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Review Article

Phacoemulsification Incision- Creation, Evaluation and Closure: A Review

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Abstract

Creating an ideal incision is the foremost and the most crucial step in phacoemulsification. The most commonly used incision for phacoemulsification is sutureless clear corneal incision (CCI). The location, size and the architecture of incision are as important as the equipment to create it. Surgical equipment and techniques play a very important role in creation of an optimal incision. The location and the technique of incision continue to be perfected as the understanding of the dynamic architecture and the technology are improving. Newer tools such as femtosecond laser help to create a near-perfect incision improving the safety profile of the surgery. Likewise the adequate closure of the incision is equally important. Stromal hydration, suturing, tissue adhesives, such as cyanoacrylate, fibrin and polyethylene glycol (PEG), corneal soldering and tissue welding are some techniques for incision closure. Each has its own merits and demerits. This article reviews various published studies and literature related to the techniques of creation, evaluation and closure of phacoemulsification incision. PubMed and CrossRef (Google) search engines have been used as the primary media for literature research.

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Introduction

Currently, phacoemulsification is the surgery performed through the smallest incision on a major organ system in the human body.[1] Most surgeons use sutureless superior or temporal clear corneal incisions (CCIs) in phacoemulsification surgery, depending on the preexisting corneal astigmatism, patient's eye and surgeon's preference. During the early post-operative (PO) period, intraocular pressure (IOP) fluctuation is common, since patients may inadvertently rub their eye, dab instilled eye medications from their eye, or squeeze their eyelids.[2-4] IOP fluctuation may result in anterior chamber fluid egress, or iris prolapse during PO period.[5-7] A leaking incision is shown to be associated with increased risk of endophthalmitis.[8] The other risk with poorly constructed incision is hypotony resulting in rotation of toric intra-ocular lens (IOL).[9] Thus achieving water-tight closure of the incision after phacoemulsification becomes very important.

Creation of the incision

Location:

Preferred locations for phacoemulsification incision include sclera, sclera-cornea and clear cornea.[10,11] When compared to CCIs, scleral and sclera-corneal incisions have an earlier fibroblastic response, are stronger and more self-sealing.[12] (Figure-1) They produce lesser surgically induced astigmatism (SIA) than CCIs by virtue of their further distance from the visual axis. SIA depends upon many factors including not only the size and location of incision but also on the technique of wound closure.[13,14] (Table-1) Sclera-corneal incision, due to their distal location away from the endothelium, cause less endothelial trauma.[15] On the other hand, they require more surgical time, conjunctival dissection, and increased anesthesia; and are associated with increased risk of hemorrhage and immediate post-operative inflammation.[16]

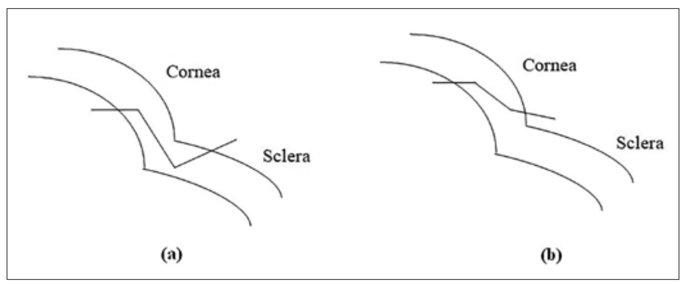

Figure 1: *(a) Sclero-corneal incision (b) Clear corneal incision*

Table 1: Factors affecting SIA

Factors	Less SIA	More SIA
Type[13]	Scleral or Sclera-corneal	CCI
Size[14]	≤ 2.6 mm	≥ 3 mm
Location[18,23]	Temporal	Superior

CCIs offer many advantages over scleral and sclero-corneal tunnel incision, viz. greater ease with topical anesthesia, relative ease of creating a presumed watertight corneal incision, minimal trauma to conjunctiva, minimal hemorrhage, better maneuverability, optimal wound stability, and relatively faster visual recovery.[1,16,17] Temporal CCI is better than superior CCI as far as SIA is concerned.[18] (Figure-2) CCIs (2.0 mm or more) demonstrate greater resistance to leakage than scleral tunnel incisions.[19] Disadvantages include lack of consistency and reproducibility, higher risk of bacterial endophthalmitis, wound instability under high IOPs and vulnerability to mechanical or thermal trauma during phacoemulsification and IOL insertion.[20-22] CCIs can be superior or temporal. The temporal incisions affords advantages in both accessibility and minimal SIA compared with superior incisions, since the superficial horizontal diameter of the cornea is greater than the vertical.[23] Temporal CCIs have been reported to be more stable than superior incisions.[24] Since 1998, the temporal CCI has been the most commonly used incision in cataract surgery.[20] However studies have suggested that a temporal corneal incision may lead to an increased risk of postoperative endophthalmitis.[25]

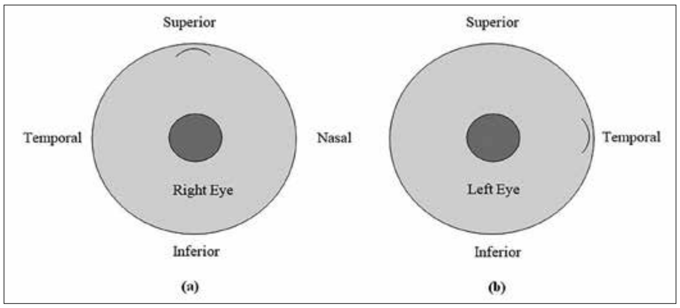

Figure 2: *(a) Superior CCI (b) Temporal CCI*

Size:
Studies have demonstrated that the size of the incision also has an effect on fluid leakage.[26,27] A smaller incision size would allows less area for fluid egress as well as pathogen accumulation, thus appears to be stronger and safer. However, incisions too small may need to be enlarged; rendering them more prone to leak and infections.[26,27] Even side port incisions may not have a watertight seal under IOP fluctuation.[2] Therefore, the size of incision needs to be appropriate. Neither very small nor too large incisions have better safely profiles.

