CrossMark

ORIGINAL PAPER

Corneal incision architecture after IOL implantation with three different injectors: an environmental scanning electron microscopy study

Rita Mencucci · **Eleonora Favuzza** · **Maria Cristina Salvatici** ·
Leopoldo Spadea · **David Allen**

Abstract

Purpose To evaluate by Environmental Scanning Electron Microscopy (ESEM) the corneal incision architecture after intraocular lens (IOL) implantation in pig eyes, using manual, automated injectors or preloaded delivery systems.

Methods Twenty-four pig eyes underwent IOL implantation in the anterior chamber using three different injectors: manual (Monarch III) ($n = 8$), automated (AutoSert) ($n = 8$), or a preloaded system (UltraSert) ($n = 8$). Acrysof IQ IOLs, 21 Dioptres (D) ($n = 12$) and 27D ($n = 12$), were implanted through 2.2 mm clear corneal incisions. Incision width was measured using corneal calipers. The endothelial side of the incision was analyzed with ESEM.

Results In each group, the final size of the corneal wound after IOL implantation, measured by calipers, was 2.3–2.4 mm. The incision architecture resulted more irregular in the Monarch group compared with the other injectors. In every group the 27D IOL-implanted specimens showed more alterations than in 21D IOL-implanted samples, and this was less evident in the UltraSert group. The Descemet tear length was higher in the Monarch group than AutoSert and UltraSert group.

Conclusions The automated and preloaded delivery systems provided a good corneal incision architecture; after high-power IOL implantation the incisions were more regular and less damaged with the preloaded system than with the other devices.

Keywords Corneal incision · Environmental scanning electron microscopy · Injector · Preloaded injector · Intraocular lens · Cataract

R. Mencucci (✉) · E. Favuzza
Eye Clinic, Department of Surgery and Translational Medicine, University of Florence, Largo Brambilla 3, 50134 Florence, Italy
e-mail: rita.mencucci@unifi.it

M. C. Salvatici
Electron Microscopy Centre "Laura Bonzi" (Ce.M.E.), ICCOM, CNR, Sesto Fiorentino, Florence, Italy

L. Spadea
Department of Biotechnology and Medical-Surgical Sciences, "Sapienza" University of Rome, Rome, Italy

D. Allen
Sunderland Eye Infirmary, Queen Alexandra Road, Sunderland, UK

Introduction

Currently, cataract surgery incisions of 2.2 mm or smaller are associated with fewer postsurgical complications, lower surgically-induced astigmatism, and less severe postoperative inflammation [1, 2]. Furthermore, it is suggested that small incision size might be associated with less postoperative wound leakage and a lower risk of postoperative endophthalmitis.

Springer

However, it is also considered that corneal wound architecture may play a leading role in affecting wound closure and tightness after stromal hydration at the end of cataract surgery [3–6].

A small-size incision is more likely to be altered in its structure by thermal or mechanical damage due to ultrasound or by manipulation of the phacoemulsification tip, especially during a long or complicated phacoemulsification in hard cataract. Even in an uncomplicated surgery the intraocular lens (IOL) injection through a small-size incision can be often a difficult step, where the surgeon has to be careful to preserve a regular incision architecture and to avoid its enlargement [6–12].

To help the IOL insertion procedure new motorized injectors (AutoSert, Alcon Laboratories Inc.) or preloaded manual controlled delivery systems (UltraSert, Alcon Laboratories Inc.) have been recently introduced. In recent studies [13, 14], AutoSert was found to cause less incision enlargement and better wound architecture integrity than the manual injector.

Previous studies of wound architecture following cataract surgery and IOL implantation have used high resolution optical coherence tomography (OCT) imaging and/or standard scanning electron microscopy (SEM) [10–12, 14–16]. They have described endothelial cell loss around the incision, tearing of incision stroma at wound edges, tearing of Descemet membrane at wound edges or on the anterior or posterior lip and creation of Descemet flaps [10, 11, 15].

The purpose of our study was to evaluate the impact on incision enlargement and architecture of IOL implantation using these new devices, compared to the manual Monarch III injector (Alcon Laboratories Inc.) in ex vivo pig eyes, by the new environmental scanning electron microscopy technique (ESEM). This technique is thought to provide an examination environment much closer to physiological and should be free of structural artifacts produced by the specimen preparation for standard SEM.

