Clinical Evaluation of an Instrument-Integrated OCT-Based Distance Sensor for Robotic Vitreoretinal Surgery

Matteo Giuseppe Cereda, MD,1 Salvatore Parrulli, MD,1 Y.G.M. Douven,2 Koorosh Faridpooya, MD,3 Saskia van Romunde, MD,3 Gereon Hüttmann, PhD,4,5 Tim Eixmann, MSc,4 Hinnerk Schulz-Hildebrandt, PhD,4 Gernot Kronreif, MD,6 Maarten Beelen, MSc,7 Marc D. de Smet, MD, PhD7,8

Purpose: To assess the efficacy of an instrument-integrated OCT (iiOCT)-based distance sensor during robotic vitreoretinal surgery using the Preceyes Surgical System (PSS; Preceyes B.V.).

Design: Single-center interventional study.

Participants: Patients requiring vitreoretinal surgery.

Methods: Five patients were enrolled. Standard preoperative OCT images were obtained. After vitrectomy, a predefined set of actions was performed using the iiOCT-based sensor. Images then were processed to assess the signal-to-noise ratio (SNR) at various angles to the retina and at different distances between the instrument tip and the retinal surface. Preoperative and intraoperative OCT images were compared qualitatively and quantitatively.

Main Outcomes Measures: The feasibility in performing surgical tasks using the iiOCT-based sensor during vitreoretinal surgery, the SNR when imaging the retina, differences among intraoperative and preoperative OCT images, and characteristics of intraoperative retinal movements detected with the iiOCT-based probe.

Results: Surgeons were able to perform all the tasks but one. The PSS was able to maintain a fixed distance. The SNR of the iiOCT-based sensor signal was adequate to determine the distance to the retina and to control the PSS. Analysis of iiOCT-based sensor A-scans identified 3 clearly distinguishable retinal layers, including the inner retinal boundary and the interface at the retinal pigment epithelium—Bruch’s membrane. Thickness values differed by less than 5% from that measured by preoperative OCT, indicating its accuracy. The Fourier analysis of iiOCT-based sensor recordings identified anteroposterior retinal movements attributed to heartbeat and respiration.

Conclusions: This iiOCT-based sensor was tested successfully and promises reliable use during robot-assisted surgery. An iiOCT-based sensor is a promising step toward OCT-guided robotic retinal surgery. Ophthalmology Science 2021;1:100085 © 2021 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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distance from the retinal surface or other visible retinal structures such as the retinal pigment epithelium (RPE) by means of a virtual boundary function. Any anteroposterior motion would be compensated for by the PSS to maintain the tip of the instrument at a constant distance through a rapid feedback loop that is several times more reactive than is humanly possible. Because the robot has an inherent positional accuracy at < 5 μm, the ideal distance sensor in the tip of the instrument should function at this level of resolution. OCT is the ideal technology for this sensor because it was developed for tomographic imaging of the retina, has the required resolution, and not only allows the detection of the surface of the retina, but also visualizes deeper structures, including the RPE and choroid, with micrometer-depth precision. The use of line measurements (A-scans) instead of cross-sectional images (B-scan), which are commonly used in diagnostics and surgical devices, is sufficient for distance measurements and simplifies data acquisition, processing, and response time. An OCT probe made of a bare single-mode fiber without focusing optic would result in a working distance of a few hundred micrometers only, which would be unsuitable for this application. Therefore, we developed a small-distance sensor with a high working distance (approximately 1.9 mm) and a large measuring range of 12 mm in water, defined as the 12-dB intensity roll-off. This was achieved by adding a multimode gradient index fiber with a low numerical aperture that acts as focusing optics.

The aim of this study was to obtain OCT recordings of human retinas during robotic vitreoretinal surgery using an instrument-integrated OCT (iiOCT)-based distance sensor, and consequently, to evaluate the signal quality at different distances from the retina and to characterize the scans in static and dynamic tasks with regard to their ability to distinguish clinically relevant retinal landmarks. Clinical relevance of preoperative OCT scans was also considered because it could impact future surgical planning with OCT-controlled instruments. The iiOCT-based probe also allowed us to study physiologic variations in the position of retinal structures rarely reported in prior studies.

