Intraoperative optical coherence tomography in anterior segment surgeries

Jeewan S Titiyal, Manpreet Kaur, Ruchita Falera

Intraoperative optical coherence tomography (iOCT) is a noninvasive imaging modality that provides a real-time dynamic feedback of the various surgical steps. Comprehensive literature search was performed in MEDLINE using "intraoperative optical coherence tomography" and "iOCT" as keywords. The use of iOCT as an aid to decision-making has been successfully reported in cases undergoing keratoplasty, implantable Collamer lens (ICL) implantation as well as cataract surgery. iOCT helps to assess the graft-host relationship in penetrating keratoplasty. It helps confirm the presence of a big bubble, detect subclinical big bubbles and guide layer by layer stromal dissection in cases of deep anterior lamellar keratoplasty. It acts as a guide during crucial surgical steps in endothelial keratoplasty, right from scoring of the Descemet membrane to ensuring graft apposition at the end of surgery. The morphological features of the corneal incision in phacoemulsification may be assessed. iOCT is a useful tool in assessing the status of the posterior capsule and may help identify preexisting posterior capsular defects during cataract surgery in various clinical scenarios such as posterior polar cataract, traumatic cataract, and vitrectomized eyes. It allows on-table assessment of the ICL vault and potentially facilitates exchange of ICL in the same sitting in extremes of vault. Ocular surface disorders such as ocular surface squamous neoplasia, pterygium, and dermoid may find an application for iOCT, wherein an iOCT-guided stromal dissection will ensure adequate depth of dissection. Further technological advancements may allow for automatic centration and tracking and address the present limitation of instrument-induced shadowing.

Key words: Anterior segment iOCT, intraoperative optical coherence tomography, microscope-integrated optical coherence tomography

Access this article online
Website: www.ijo.in
DOI: 10.4103/ijo.IJO_868_16
Quick Response Code:

Optical coherence tomography (OCT) is a noninvasive imaging modality that employs the principle of low-coherence interferometry to provide an *in vivo* cross-sectional view of the ocular structures with micrometer resolution. It has found a widespread application in ophthalmology and aids in the preoperative diagnosis, intraoperative decision-making as well as postoperative monitoring of various diseases. Intraoperative OCT (iOCT) is an emerging modality with the potential to revolutionize the surgical techniques by providing a real-time dynamic feedback of the tissue alterations during surgery.[1,2] Handheld and microscope-mounted OCT devices have been successfully used in both anterior and posterior segment surgeries.[1] However, these devices require the surgical procedure to be paused to capture the images, thus adding to the duration of surgery. Moreover, the images are static in nature and do not provide a real-time picture of the tissue-instrument interactions. The recently introduced microscope-integrated iOCT seamlessly integrates image acquisition while performing surgery and allows for a real-time assessment of the various surgical steps.[2] We herein describe the applications of iOCT in anterior segment surgeries.

Cornea, Cataract and Refractive Surgery Services, Dr. Rajendra Prasad Centre for Ophthalmic Sciences, All India Institute of Medical Sciences, New Delhi, India

Correspondence to: Prof. Jeewan S Titiyal, Cornea, Cataract and Refractive Surgery Services, Dr. Rajendra Prasad Centre for Ophthalmic Sciences, All India Institute for Medical Sciences Ansari Nagar, New Delhi - 110 029, India. E-mail: titiyal@gmail.com

Manuscript received: 09.11.16; Revision accepted: 25.01.17

Keratoplasty

iOCT may be used in both full-thickness and lamellar keratoplasty procedures as an aid to decision-making.[3-12] In penetrating keratoplasty, iOCT helps to delineate the anterior segment architecture in cases with extensive synechiae or corneo-iridic scars and help avoid iris trauma during initial trephination.[3] The graft-host relationship can be continually assessed during surgery, and this can help prevent over- or under-riding of the graft and ensure proper apposition at the host-graft edge.

Superficial anterior lamellar keratoplasty and anterior lamellar therapeutic keratoplasty involve microkeratome-assisted preparation of the donor tissue as well as the host bed. After microkeratome-assisted removal of the anterior stromal layers, the presence of residual corneal opacities as well as their extent may be confirmed by the iOCT. Intraoperative OCT can help guide further manual lamellar dissection in cases with persistent opacities after the initial microkeratome pass. The residual stromal bed thickness can be ascertained on-table, thereby enhancing the safety of the procedure. The host-donor

Cite this article as: Titiyal JS, Kaur M, Falera R. Intraoperative optical coherence tomography in anterior segment surgeries. Indian J Ophthalmol 2017;65:116-21.

apposition can be directly observed on the iOCT, and any interface fluid or debris can be detected as well as removed under direct visualization.