Methods

In this ex vivo animal study, 30 pig cadaver eyes (whole globes) were obtained from the Italpork S.r.l. abattoir (Borgo a Buggiano, Italy) and preserved in Optisol solution (Chiron Ophthalmics), for less than

12 h. Eyes with edematous, opaque, or damaged corneas were excluded from the study ($n = 6$).

They were randomly divided in three groups: in the first group ($n = 8$), IOL implantation was performed with Monarch III manual injector (Monarch group); in the second group ($n = 8$), IOLs were inserted with the AutoSert motorized injector (AutoSert group); in the third group ($n = 8$) with UltraSert preloaded manual delivery system (UltraSert group).

Characteristics of the injectors
and of the implanted IOLs

The AutoSert motorized injector was connected to the Alcon Infiniti Vision System (Alcon Laboratories, Inc.). The speed of IOL delivery into the eye was set at the fastest available speed (4.4 mm/min) which had been shown by Allen et al. [13] to cause less incision stretch than slower speed. The implantation was initiated by the surgeon (R.M.) using the footpedal of the phaco machine. For both motorized and Monarch III manual injector, the Acrysof D cartridges were used. IOLs were loaded into the cartridge (Monarch III and AutoSert group) using Provisc ophthalmic viscosurgical device (sodium hyaluronate, Alcon Laboratories Inc).

UltraSert is a preloaded delivery system that is designed to allow a manual smooth controlled delivery of AcrySof IQ IOL in the capsular bag, by means of the TensionGlide Plunger, a spring-controlled mechanism. The injector features also a tip with a very slightly larger tip than the Acrysof D cartridge and but a depth guard nozzle that prevents the device being inserted deeper than necessary into the incision. The manufacturers claim that this should better preserve the original size of the incision.

Each group had implantation of 4 AcrySof IQ SN60WF (Alcon Laboratories, Inc.) IOLs of 21D power and 4 of 27D.

Description of experimental procedure

All the procedures were performed by the same experienced surgeon (R.M.) and followed the tenets of the Helsinki Declaration.

At the beginning of every surgical procedure, pig globes were fixed on a holder. After a bi-planar clear corneal incision was made with a 2.2 mm surgical knife (Beaver-Visitec International, Whaltam, MA),

an IOL was implanted in the anterior chamber using one of the three injectors. The size of incision was measured using calipers sized in 0.1 mm increments (Duckworth and Kent Ltd., Baldock, England) before and after IOL implantation and recorded. No stromal hydration was performed.

The corneas were then carefully dissected by the same investigator, leaving a thin scleral rim to facilitate manipulation, washed with Milli-Q water, and immediately transferred onto mounts covered by adhesive tabs for scanning electron microscopy analysis, with the epithelial side in contact with the tab.

All the evaluations were performed at the Electronic Microscopy Centre (CeME), Italian National Research Council (CNR), Sesto Fiorentino, Florence, Italy.

Environmental scanning electron microscopy (ESEM)

Samples were analyzed by ESEM, a scanning electron microscope that allows for the option of collecting electron micrographs of specimens that are wet, uncoated or both, creating a gaseous environment in the specimen chamber. With its specialized electron detectors and its differential pumping systems, it allows for the transfer of the electron beam from the high vacuums in the gun area to the high pressures attainable in its specimen chamber. These characteristics make it a complete and unique instrument designed for the purpose of imaging specimens in their natural state [17, 18].

An ESEM employs a scanned electron beam and electromagnetic lenses to focus and direct the beam on the specimen surface in a way identical to a conventional SEM. Beyond these common principles, the ESEM deviates substantially from an SEM in several respects, all of which are important in the correct design and operation of the instrument. The presence of gas around a specimen creates new possibilities unique to ESEM: hydrated samples can be examined, since any pressure greater than 609 Pa allows water to be maintained in its liquid phase for temperatures above 0 °C, in contrast to the SEM where specimens are desiccated by the vacuum condition; electrically non-conductive specimens do not require the preparation techniques used in SEM to render the surface conductive, such as the deposition of a thin gold or carbon coating, or other treatments, techniques which also need vacuum in the process [17, 18].