**Methods**

**Surgical Methods**

Five patients were enrolled and scheduled to undergo vitreoretinal surgery at Rotterdam Eye Hospital in February 2018 for this first-in-human clinical evaluation of a robot-controlled instrument with a real-time iiOCT-based sensor. The study was conducted in accordance with the principles of the Declaration of Helsinki (October 2013); the guidelines for good clinical practice for the design, conduct, recording, and reporting of clinical investigations carried out in human subjects to assess the safety or performance of medical devices (ISO 14155, 2011); and the Medical Research Involving Human Subjects Act (Wet medisch-wetenschappelijk onderzoek met mensen, 2006). The study was approved by the ethics committee of the Rotterdam Eye Hospital. The trial was registered in the Dutch national Algemeen Beoordelings en Registratie with the identifier NL63238.078.17. All patients signed an informed consent form. In all patients, a presurgical ophthalmologic assessment was performed that included best-corrected visual acuity (decimal) assessment, anterior segment evaluation at the slit lamp, Goldmann tonometry, and funduscopy. Multiple spectral-domain OCT scans were obtained using the OCT-HS100 (Canon; preoperative OCT) with a predetermined B-scan radial raster of 12 B-scans to study the macular region of each patient and to obtain B-scans useful for follow-up comparisons with the measurements of the iiOCT-based sensor.

All patients underwent surgery under general anesthesia. All surgeries were recorded with a camera coupled to the microscope (Leica Microsystems). Intraoperative systemic parameters were recorded during surgeries, particularly heartbeat and ventilation. Surgeries were performed by 2 surgeons (M.G.C., K.F.). For all surgeries, vitrectomy was performed using a 23-gauge system (Stellaris PC; Bausch & Lomb). The robotic section of the surgery started at the end of the standard vitreoretinal procedure. Surgeons followed a predefined protocol of actions that were split into 4 main parts: (1) instrument insertion into the vitreous cavity; (2) synchronization of recording devices (OCT, robot encoders, microscope camera) through sawtooth-like motions and backward steps; (3) movements of the instrument without virtual bound, divided into 4 steps, including (a) free approach to the retina to simulate instrument movements and velocities during a normal surgery, (b) lateral movements close to the retina following predefined lines and locations specified in Figure S1, (c) static positioning close to the retina at a structure-free location, and (d) pure axial movements using stepwise forward or retracting motions from the retina with a predetermined step size of 200 μm; and (4) evaluation of a virtual bound. A virtual bound was programmed to limit the forward movement of the instrument. The virtual bound was placed at 2 mm, providing sufficient distance to allow the surgeon to abort the attempt if, in his opinion, the retina was approached too closely (i.e., closer than 2 mm). The surgeon judged if the virtual bound was passed; this was later confirmed by the recordings.

**Surgical Setup**

The instrument inserted into the vitreous consisted of a tool incorporating an OCT-based distance sensor (the iiOCT-based sensor) coupled to the Preceyes Surgical System (PSS; Preceyes B.V.), a teleoperated robotic arm (Fig 1). The iiOCT-based sensor’s optical fiber was inserted manually into a 23-gauge needle that was mounted to an instrument body that connected the instrument to the robot (Fig S2).

The iiOCT-based sensor consists of a single-mode fiber (SM800-5.6-125; Thorlabs GmbH) and a focusing optics produced from a gradient-index fiber (OFS Fitel LLC). A total of 56 iiOCT-based probes with a working distance in water of 2.16 ± 0.29 mm and a spot size of 26 ± 5 μm of full width and half maximum were built for clinical evaluation (Fig 2). A spectral-domain OCT engine (Ganymede-II-SP12; Thorlabs GmbH) with a center wavelength of 930 nm was used in these experiments.

**Processing Methods**

A-scans of the targeted retina were acquired continuously at a frequency of 36 kHz, averaged in batches of 36 scans and further downsampled numerically (because of computational effects) to 700 Hz. The lateral resolution of each A-scan was 26 μm, with a depth resolution of 3.6 μm in water. Three separate processors were involved in the feedback loop to the instrument. One was used to process the OCT spectrum into A-scans and to obtain the distance measurement. The second processor was used to send commands to the robot, such as to enable the virtual bound and the
position of this virtual bound. The third processor is the robot controller for positioning the instrument tip. The total response time, defined as the duration from a physical event occurring (e.g., a retina movement) to the robot initiating a responding movement (e.g., a retracting motion) was 5 to 7 ms. This includes all communication steps between the processors and the contribution of the sensor-processing algorithm that is detecting the retina movement.