The success of deep anterior lamellar keratoplasty (DALK) depends on preserving an intact Descemet membrane (DM) while leaving the minimal amount of residual stroma. The big-bubble technique is commonly used to achieve maximum stromal dissection. Intraoperative OCT facilitates the creation of a big bubble by aiding in the assessment of the initial depth of trephination and the depth of needle insertion. The achievement of the big bubble can usually be ascertained clinically.[4] The iOCT helps to confirm the presence of a big bubble, detect subclinical big bubbles, and guide further dissection. However, metallic instruments cause a shadowing effect on the iOCT images and hamper the visualization of the underlying structures, thus limiting the potential use of iOCT during intrastromal insertion of the needle or during lamellar dissection. The instruments need to be transiently removed from the surgical field to allow an accurate assessment of the underlying ocular structures. Despite these limitations, iOCT has emerged as an invaluable tool in cases that require a layer by layer dissection of stroma, where it allows a continuous assessment of the surgical steps, including the depth of the initial trephination, the level of dissection, and the amount of residual stroma [Fig. 1]. The presence of any interface fluid can be ascertained with the help of an iOCT. Further maneuvers such as corneal massage or venting incisions may be performed toward the end of surgery to ensure proper apposition. This decreases the incidence of a double anterior chamber in the postoperative period and may help avoid a second surgical procedure.[2,5,6]

DM detachment (DMD) is a common postoperative complication after DALK, especially in cases that have a microperforation during the initial surgery. Intraoperative OCT has been reported to aid in the injection of isoexpansile gas in the anterior chamber to manage the DMD. It helps to select the site of placement of venting incisions to drain the interface fluid, and the reapposition of the DM can be confirmed during surgery.[7]

Endothelial keratoplasty is the procedure of choice for cases with corneal decompensation secondary to endothelial dysfunction. iOCT helps in monitoring the crucial surgical steps in both Descemet stripping automated endothelial keratoplasty (DSAEK) and DM endothelial keratoplasty (DMEK), right from scoring of the DM to ensuring graft apposition at the end of surgery.[2,8-10]

Double-pass technique that involves cutting the donor tissue twice with different microkeratome blades has been described to ensure the creation of thin lenticules to enhance visual outcomes after DSAEK. After the initial microkeratome pass, the residual donor thickness can be assessed with the help of iOCT to guide the surgeon in the selection of the ideal blade size for the second microkeratome pass. This will help achieve extremely thin donor lenticules while minimizing the chance of perforation of the donor tissue. Even in cases where a single microkeratome pass is used for donor tissue preparation, iOCT accurately assesses the donor thickness and helps select the ideal blade size [Fig. 2].[12]

DM visualization may pose a difficulty during scoring. Different techniques have been described to enhance visualization of the DM, such as the use of trypan blue dye to stain the DM and the use of a crescent blade as a reflector.[13] iOCT aids in the identification and removal of DM in cases with severely edematous corneas. Remnant DM tags can be easily identified in cases with a fibrosed and scarred DM and removed under direct visualization.