ESEM (ESEM Quanta 200, FEI) evaluation of the endothelial side of the specimens was performed at multiple magnifications, and digital images obtained at $100\times$ and $500\times$ magnifications were recorded. Each corneal surgical wound was carefully analyzed; to evaluate the presence and the extent of tears in Descemet membrane, the overall aspect of stromal tissue inside the incision and the endothelial side incision profile. The length of Descemet membrane tears was measured by ImageJ software in the images that showed good definition, according to a previous published method [15]. The reference scale included in each ESEM image was used to calibrate the measurements that were performed by the same technician and masked to the different IOL implantation procedures and IOL powers.

Results were reported as mean ± standard deviation.

Results

While, before IOL implantation, the incision size measured by calipers was 2.2 mm in all samples, at the end of the procedure, it was either 2.3 mm (87.5% of specimens, $n = 21$) or 2.4 mm (12.5% of specimens, $n = 3$). The 2.4 mm incisions were distributed evenly among the three study groups: one in each, and all with 27D IOLs.

Among all digital ESEM images acquired, those related to 5 samples (2 in the AutoSert group, 21D and 27D IOLs, 2 in the UltraSert group, 27D IOL, 1 in the Monarch group, 21D) were excluded from evaluation because of low definition or presence of residual organic material that might partially cover the internal side of the wound. Images related to 19 samples were thus analyzed.

In all samples, lateral Descemet tears (lateral extension of the wound edges) were observed.

In the AutoSert group, the Descemet tearing length was 0.33 ± 0.20 mm for 21D IOL subgroup, 0.33 ± 0.14 mm for 27D IOL; in the UltraSert group was 0.32 ± 0.16 mm for 21D IOL subgroup, $0.33 \pm 0,15$ mm for 27D IOL; in the Monarch group was 0.36 ± 0.13 mm for 21D IOL subgroup, $0.38 \pm 0,20$ mm for 27D IOL (Fig. 1).