**Signal-to-Noise Ratio Analysis**

For iiOCT-based sensor images, the signal-to-noise ratio (SNR) was used to define the quality of the signal at various angles to the retina and at different distances between the instrument tip and the retinal surface. When no object was in range of the sensor, the A-scan showed an average intensity of more than zero. This average intensity is called the offset of the A-scan. A is the A-scan with this offset subtracted. The SNR is then defined as the maximum value of (i.e., max(A)) divided by the standard deviation of (i.e., std(A)):

$$SNR = \frac{\text{max}(A)}{\text{std}(A)}$$

This definition of SNR was chosen over other possible definitions because this directly quantifies the signal strength of the retina compared with the baseline noise.

The OCT device and the software were optimized to obtain an SNR suitable for small working distances.

**Retinal Thickness Comparison**

As a postoperative process, recorded microscope video was synchronized with the iiOCT-based sensor signal. The location of the preoperative OCT scans was registered manually to the microscope videos. Specific retinal locations scanned with both the preoperative OCT device and iiOCT-based sensor were used to compare image quality and retinal thickness between the preoperative OCT device and iiOCT-based sensor. Two experienced clinicians (M.G.C. and S.P.) analyzed OCT images to identify the number of recognizable retinal layers using both OCT systems. Retinal thickness was measured from the retinal surface to the RPE surface. Thickness recorded by the iiOCT-based sensor required compensation for the inclination angle of the instrument relative to the retina. To calculate the inclination angle, the distances acquired from the A-scans were combined with the robot position to obtain the retinal position in the robot coordinate frame. Then, a sphere was fitted through all retinal positions. The inclination angle was then calculated as

$$E = T - C$$

$$\alpha = \sin^{-1}\left(\frac{\langle E, T \rangle}{\|E\| \cdot \|T\|}\right)$$

where $T$ is the instrument tip position, $C$ is the center of the fitted sphere, $E$ denotes the vector from $C$ to $T$, and $\langle \cdot, \cdot \rangle$ denotes the inner product.

**Analysis of Retinal Dynamics**

Observable retinal movements were analyzed to detect any harmonic components. A Fourier transform of the retinal position over time was calculated to determine the frequency content of the retinal position.

**Results**

**Surgical Results**

The baseline characteristics of the 5 patients included in this study are listed in Table 1. In all patients, pars plana vitrectomy and any additional surgical task were executed first.

During robotic surgery, sequential phases were assessed as follows. During step 1, no difficulties were encountered in any of the patients or by either surgeon. In step 3a,
unrestricted movements were made by the surgeon with velocities mostly in the range of 0 to 1 mm/s, in both axial and lateral directions. When retracting the instrument, velocities of up to 10 mm/s were measured. In step 3b, lateral movements were made along predefined patterns. The movement was perceived as smooth, controlled, and linear by both surgeons. Temporal locations were more difficult to reach because of the position of the trocar on the temporal side of the eye. In step 3c, 2 to 5 events of static positioning were executed at structure-free locations (Fig S1) with the instrument located at a distance of 1.29 ± 0.44 mm from the retina. During each static event, the distance to the retina remained steady, with the only deviations caused by heartbeat and breathing. No drift was observed. In step 3d, the instrument was advanced robotically in steps of 200 μm from the core of the eye down to a minimum distance from the retina of between 1 and 2.5 mm. No drift was observed. In step 4, a virtual bound test was performed successfully. The instrument tip stopped as the virtual bound was reached (Fig 3). Three types of events may cause the distance between the instrument and the retina to decrease: (1) the surgeon provides commands via the motion controller to position the instrument closer to the retina, (2) retinal movements, and (3) lateral instrument movements combined with the local retinal geometry. For movements of type 1, violation of the virtual bound was prevented; the robot disallowed all positioning commands past the virtual bound. For movements of type 2 and 3, bound overshoots up to 40 μm were observed. The robot responded within 5 to 7 ms by retracting the instrument.