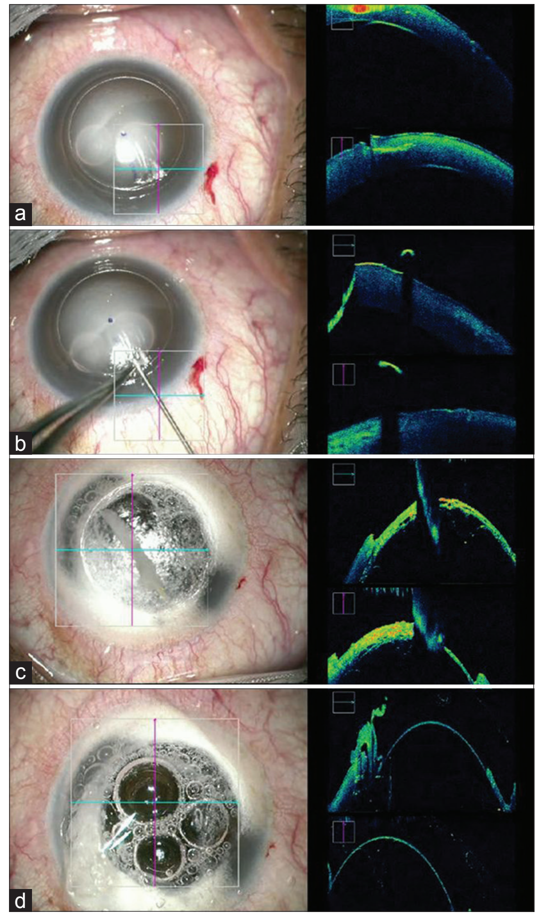

Figure 1: Intraoperative optical coherence tomography-guided deep anterior lamellar keratoplasty. (a) Depth of initial trephination as assessed by intraoperative optical coherence tomography. (b) Needle insertion in corneal stroma to attempt “big-bubble” formation. Shadowing effect induced by the needle with obscuration of underlying structures. (c) Layer by layer stromal dissection. (d) Bare Descemet membrane exposed by intraoperative optical coherence tomography-guided meticulous layer by layer dissection

The true stromal thickness can be assessed in cases with bullous keratopathy with the help of an iOCT, where the hypertrophic epithelium gives a fallaciously high total corneal thickness by other investigative modalities.

The graft insertion and unfolding can be continuously monitored with an iOCT. This is especially advantageous in severely edematous corneas with poor visibility where the graft may open in an inverse configuration and lead to a failure of the surgery. Thin donor lenticules are associated with superior visual outcomes; however, their handling is more difficult, and the thin lenticules have a propensity to fold upon themselves and roll. Intraoperative OCT is an invaluable tool to ensure proper unfolding and orientation of extremely thin lenticules.

The complete apposition of the donor lenticule is a critical step determining the success of surgery, and various maneuvers such as corneal massage, internal air tamponade, and venting incisions have been described to ensure complete removal of interface fluid. iOCT helps in determining the efficacy of these techniques, and it has been reported that simultaneous corneal massage while maintaining a positive intracameral pressure is the most important maneuver to ensure a rapid and complete donor lenticule adherence [Fig. 3].[2,8,9]

iOCT also provides an objective end point to these maneuvers since complete graft apposition can be directly visualized at the completion of surgery. Its use has helped in understanding that the donor lenticule is well apposed within one to three minutes with the help of simultaneous positive intracameral pressure and external corneal massage. The decrease in the waiting time for graft apposition prevents unnecessarily prolonged IOP elevation and promotes optimal utilization of the operating theater time.[8]

A study to determine the feasibility and utility of iOCT reported that it helped in decision-making, and additional maneuvers were required on the basis of iOCT in 41% of cases undergoing DSAEK. Intraoperative OCT revealed persistent fluid in 19% of cases where the surgeon believed the graft to be completely apposed clinically, thus necessitating further maneuvers. It revealed complete apposition in 47% of cases where the surgeon did not believe the graft to be entirely apposed, thus minimizing surgical time and unnecessary manipulations. The use of iOCT during DSAEK has the potential to decrease total surgical duration as well as minimize postoperative graft dislocations.[2]

Intraoperative OCT has also been reported to enhance the visibility of graft orientation and unfolding, thereby improving the safety of the DMEK procedure.[10,11]

Cataract Surgery

Cataract is a leading cause of vision loss and morbidity in the elderly population, and cataract surgery is one of the most common ophthalmic surgical procedures. Proper incision construction is essential to prevent wound-related complications and postoperative hypotony in cases undergoing cataract surgery.[14] Intraoperative OCT has been used to assess the morphological features of the wound such as length, breadth, and the number of planes in real time as well as epithelium disruption, amount of wound gape, endothelial alignment, and Descemet's detachment [Fig. 4]. The adequacy of stromal hydration and wound apposition can be ascertained at the end of surgery, thus decreasing the incidence of postoperative wound leak.[15]

We have studied the morphology of the internal opening of the corneal incision using iOCT and determined that a ragged slit morphology predisposes to wound site DMD (unpublished results). Maximum incidence of wound site DMD was observed during the step of final stromal hydration and can be easily assessed by the iOCT on-table.