Fig. 1 Measurement method of lateral Descemet tear length by the Image J software in ESEM images of the endothelial side of the incisions. **a**, **b** Descemet tears at both edges of corneal incision after 27D IOL implantation with UltraSert. **c**, **d** Descemet tears at both edges of corneal incision after 27D IOL implantation with AutoSert. **e**, **f** Descemet tears at both edges of corneal incision after 27D IOL implantation with Monarch III. The reference scale included in each ESEM image was used to calibrate the measurements. For each sample, the lengths of the Descemet tears of the right and the left edges were added together. (Magnification 500×)
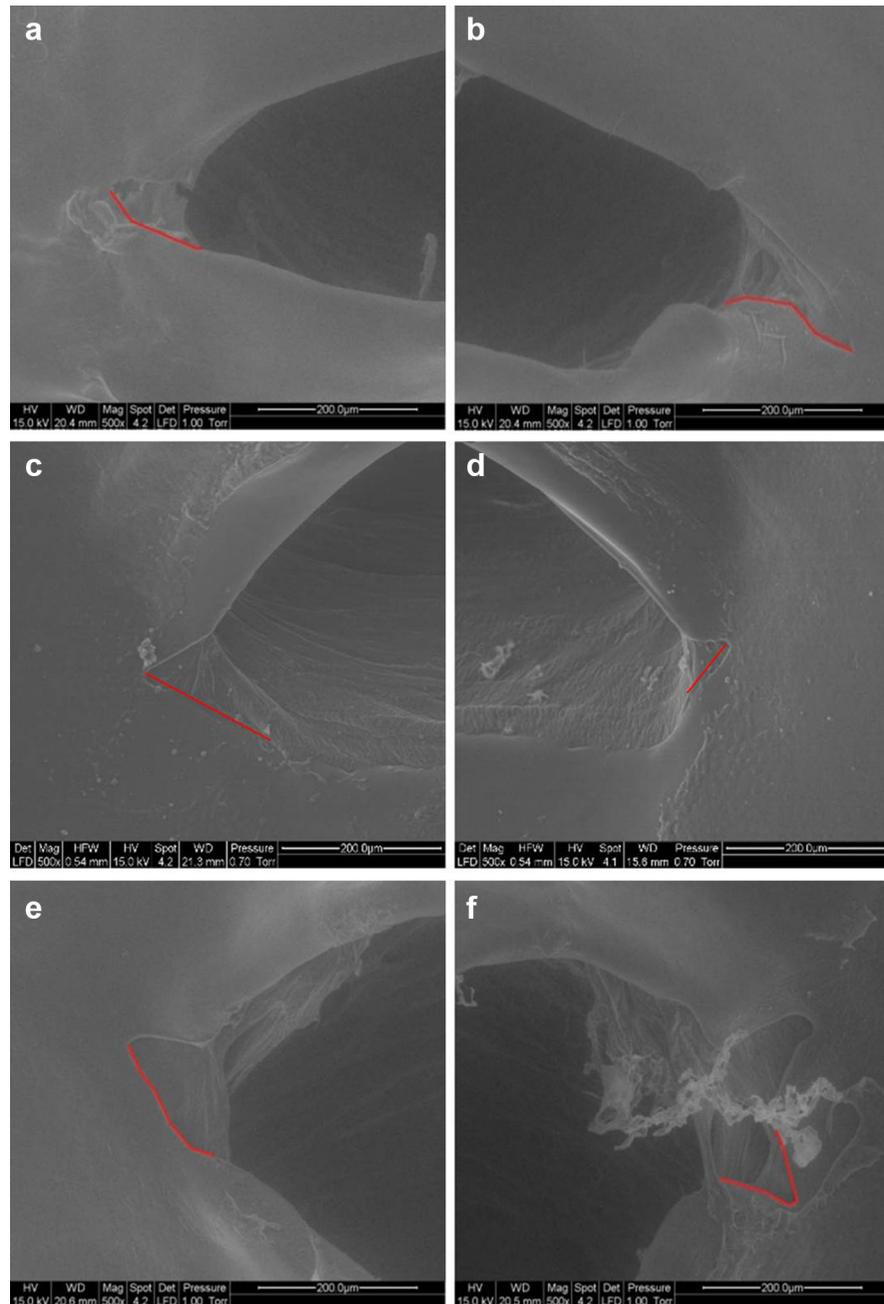
Only, in two specimens, a rupture of the anterior wound lip was observed (Monarch group).

The corneal stroma visible through the incision opening seemed to be more irregular and less smooth in all samples of the Monarch group than the other groups (Fig. 2).