For patient 4, a communication problem occurred between the OCT processor and the robot processor. The procedure was aborted by the surgeon before its initiation. No surgical complications related to this malfunction occurred. In all other cases, the two surgeons never had the perception of being closer to the retina than the virtual bound and never felt the need to abort the surgery.

Signal-to-Noise Ratio

A-scans from the iiOCT-based sensor were recorded in all cases. Postprocessing allowed an assessment of the SNR of the recorded data (Fig 4). The fitted trendline shows an inverse linear relationship to the distance from the retina with a slope of $-5.3 \text{ mm}^{-1}$.

Validation of Retinal Detection

From the A-scan measurements, the processing algorithm calculated the retinal positions. This algorithm has 2 implementations: (1) detection of the retina in a single A-scan only and (2) detection of the retina using the full history of A-scans. Any discontinuities in the detected retina position signal would indicate faults in the detection algorithm. The position signal was fully continuous. This partly validated the quality of retinal detection. In addition, whenever the surgeon indicated proximity to the retina, retinal detection from the distance sensor was confirmed. At higher distances from the retina, the number of A-scans wherein the retina was detected decreased progressively. This means that implementation 1 of this processing algorithm was not able to detect the retina in some single A-

| Patient No. | Sex | Age (yrs) | Eye | Cause of Vitrectomy      | Best-Corrected Visual Acuity (Decimal) | Follow-up (mos) |
|-------------|-----|-----------|-----|--------------------------|----------------------------------------|----------------|
| 1           | Male| 63        | LE  | ERM                      | Baseline: 0.3                        | Postoperative: 0.6 | 8    |
| 2           | Male| 68        | LE  | ERM                      | Baseline: 0.3                        | Postoperative: 0.7 | 15   |
| 3           | Male| 55        | RE  | ERM                      | Baseline: 0.2                        | Postoperative: 0.3 | 18   |
| 4           | Female| 68    | RE  | Silicone oil removal     | Baseline: 0.05                       | Postoperative: 0.1 | 15   |
| 5           | Female| 49    | RE  | Floaters                | Baseline: 0.05                       | Postoperative: 0.3 | 15   |

Mean ± standard deviation: 60.6 ± 8.40

ERM = epiretinal membrane; LE = left eye; RE = right eye.
scans. However, at long distances, implementation 2 is acceptable. In this implementation, the SNR increases by averaging more A-scans over time, enabling retinal detection even up to the end of the measurement window of 3.2 mm, at the expense of response speed. Whenever the instrument approaches the retina, the SNR increases again, and the retina can be detected using single A-scans only (implementation 1), allowing the highest response speeds. The data showed that the retinal position could be estimated reliably from the iiOCT-based signal throughout the entire measurement window.

**Effect of Inclination Angle**

During surgery, inclination angles of between 53° and 79° were encountered (Fig S3). No specific correlation between the SNR and the inclination angle was observed; the retina could be detected for the entire range of inclination angles.

**Effect of Axial Velocity**

During pure axial movements, for all iiOCT-based sensor scans obtained, the SNR was not significantly influenced by the axial velocity of the instrument (Fig 5). Fringe washout occurs at 8.4 mm/s, as calculated based on the central wavelength and the acquisition frequency. This enforces an upper limit of 8.4 mm/s on the axial velocity of the instrument, above which the signal is of insufficient quality to be used for retinal detection. The instrument velocities are much lower, especially in close proximity to the retina, and hence fringe washout is easily prevented by restricting robotic velocities.

**Retinal Structures**

During pauses at prespecified retinal locations, the structures imaged by the iiOCT-based sensor scans were analyzed by the 2 clinicians. A series of bands were visible: an inner band with moderate reflectivity (from internal limiting membrane [ILM] to outer plexiform layer), a large hyporeflective outer band (outer nuclear layer), and a thin hyperreflective outermost band (ellipsoid zone—interdigitation zone junction to RPE; Fig S4). While stepwise increasing the distance from the tip of the instrument to the retina, iiOCT-based sensor scans showed a progressive decrease in reflectivity. At 3.2 mm from the retina, ellipsoid zone—interdigitation zone junction to RPE remained easily discernible, whereas inner retinal layers could barely be distinguished from one another (Fig 6).