Intraoperative OCT is a useful tool in assessing the status of the posterior capsule during cataract surgery in various clinical scenarios. In cases with posterior polar cataract, it may help detect cases with a true posterior capsular defect [Fig. 5]. This may allow the surgeon to exercise extra caution in such cases, thus reducing the incidence of complications. It may also help ascertain the posterior capsule status in cases with a traumatic cataract.[15] Patients with posterior segment pathology often develop cataract during the course of treatment which may be associated with iatrogenic posterior capsular defect. Intraoperative OCT-assisted phacoemulsification can help identify the preexisting posterior capsular defect in cases with operated pars plana vitrectomy or a history of multiple intravitreal injections [Fig. 6]. In cases with silicon oil *in situ* and hyperoleon, the density and extent of silicon oil in anterior chamber can be assessed with the help of iOCT. In pediatric patients, the presence of fibrovascular stalk in cases of primary hyperplastic persistent vitreous and posterior capsular defect in posterior polar cataract may be ascertained with the help of iOCT.

The position of the intraocular lens (IOL) as well as its stability can be assessed at the end of surgery.[16] IOL position and stability is crucial in cases undergoing penetrating

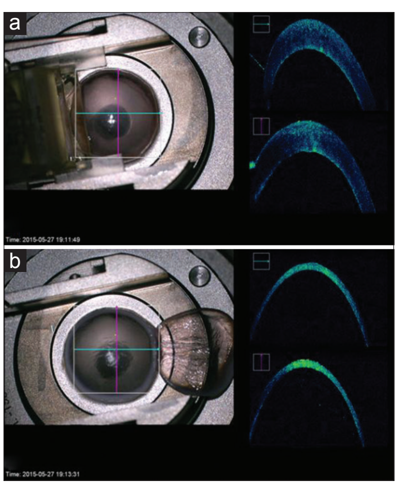

Figure 2: Intraoperative optical coherence tomography-guided microkeratome-assisted donor preparation in a case of Descemet stripping automated endothelial keratoplasty. (a) Appropriate blade size selected based on the corneal thickness as assessed by the intraoperative optical coherence tomography. (b) Thin donor lenticule after microkeratome pass

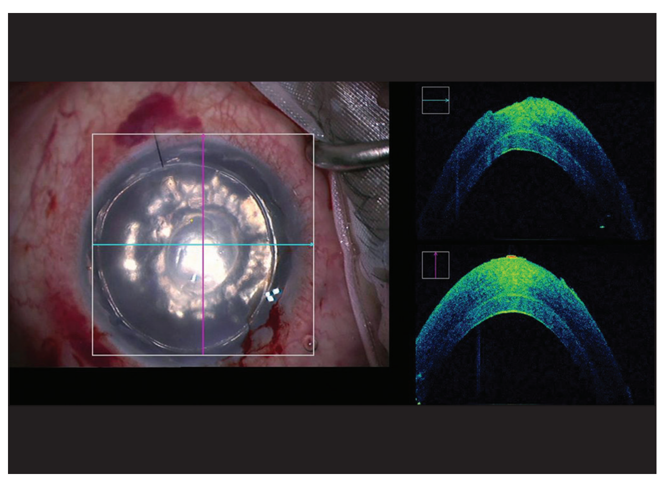

Figure 3: Complete donor apposition as assessed by intraoperative optical coherence tomography at the end of surgery in a case of Descemet stripping automated endothelial keratoplasty

keratoplasty or endothelial keratoplasty, where iOCT may help in decision-making regarding exchange or explant of IOL.

Novice surgeons can assess the depth of trenching using an iOCT, thus decreasing the incidence of posterior capsular rupture during phacoemulsification and increasing the safety of the procedure.[15]

It has an application in intumescent white cataracts, where the presence of fluid clefts on an iOCT with a bulging anterior capsule may alert the surgeon to the presence of raised intralenticular pressure and the possibility of anterior capsular extension.

Phakic Intraocular Lens Implantation

Phakic IOL (pIOL) implantation has emerged as a safe and effective alternative to corneal ablative procedures to correct moderate to high refractive errors.[17] Implantable Collamer lens (ICL) is a posterior chamber pIOL that is the Food and Drug Administration approved for correction of myopia. The success of ICL implantation depends on achieving an adequate vault since extremes of vaulting are associated with complications such as glaucoma and cataract.[18,19] Vaulting is generally assessed clinically as well as on anterior segment OCT in the postoperative period. Intraoperative OCT allows on-table assessment of the ICL vault and potentially facilitates exchange of ICL in the same sitting in cases of extremes of vault [Fig. 7]. This may help prevent the development of cataract and glaucoma in the postoperative period. Furthermore, the ICL-lenticular relationship can be assessed continually during the surgery, and this may help avoid any inadvertent lens touch.[20] Intraoperative OCT may also help novice surgeons to assess the orientation of the ICL and detect an inadvertent inverse ICL on-table.