Even if the length of the incisions was similar in the three groups, the appearance of those implanted with 27D IOLs was wider, resembling a "fish mouth", and the UltraSert group tunnels seemed to be less stretched than in the other groups (Fig. 2).
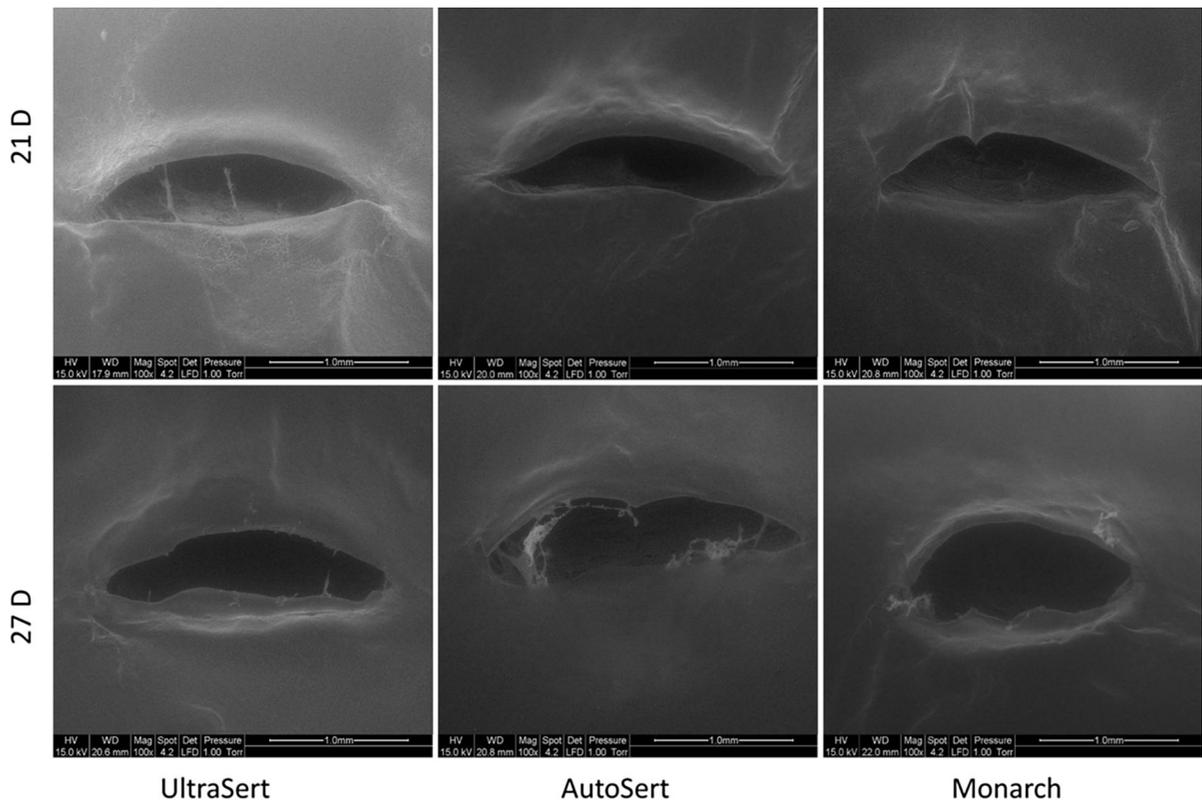
Fig. 2 ESEM images of the endothelial side of corneal incisions after IOL implantation (21 and 27D) with the three injectors (UltraSert, AutoSert, Monarch). The corneal stroma visible through the incision opening seems to be more irregular and less smooth in the Monarch group than the other groups. In the Monarch group, the appearance of those implanted with 27D IOLs is wider, resembling a "fish mouth" (especially in the Monarch group) and the UltraSert group tunnels seemed to be less stretched than in the other groups. (ESEM images, magnification 200×)

Discussion

It is known that wound leakage after cataract surgery can increase the risk of postoperative endophthalmitis: incision architecture might affect wound tightness [5, 6]. IOL implantation can be a crucial step during surgery in preserving incision size and its structural integrity, especially in small-size incisions. [7–12] Several IOL manufacturers have developed systems and cartridges to help surgeons introduce IOLs through smaller incisions. These developments include use of single-handed plunger-type delivery (allowing surgeons to use second instrument to stabilise the eye) and motorized units. These have often been combined with a "preloaded" system that theoretically protects the IOL from damage or contamination through incorrect handling by surgeons or technicians.

Allen et al. [13] measured incision size just before and immediately after IOL implantation during routine cataract surgery. Of those incisions that were 2.2 mm prior to IOL implantation (equivalent to the present study), they found that the motorized AutoSert injector used at the fastest speed caused less enlargement than the manual injector: in the AutoSert group 8 showed 0 mm enlargement and 7 showed 0.1 mm, while in the Monarch group, only 1 showed 0 mm enlargement, 15 showed 0.1 mm, and 3 showed > 0.1 mm enlargement.

In our study, no difference was detected in incision enlargement after IOL implantation by manual, automated, or preloaded injectors, measured by calipers: incision enlargement was 0.1 mm in 7 specimens in each group (87.5%), while 1 specimen per group showed a 0.2 mm enlargement.

The difference from previously published results could be due to the small sample size, in addition to the

unavoidable approximation of the measurements performed by the calipers, that are sized in 0.1 mm increments, and do not allow more accurate measurement. Moreover, as pig eyes have thicker corneas, these results need to be confirmed by studies on human eyes. However, pig eyes have been recently used also in other similar studies on IOL injectors [19], probably due to their higher availability than human whole globes.