In 4 patients, we were able to identify at least 2 retinal locations per eye that were scanned with both the preoperative OCT and the iiOCT-based sensor, for a total of 10 locations. Conventional retinal layers according to the International Nomenclature for OCT were recognizable in all preoperative OCT images. Compared with preoperative OCT images, inner retinal layers (from the ILM to outer plexiform layer) were not clearly discernible in iiOCT-based sensor images. However, the inner retinal boundary was always clearly visible and distinct from the vitreous cavity. A weak hyperreflective band corresponding to the ELM was visible in 4 of 10 (40%) iiOCT-based sensor recorded points (whereas it was always detectable on preoperative OCT scans). A hyperreflective outer retinal layer (RPE—Bruch’s membrane) was visible in all 10 positions.

Detailed thickness values are reported in Table 2. The minimum and maximum thickness difference between the 2 devices were 0 and 39 µm, respectively. The mean ± standard deviation absolute difference obtained by the 2 instruments in the same location was 16.11 ± 14.53 µm, with a mean relative difference of 5%. No corresponding spots were found for patient 3.
Retinal Dynamics

While holding the instrument motionless at a prespecified location, recorded A-scans allowed the visualization of retinal movements (Fig 7). Axial retinal movements were visible as a series of repetitive patterns. A Fourier transform of these retinal movements revealed that the periodicity corresponded to heartbeats (approximately 1 Hz) and breathing (approximately 0.2 Hz). Other harmonic components were negligible. Movements resulting from heartbeat showed an average amplitude of 8 μm, and movements resulting from breathing showed an average amplitude ranging from 5 to 12 μm for patients 1, 2, 4, and 5. In patient 3, retinal movements induced by breathing of more than 200 μm were recorded. This patient experienced an AV block during surgery, with ventricular escape rhythm leading to bradycardia.

Discussion

Robotic Precision and Potential Sensor Benefits

In a recent study, accuracy and precision in performing simulated stationary and dynamic tasks with and without the use of a robotic assistant were compared. Instrument positioning was improved significantly by the addition of a robotic assistant in both expert and novice surgeons. However, both accuracy and precision were more than 10 times better when under full robotic control. Eye–hand coordination and the limits of human physiology were identified as contributors to this difference. The optimal use of a robot’s precision can be achieved only by providing information about the distance between instruments and intraocular tissues. Sensor-integrated instruments providing this distance to the robot in real time could allow the robot to provide fine adjustments in delicate procedures requiring micrometer precision. Another benefit is improved safety by preventing accidental retinal or lens contact. Safety can also be enhanced by providing acoustic feedback related to the distance of the instrument tip for the retina.

Virtual Bound and Robotic Response Time

Maintaining a constant position or minimum distance from delicate retinal structures is a characteristic challenge in vitreoretinal surgery. The use of the iiOCT-based sensor with the robotic setup was successful in maintaining a minimum distance to the retina at all times, using a virtual bound. The current response time is 5 to 7 ms, 60-fold faster than the response of a surgeon. It suggests the possibility of enhanced safety during intraocular tissue manipulations as well as from inadvertent head or eye movements, which will be the subject of future investigations.

Signal-to-Noise Ratio

Although a linear reduction of SNR was observed with increasing distance from the retina (Fig 4), throughout the entire measurement window of 3.2 mm, the sensor processing algorithm was estimating the retinal position reliably from the A-scans. At larger distances, several A-scans did not have a sufficient SNR to be used reliably for retinal detection on a single A-scan only. Below a certain SNR value, detection of the retina using the full history of A-scans may also fail to provide a continuous retinal position. In this case, a manual approach could be favored, with an automated switch back to robotic control above this SNR value. No correlation between SNR and inclination angle was observed for inclination angles of 53° to 79° (Fig S3). This is well within the usual surgical field of most intraocular procedures.