Ocular Surface Disorders

Ocular surface disorders such as ocular surface squamous neoplasia (OSSN), pterygium, and dermoid may find an application for iOCT though no study has evaluated the role of iOCT in such cases. Extensive, recurrent pterygium may be associated with underlying corneal thinning as a result of

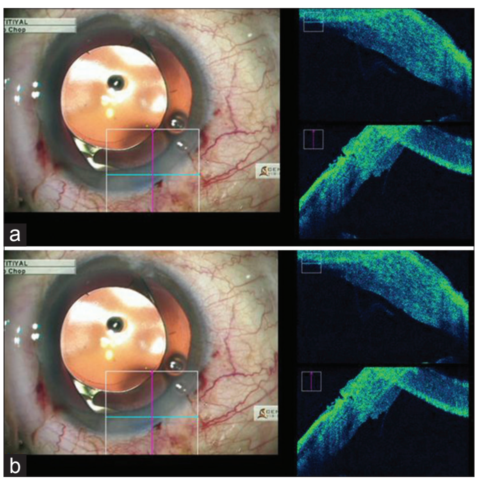

Figure 4: Intraoperative optical coherence tomography-guided assessment of corneal incision. (a) Biplanar morphology of the corneal incision at the beginning of surgery. (b) Localized incision-site Descemet membrane detachment toward the end of surgery after stromal hydration

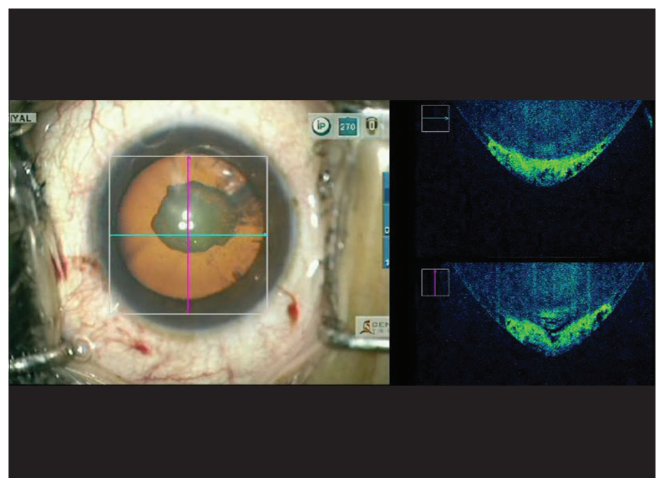

Figure 5: Posterior polar cataract with intact posterior capsule as assessed by intraoperative optical coherence tomography

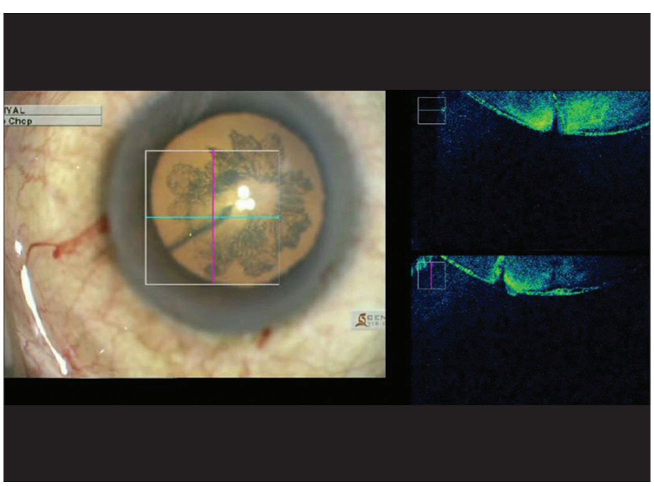

Figure 6: Preexisting posterior capsular defect in a case with history of multiple intravitreal injections planned for cataract surgery