To more deeply analyze the incision architecture, SEM analysis has been performed in previous studies, evaluating (qualitatively or quantitatively) incision profile, endothelial cell loss around the incision, tearing of the Descemet membrane at the wound edges, and Descemet flaps [10, 11, 15].

To our knowledge, this is the first paper to report on corneal wound architecture using the relatively new technique of ESEM. With this technique, specimens can be examined faster and more easily, avoiding complex and time-consuming preparation methods involving the deposition of a thin gold or carbon coating, without modifying the natural surface or creating artifacts by the preceding preparation work, or the vacuum of the SEM. Therefore, ESEM constitutes a radical breakthrough from the conventional electron microscopy.

Before performing the whole experiment series, we analyzed few specimens after IOL implantation with the different injectors, with the conventional SEM technique (data not shown). To ensure a correct dehydration and coating of the samples, the specimens were cut in small pieces (5×5 mm), quite close to the incision edges: it resulted in an evident damage of the Descemet membrane and folded at the specimen sides. Moreover, the incision profile seemed to be "closed" and the visible inner stroma collapsed. Thanks to the metallic coating, the endothelial cells were visible, and an area of endothelial cell loss around the incision could be detected; nevertheless, the endothelial cells were detached also in areas far from the incision, so that it could be difficult to assess the artifacts extension (data not shown). In our ESEM images, conversely, endothelial cell loss was not clearly visible, probably due to the lack of coating, but the specimens, being analyzed in their entirety and without any further manipulation, seemed less damaged.

All specimens showed lateral Descemet tears at the edges of the incisions, that were measured following the method published by Weikert et al. [15]: the metrics of the tearing of Descemet membrane were not subjected to statistical analysis, because the size of groups and subgroups was too small, but it is possible that there was more Descemet tearing in the Monarch group.

Moreover, the corneal stroma visible through the incision opening seemed to be more smooth and homogeneous in the AutoSert and UltraSert groups compared to the Monarch group.

From these quantitative and qualitative analyses, even in the absence of significant incision enlargement after IOL implantation in all groups, the incision architecture seemed to be more regular and preserved in the motorized and preloaded systems compared to the manual injector.

A difference between the UltraSert preloaded system and the other injectors considered was detected especially analyzing the subgroups implanted with the thick 27D IOLs: while in the AutoSert and Monarch 27D subgroups, the incision seemed wide open, resembling a "fish mouth"; in the UltraSert group, the incision profile was similar to the 21D IOL subgroup.

In the presence of incisions of 2.2 mm, the passage of the IOL into the eye is "incision assisted"; i.e., the cartridge tip cannot go completely through the incision and so the incision itself acts as an extension to the cartridge tip. A possible greater incision enlargement after high-power IOL implantation through such incisions has already been reported [13], and Ouchi [12] showed that the cross-sectional area of the cartridge tip expands when an IOL is present in the tip. Moreover, it can be hypothesized that the passage within the cartridge tip of a high-power IOL with additional volume can be slightly more slow and difficult, thus inducing the surgeon to exert more pressure on the injector, and consequently, on the corneal wound: this could cause a deeper penetration of the cartridge tip within the corneal tunnel and its enlargement, due to the progressive increase of the tip diameter. The UltraSert preloaded delivery system tip is provided with a depth guard nozzle that prevents the device being inserted deeper than necessary into the incision: this could be the reason for the better profile of the incisions after 27D IOL implantation compared to the automated and the manual injectors.

Regardless of IOL power, when using a screw-type injector such as the Monarch, there are pauses in the

advancement of the IOL through the incision. The forces generated by potential re-expansion and unfolding of the IOL during these pauses could be another factor responsible for the greater incision enlargement seen in those studies and the greater damage to the internal lip of the incision in this study. Both the motorized AutoSert and the manual plunger-type UltraSert deliver the IOL through the incision in a continuous fashion with no pauses.