Different axial velocities of the instrument were tested, without significantly influencing the SNR (Fig 5). The instrument velocities are much lower than the fringe washout value of 8.4 mm/s, especially in close proximity to the retina.
to the retina. Such problems are prevented easily by restricting robotic velocities.18

Retinal Structures

Analyzing A-scans during static positioning allowed us to define 3 main layer groups based on reflectivity (Fig S4). The innermost layer group presented a moderate reflectivity and, according to the International Nomenclature for OCT,16 comprised layers from the ILM to the outer plexiform layer. The intermediate layer group presented a low reflectivity and corresponded to Henle’s fiber layer and the outer nuclear layer. The outermost highly reflective layer represented the photoreceptor–RPE complex. The 2 clinicians considered the A-scan images of sufficient quality to identify the inner boundary of the retina and to guide an epiretinal membrane–ILM peeling. However, additional A-scan averaging may be of benefit for high-precision intraretinal tasks such as subretinal or sub-RPE injections. Furthermore, it is acceptable that the distance from the retina may influence the visibility of retinal layers as a consequence of SNR reduction.

Retinal Dynamics

The analysis of OCT recordings with the instrument pausing at a free location allowed the recognition of periodic retinal movements (Fig 7). From analysis of Fourier transforms, we could isolate movements resulting from heartbeats with a mean amplitude of 8 μm. Previous work using preoperative OCT showed an amplitude of 10 to 29 μm.19 These measurements may have included a second periodic component attributable to breathing. Moreover, in our case, the robot suppresses eye movements because of its connection to the trocar. We measured breathing amplitudes of 5 to 12 μm.

Interest in targeting precise locations such as the subretinal space in gene therapy is considerable. Even in the presence of minor eye movements, a risk exists of penetrating through Bruch’s membrane and exposing the subretinal space to the systemic immune response. With the iiOCT-based sensor, the robotic system would be able to follow these periodic fluctuations, continuously correcting the instrument position based on the preset distance from the retina or RPE.

In conclusion, we demonstrated that an instrument-integrated OCT-based distance sensor can be used successfully and reliably during robot-assisted vitreoretinal surgery. It allowed us to obtain reliable OCT measurements of good quality with discernible retinal layers throughout the entire measurement window of 3.2 mm. These were not influenced by the instrument velocities up to 3.5 mm/s or by instrument inclination angles within the commonly used surgical field. Minimum distances from

### Table 2. Thickness Values Obtained with the 2 OCT Devices

| Patient No. | Position | Preoperative OCT Thickness (μm) | Instrument-Integrated OCT Thickness (μm) | Difference* | Absolute Difference | Relative Difference (%) |
|-------------|----------|---------------------------------|----------------------------------------|-------------|---------------------|-------------------------|
| 1 A         | 453      | 456                             | –3                                     | 3           | 0.6                 |
| 1 B         | 315      | 313                             | 2                                      | 2           | 0.6                 |
| 1 C         | 330      | 317                             | 13                                     | 13          | 3.9                 |
| 2 A         | 439      | 439                             | 0                                      | 0           | 0                   |
| 2 B         | 340      | 377                             | –37                                    | 37          | 10                  |
| 3 A         | 293      | 303                             | –10                                    | 10          | 3.4                 |
| 3 B         | 289      | 266                             | 23                                     | 23          | 7.9                 |
| 4 A         | 315      | 276                             | 39                                     | 39          | 12                  |
| 4 B         | 340      | 322                             | 18                                     | 18          | 7.5                 |
| 5 A         | 315      | 326                             | 18                                     | 18          | 5.1                 |
| 5 B         | 340      | 322                             | 18                                     | 18          | 5.1                 |

*Preoperative OCT thickness minus instrument-integrated OCT-based sensor thickness.

Mark: Absolute difference divided by the preoperative OCT thickness.

ELM = external limiting membrane; EZ–IZ = ellipsoid zone–interdigitation zone; IRL = inner retinal layers, from the internal limiting membrane to the outer plexiform layer; ONL = outer nuclear layer; RPE = retinal pigment epithelium.

Figure 7. Image showing instrument-integrated OCT-based sensor A-scan recordings with the instrument in static position. Repetitive retinal movements are visible.
the retina were maintained using the sensor. The robot retracted the instrument after any physiologic anteroposterior movement of the retina, keeping any virtual bound overshoots to within 40 μm. Future work is required for seamless use of the iiOCT-based sensor by surgeons during robot-assisted procedures. This should include the integration of the iiOCT-based sensor in real surgical instruments and software functionality for supporting specific surgical procedures.

