinolone installation to visualise the hyaloid. (B) B-scan following OCT contrast enhancement with triamcinolone with excellent visualisation of the posterior hyaloid (orange arrow) and attachment at the optic nerve (red arrow). Underlying retina is shadowed due to density of triamcinolone (yellow arrow). (C) Surgical view following internal limiting membrane (ILM) peeling with 5-line raster display. (D) Following ILM peeling, *i*OCT reveals persistence of the retinal flap and full-thickness macular hole (yellow arrow).

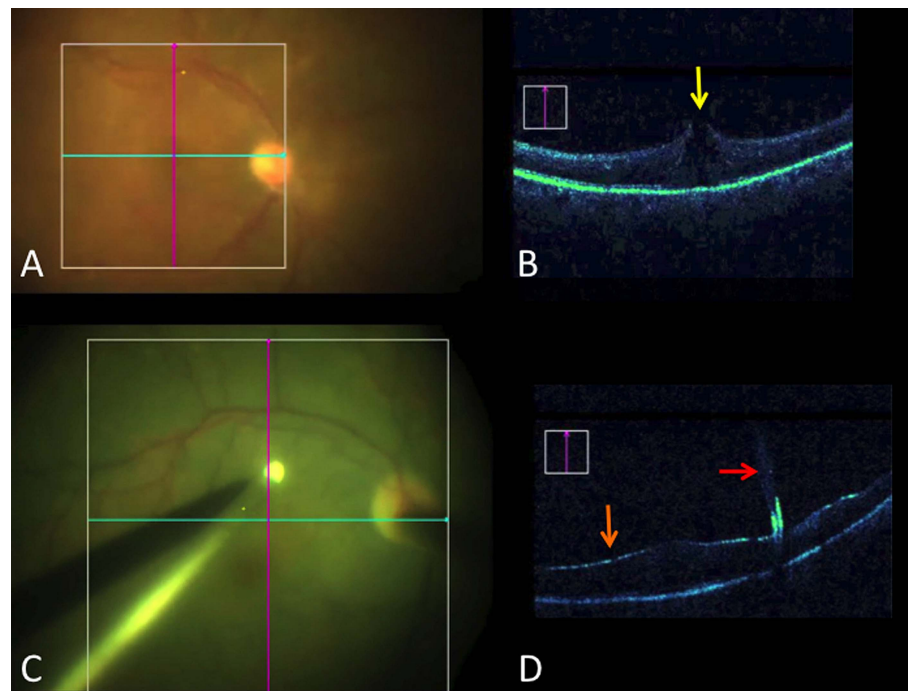
display system facilitated visualisation of instrument–tissue interactions, including the diamond dusted membrane scraper and intraocular forceps ([figures 4B](#) and [5](#); see online supplementary videos 3 and 4). Metallic instruments resulted in significant shadowing of underlying tissues ([figure 5](#); see online supplementary video 4). No intraoperative adverse events occurred during these initial cases of the DISCOVER study.

DISCUSSION

In this study, we demonstrate the feasibility of real-time *i*OCT for anterior and posterior segment surgery with a microscope integrated *i*OCT system with heads-up display surgeon feedback. Both real-time and static imaging were obtained to provide feedback to the surgeon with minimal disruption of surgical flow and outstanding visualisation of tissues during surgery. Current metallic surgical instrumentation was noted to have significant shadowing of underlying tissues, limiting the visualisation of instrument–tissue interaction.⁷

The integration of the OCT scanner into the surgical environment has been one of the major limiting factors for wider use of *i*OCT technology. Preliminary studies have described portable systems that were initially used in a handheld fashion.^{2 3 10} Microscope mounting of portable SD-OCT systems have more recently described that provide foot-pedal control of X-Y-Z translation and increased stability for the scan axis.^{2-4 11} Microscope integrated prototypes have also been developed that allow for simultaneous surgical manoeuvres and OCT scanning.^{5 7 8} To date and to our knowledge, all microscope integrated *i*OCT systems have been add-on systems that mounted within the optical path (eg, before the objective lens) or accessed a side port for introducing the OCT beam, altering the overall

Figure 4 Visualising the impact of surgical manoeuvres. (A) Surgical view with crosshairs of optical coherence tomography (OCT) scanner following elevation of the posterior hyaloid in a vitreomacular traction (VMT) case. (B) B-scan following hyaloid elevation in VMT case reveals occult full-thickness macular hole (yellow arrow), altering surgical planning (eg, internal limiting membrane peeling, gas tamponade). (C) Surgical view of diamond dusted membrane scraper initiating membrane peel. (D) Real-time visualisation with intraoperative OCT of instrument-tissue interaction (red arrow). Indocyanine green staining results in shadowing of underlying tissue and enhanced visualisation of the internal limiting membrane (orange arrow).