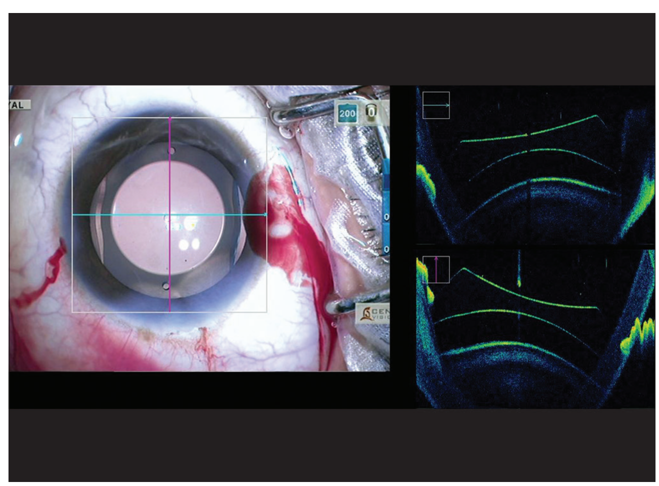

Figure 7: On-table vault of implantable collamer lens assessed with the help of intraoperative optical coherence tomography at the end of surgery

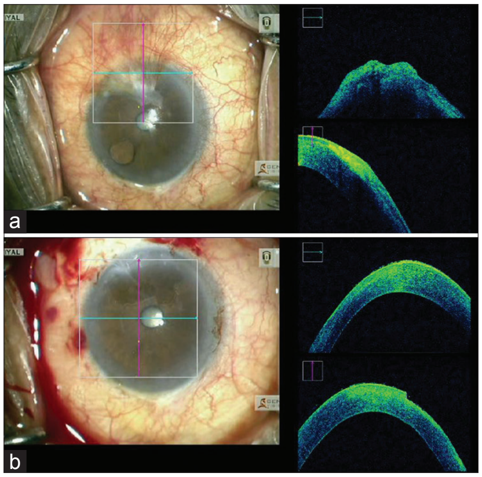

Figure 8: Intraoperative optical coherence tomography-guided pterygium excision. (a) Preoperative assessment of the extent and depth of the pterygium. (b) Postoperative smooth corneal surface after pterygium excision

previous surgeries. An iOCT-guided dissection of pterygium will help in the continuous assessment of the residual stromal bed and ensure adequate depth of dissection [Fig. 8]. The same principle applies in cases with OSSN and dermoid, where the residual stromal bed could be assessed during excision of the pathological lesion. This will help prevent inadvertent corneal perforations. The need for a lamellar graft can be assessed on-table based on the residual stromal depth.