Footnotes and Disclosures

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1 Eye Clinic, Department of Biomedical and Clinical Science “Luigi Sacco,” Sacco Hospital, University of Milan, Milan, Italy.
2 Department of Mechanical Engineering, University of Technology, Eindhoven, The Netherlands.
3 Rotterdam Eye Hospital, Rotterdam, The Netherlands.
4 Department of Biomedical and Clinical Science, Eye Clinic, Department of Biomedical and Clinical Science, Rotterdam, The Netherlands.

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References

1. de Smet MD. Robotic assistance and its impact on vitreoretinal surgery. Expert Rev Ophthalmol. 2020;15(3):127–128.
2. Gerber MJ, Pettenkofer M, Hubschman J-P. Advanced robotic surgical systems in ophthalmology. Eye (Lond). 2020;34(9):1554–1562.
3. Chammas T, Sauer A, Pizzuto J, et al. Da Vinci Xi robot-assisted penetrating keratoplasty. Transf Vis Sci Technol. 2017;6(3):21.
4. Bourcier T, Chammas J, Becmeur P-H, et al. Robot-assisted simulated cataract surgery. J Cataract Refract Surg. 2017;43(4):552–557.
5. Bourcier T, Chammas J, Becmeur P-H, et al. Robotically assisted pterygium surgery: first human case. Cornea. 2015;34(10):1329–1330.
6. Boursal DH, Hubschman JP, Culjat M, et al. Feasibility study of intracocular robotic surgery with the da Vinci surgical system. Retina. 2008;28(1):154–158.
7. Harwell RC, Ferguson RL. Physiologic tremor and microsurgery. Microsurgery. 1983;4(3):187–192.
8. de Smet MD, Naus GJL, Faridpooya K, Mura M. Robotic-assisted surgery in ophthalmology. Curr Opin Ophthalmol. 2018;29(3):248–253.
9. de Smet MD, Stassen JM, Meenink TCM, et al. Release of experimental retinal vein occlusions by direct intraluminal injection of ocirplasin. Br J Ophthalmol. 2016;100(12):1742–1746.
10. Edwards TL, Xue K, Meenink HCM, et al. First-in-human study of the safety and viability of intraocular robotic surgery. Nat Biomed Eng. 2018;2:649–656.
11. Maberley DAL, Beelen M, Smit J, et al. A comparison of robotic and manual surgery for internal limiting membrane peeling. Graefes Arch Clin Exp Ophthalmol. 2020;258(4):773–778.
12. de Smet MD, de Jonge N, Iannetta D, et al. Human/robotic interaction: vision limits performance in simulated vitreoretinal surgery. *Acta Ophthalmol.* 2019;97(7):672–678.
13. Huang D, Swanson EA, Lin CP, et al. Optical coherence tomography. *Science.* 1991;254(5035):1178–1181.
14. van Velthoven MEJ, Faber DJ, Verbraak FD, et al. Recent developments in optical coherence tomography for imaging the retina. *Prog Retin Eye Res.* 2007;26(1):57–77.
15. Sun X, Li J. Design of a long working distance graded index fiber lens with a low NA for fiber-optic probe in OCT application. *Proc SPIE.* 2014;8938–8944.
16. Staurenghi G, Sadda S, Chakravarthy U, Spaide RF. Proposed lexicon for anatomic landmarks in normal posterior segment spectral-domain optical coherence tomography: the IN*OCT consensus. *Ophthalmology.* 2014;121(8):1572–1578.
17. Pfister M, Lue J-CL, Stefanini FR, et al. Comparison of reaction response time between hand and foot controlled devices in simulated microsurgical testing. *Biomed Res Int.* 2014;2014:769296.
18. Yun SH, Tearney G, de Boer J, Bouma B. Motion artifacts in optical coherence tomography with frequency-domain ranging. *Opt Express.* 2004;12(13):2977–2998.
19. de Kinkelder R, Kalkman J, Faber DJ, et al. Heartbeat-induced axial motion artifacts in optical coherence tomography measurements of the retina. *Invest Ophthalmol Vis Sci.* 2011;52(6):3908–3913.