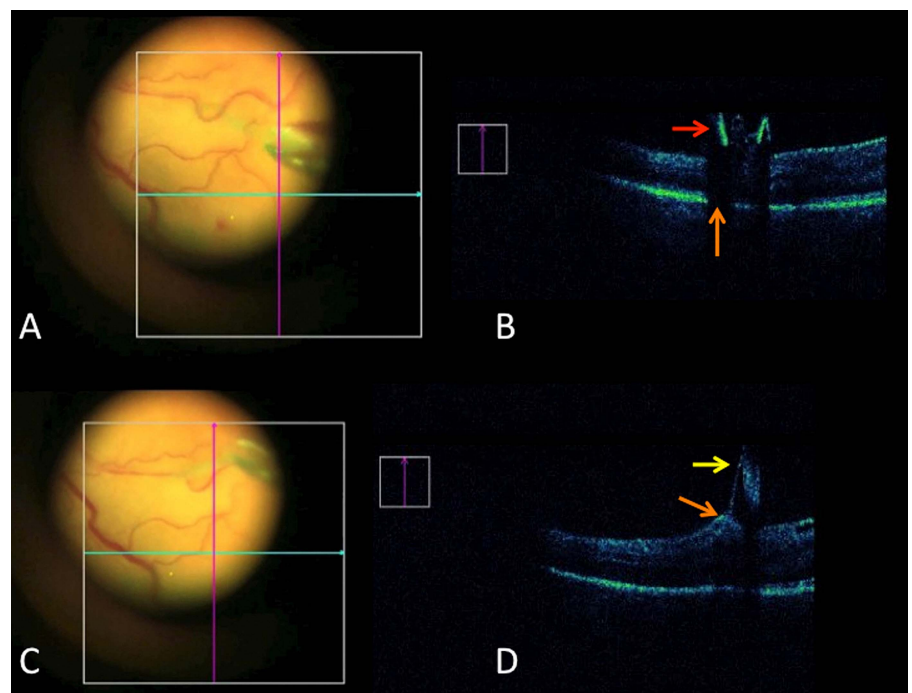


ergonomics of the microscope profile.^{5 7} Additionally, most of these systems used an OCT engine that resided outside of the housing of the surgical microscope, increasing the footprint of the overall system.^{5 7} The RESCAN 700 integration of microscope and OCT technology is a unique melding of the technologies that does not alter the external physical presence of the microscope head and has minimal alterations to the overall footprint of the system in the operating room. The RESCAN 700 is one of two prototypes that have been reported that includes the heads-up display system, and the first to be described in human use. The second system with heads-up display capability is the Cole Eye Institute microscope integrated *i*OCT prototype.^{9 12}

The progression of technology to include improved surgeon feedback, minimal disruption to surgical workflow and enhanced independent control will likely help facilitate the use of this technology. Further research is needed to continue to enhance our understanding of the role of *i*OCT in the surgical management of ophthalmic disease and to better delineate how *i*OCT can maximise surgical outcomes. We hope the final results of the DISCOVER study will help to improve our understanding of the role of microscope integrated *i*OCT in the management of ophthalmic surgery.

Contributors All authors contributed to the collection of data, conception and design of this study. All authors also contributed to drafting the manuscript and/or critical revisions and input on the manuscript. All authors also approved the final version.

Figure 5 Visualising instrument-tissue interactions. (A) Surgical view with optical coherence tomography (OCT) crosshairs near forceps engaging the internal limiting membrane (ILM). (B) Intraoperative OCT (*i*OCT) of forceps (red arrow). Metallic material results in absolute shadowing of the underlying tissues (orange arrow). (C) Surgical view of forceps actively peeling the ILM. (D) *i*OCT revealing ILM (yellow arrow) with focal traction and the internal retinal surface (orange arrow).



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Competing interests The following competing interests may be relevant to this publication: JE-Bioptigen (P); PK-Carl Zeiss Meditec (C), Alcon (C); SS-Bausch and Lomb (C); Bioptigen (P).

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