What the Future Holds

Intraoperative OCT aids in decision-making in various anterior segment surgeries and has the potential to decrease surgical time as well as postoperative complications. Technological advancements have led to the replacement of handheld and microscope-mounted OCT devices with microscope-integrated iOCT that seamlessly integrates image acquisition with the various surgical steps. A prototype automated stereo vision surgical instrument tracking system has been developed that automatically centers the iOCT scan-field on the surgical instrument tip and allows for continuous visualization of instrument-tissue interactions over a 2500 mm^2 field.[21] Widespread use of this technology will further enhance the advantages of iOCT. One of the major limitations of microscope-integrated iOCT is the shadowing induced by the surgical instruments, obscuring the underlying cross-sectional view. Further advances in the iOCT technology may help overcome these obstacles in the near future and enhance the safety of various surgical procedures.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Ehlers JP, Dupps WJ, Kaiser PK, Goshe J, Singh RP, Petkovsek D, *et al.* The Prospective Intraoperative and Perioperative Ophthalmic ImagiNg with Optical CoherEncE TomogRaphy (PIONEER) Study: 2-year results. Am J Ophthalmol 2014;158:999-1007.
2. Ehlers JP, Goshe J, Dupps WJ, Kaiser PK, Singh RP, Gans R, *et al.* Determination of feasibility and utility of microscope-integrated optical coherence tomography during ophthalmic surgery: The DISCOVER Study RESCAN Results. JAMA Ophthalmol 2015;133:1124-32.
3. Eguchi H, Kusaka S, Arimura-Koike E, Tachibana K, Tsujioka D, Fukuda M, *et al*. Intraoperative optical coherence tomography (RESCAN(®) 700) for detecting iris incarceration and iridocorneal adhesion during keratoplasty. Int Ophthalmol 2016 Aug 11. [Epub ahead of print].
4. AlTaan SL, Termote K, Elalfy MS, Hogan E, Werkmeister R, Schmetterer L, *et al.* Optical coherence tomography characteristics of different types of big bubbles seen in deep anterior lamellar keratoplasty by the big bubble technique. Eye (Lond) 2016;30:1509-16.
5. Steven P, Le Blanc C, Lankenau E, Krug M, Oelckers S, Heindl LM, *et al.* Optimising deep anterior lamellar keratoplasty (DALK) using intraoperative online optical coherence tomography (iOCT). Br J Ophthalmol 2014;98:900-4.
6. Au J, Goshe J, Dupps WJ Jr., Srivastava SK, Ehlers JP. Intraoperative optical coherence tomography for enhanced depth visualization in deep anterior lamellar keratoplasty from the pioneer study. Cornea 2015;34:1039-43.
7. Sharma N, Aron N, Kakkar P, Titiyal JS. Continuous intraoperative OCT guided management of post-deep anterior lamellar keratoplasty descemet's membrane detachment. Saudi J Ophthalmol 2016;30:133-6.
8. Titiyal JS, Kaur M, Falera R, Jose CP, Sharma N. Evaluation of time to donor lenticule apposition using intraoperative optical coherence tomography in descemet stripping automated endothelial keratoplasty. Cornea 2016;35:477-81.
9. Xu D, Dupps WJ Jr., Srivastava SK, Ehlers JP. Automated volumetric analysis of interface fluid in descemet stripping automated endothelial keratoplasty using intraoperative optical coherence tomography. Invest Ophthalmol Vis Sci 2014;55:5610-5.
10. Steven P, Le Blanc C, Velten K, Lankenau E, Krug M, Oelckers S, *et al.* Optimizing descemet membrane endothelial keratoplasty using intraoperative optical coherence tomography. JAMA Ophthalmol 2013;131:1135-42.
11. Saad A, Guilbert E, Grise-Dulac A, Sabatier P, Gatinel D. Intraoperative OCT-assisted DMEK: 14 consecutive cases. Cornea 2015;34:802-7.
12. Kobayashi A, Yokogawa H, Mori N, Sugiyama K. Visualization of precut DSAEK and pre-stripped DMEK donor corneas by intraoperative optical coherence tomography using the RESCAN 700. BMC Ophthalmol 2016;16:135.
13. Sharma N, Sharma VK, Arora T, Singh KR, Agarwal T, Vajpayee RB. Novel technique for descemet membrane remnant stripping in hazy cornea during DSAEK. Cornea 2016;35:140-2.
14. Taban M, Sarayba MA, Ignacio TS, Behrens A, McDonnell PJ. Ingress of India ink into the anterior chamber through sutureless clear corneal cataract wounds. Arch Ophthalmol 2005;123:643-8.
15. Das S, Kummelil MK, Kharbanda V, Arora V, Nagappa S, Shetty R, *et al.* Microscope integrated intraoperative spectral domain optical coherence tomography for cataract surgery: Uses and applications. Curr Eye Res 2016;41:643-52.
16. Lytvynchuk LM, Glittenberg CG, Falkner-Radler CI, Neumaier-Ammerer B, Smretschnig E, Hagen S, *et al.* Evaluation of intraocular lens position during phacoemulsification using intraoperative spectral-domain optical coherence tomography. J Cataract Refract Surg 2016;42:694-702.
17. Barsam A, Allan BD. Excimer laser refractive surgery versus phakic intraocular lenses for the correction of moderate to high myopia. Cochrane Database Syst Rev 2014;6:CD007679.

18. Kojima T, Maeda M, Yoshida Y, Ito M, Nakamura T, Hara S, *et al.* Posterior chamber phakic implantable collamer lens: Changes in vault during 1 year. J Refract Surg 2010;26:327-32.
19. Choi KH, Chung SE, Chung TY, Chung ES. Ultrasound biomicroscopy for determining visian implantable contact lens length in phakic IOL implantation. J Refract Surg 2007;23:362-7.
20. Titiyal JS, Kaur M, Sahu S, Sharma N, Sinha R. Real-time assessment of intraoperative vaulting in implantable collamer lens and correlation with postoperative vaulting. Eur J Ophthalmol 2017;27:21-25.
21. El-Haddad MT, Tao YK. Automated stereo vision instrument tracking for intraoperative OCT guided anterior segment ophthalmic surgical maneuvers. Biomed Opt Express 2015;6:3014-31.