In summary, we believe that this is the first published report of incision architecture examined with the relatively new technique of ESEM. We believe that this gives a more physiological view of the internal side of corneal incisions. Implantation of IOLs through an ex vivo corneal preparation showed less trauma to the incision (particularly with high-dioptre IOLs) with the new plunger-type delivery systems compared to the screw-type injector Monarch III. We postulate that this is due to a combination of speed of injection and the continuous passage of IOL through the incision with these new systems compared to the slower intermittent passage necessary with the Monarch system. The new preloaded device showed the least disturbed architecture, possibly because of the incision depth guard which prevents insertion of the cartridge tip too far into the incision.

Further studies on human eyes and with a wider sample size are needed to confirm these results and evaluate more deeply the incision architecture after cataract surgery and IOL implantation with different injection systems.

References

1. Hayashi K, Yoshida M, Hayashi H (2009) Postoperative corneal shape changes: microincision versus small-incision coaxial cataract surgery. J Cataract Refract Surg 35:233–239
2. Weikert MP (2006) Update on bimanual microincisional cataract surgery. Curr Opin Ophthalmol 17:62–67
3. Calladine D, Packard R (2007) Clear corneal incision architecture in the immediate postoperative period evaluated using optical coherence tomography. J Cataract Refract Surg 33:1429–1435
4. ESCRS Endophthalmitis Study Group (2007) Prophylaxis of postoperative endophthalmitis following cataract surgery: results of the ESCRS multicenter study and identification of risk factors. J Cataract Refract Surg 33:978–988
5. Cooper BA, Holekamp NM, Bohigian G, Thompson PA (2003) Case-control study of endophthalmitis after cataract surgery comparing scleral tunnel and clear corneal wounds. Am J Ophthalmol 136:300–305
6. Wallin T, Parker J, Jin Y, Kefalopoulous G, Olson RJ (2005) Cohort study of 27 cases of endophthalmitis at a single institution. J Cataract Refract Surg 31:735–741
7. Steinert RF, Deacon J (1996) Enlargement of incision width during phacoemulsification and folded intraocular lens implant surgery. Ophthalmology 103:220–225
8. Kohnen T, Lambert RJ, Koch DD (1997) Incision sizes for foldable intraocular lenses. Ophthalmology 104:1277–1286
9. Kohnen T, Kasper T (2005) Incision sizes before and after implantation of 6-mm optic foldable intraocular lenses using Monarch and Unfolder injector systems. Ophthalmology 112:58–66
10. Berdahl JP, DeStafeno JJ, Kim T (2007) Corneal wound architecture and integrity after phacoemulsification Evaluation of coaxial, microincision coaxial, and microincision bimanual techniques. J Cataract Refract Surg 33:510–515
11. Jun B, Berdahl JP, Kuo AN, Cummings TJ, Kim T (2010) Corneal wound architecture and integrity after torsional and mixed phacoemulsification: evaluation of standard and microincisional coaxial techniques. Ophthalmic Surg Lasers Imaging 41:128–134
12. Ouchi M (2012) Effect of intraocular lens insertion speed on surgical wound structure. J Cataract Refract Surg 38:1771–1776
13. Allen D, Habib M, Steel D (2012) Final incision size after implantation of a hydrophobic acrylic aspheric intraocular lens: new motorized injector versus standard manual injector. J Cataract Refract Surg 38:249–255
14. Khokhar S, Sharma R, Patil B, Aron N, Gupta S (2014) Comparison of new motorized injector vs manual injector for implantation of foldable intraocular lenses on wound integrity: an ASOCT study. Eye 28:1174–1178
15. Weikert MP, Wang L, Barrish J, Dimalanta R, Koch DD (2012) Quantitative measurement of wound architecture in microincision cataract surgery. J Cataract Refract Surg 38:1460–1466
16. Bang JW, Lee JH, Kim JH, Lee DH (2015) Structural analysis of different incision sizes and stromal hydration in cataract surgery using anterior segment optical coherence tomography. Korean J Ophthalmol 29:23–30
17. Danilatos GD (1993) Environmental scanning electron microscope: some critical issues. Scanning Microsc Suppl 7:57–80
18. Danilatos GD (1985) Design and construction of an atmospheric or environmental SEM (part 3). Scanning 7:26–42
19. Nanavaty MA, Kubrak-Kisza M (2017) Evaluation of preloaded intraocular lens injection systems: ex vivo study. J Cataract Refract Surg 43(4):558–563