Architecture:
Incision architecture is known to have an effect on its integrity.[28] Incision can be uni-planar, bi-planar, or tri-planar. Studies show that bi- or tri- planed incisions have more integrity thus minimal risk of leak than single plane incisions.[21,22,29,30] To better resist leakage under high IOP, incorporating both vertical and horizontal elements in multi-planar incisions is advocated.[21,22,29] Studies have shown that near-square incisions have better strength and integrity than more rectangular incisions.[31,32] Also, longer tunnel lengths (i.e, 2.0 mm over 1.0 mm) have been shown to be more resistant to leakage.[33] However, too long tunnels can result in distortion of the wound and corneal striae due to difficulty in manipulations through the incision.[1]

Equipment:
Studies have shown that the material of the blade may have an effect on the structural integrity of the incision.[28] Scanning electron microscopy (SEM) studies have shown diamond blades to produce cleaner cuts on a cellular level than steel.[34-37] Another study found that despite different corneal thicknesses produced by two blade types, there was no significant difference in wound healing and surgically induced astigmatism and aberrations after a one-month follow-up.[38] The disadvantages of diamond blades are that they are expensive, require maintenance, and have theoretical prion and toxic anterior-segment syndrome (TASS) risk.[1] On the other hand, disposable blades are affordable, frequently bundled in phacoemulsification packs, easily interchangeable for different incision sizes, and avoid sterility issues.[1] A single-use silicon blade material was also found to be smoother than steel on electron microscopy.[39]

Technique:
During phacoemulsification, manual manipulation of the incision needs to be minimized in order to curtail the mechanical damage to the incision site. The technique of phacoemulsification may also have an impact on the integrity and strength of the incision. Micro-coaxial phacoemulsification, by providing a more optimal healing arcuate incision configuration, is shown to be advantageous over biaxial phacoemulsification.[40] Also; smaller incision angles are suggested to have lesser chances of incision gapes and leakage.[38]

Femtosecond Laser:
Recently, femtosecond laser-assisted cataract surgery (FLACS) has evolved very rapidly, attracting the favour of newer generation of cataract surgeons. Data from multiple studies indicate that FLACS is as safe as non-FLACS phacoemulsification cataract surgery. Additionally, FLACS offers a greater level of precision and repeatability for creation of incisions than manual wound creation. As a result, FLACS is considered to offer more precise SIA management (wounds and arcuate keratotomies), lens centration (capsulotomy) and reduced effective phacoemulsification energy (nuclear fragmentation).[3] However, the statistical data regarding safety and efficacy of FLACS remains equivocal.[28] One study found that the manual and laser incisions had equivalent ability to close wounds.[41] A case-study demonstrated that laser-created CCI may leak.[42] Another study found that the laser-created incision was accurately constructed which led to improved wound closure and better predictability of SIA.[43] With further evolution in FLACS techniques, cataract surgeons will be able to flare the incision internally to decrease oar-locking and engineer a more consistently self-sealing incision.[44]

Evaluation of the incision

Association of corneal incisions and PO endophthalmitis renders evaluation of integrity of the incision very critical.[45] Until recent advances in imaging, visual inspection of the incision for any visible damage at the conclusion of surgery and detect smaller aqueous leaks with Seidel testing was surgeons' only way to passively assess the integrity and competence of the incision.[46] For dynamic testing, to increase IOP and create wound deformation, surgeons needed to apply pressure adjacent to the wound.[29] Newer diagnostic tools such as anterior segment optical coherence tomography (OCT) and India Ink particle flow studies, offer better ways to assess the integrity of the incision and different modalities to seal it.

Static evaluation:
Five classic OCT features of the CCIs have been described: endothelial or epithelial gaping, loss of coaptation, endothelial misalignment, and local Descemet's detachment.[47] OCT imaging studies revealed the variation in the incision lengths despite surgeons' intended uniformity.[48,49] Quantitative evaluation of the incision using SEM demonstrated that micro Descemet's tears and endothelial cell loss were present in every case following phacoemulsification.[50]

Dynamic evaluation:
Conventionally, the Seidel's test has been the widely accepted dynamic test for the incision integrity. The study of dynamic changes in wound architecture and fluid flow demonstrated that while IOPs up to 50 mmHg didn't cause loss of wound integrity or leakage, reduction of IOP to the 5-10 mmHg range did cause India Ink ingress and visible gaping of the wounds on OCT. This and other studies proved ocular hypotony to be the potential culprit in contaminated conjunctival fluid imbibition through gaping wounds.[4,51] Further studies showed that the angle of the incision influenced its integrity in different IOP ranges. More horizontal (parallel to the corneal surface) incisions, while having more resistance to higher IOP leakage, had more gaping with lower IOP, while more vertical (perpendicular to the corneal surface) incisions sealed less well under high pressure, but had greater apposition under low pressure.[52] Further in-vivo evidence of hypotony induced fluid influx were demonstrated with blood and Trypan blue.[53-55] Francis gave the graphic descriptions of "the sucking corneal wound" on the basis of these studies and evidences.[56] Another study showed that 3.0 mm incisions were better than 1.0 mm incisions and bi-planar incisions were superior to single step incisions in preventing inflow during periods of hypotony or sudden changes in IOP.30 Based on these evidences, it can be safely assumed that incorporating both vertical and horizontal components is the most effective in preventing bacterial influx – as it is resistant to both low and high pressure deformation.

Closure of the incision

A tri-planar near-square shaped CCI is usually self-sealing, but occasionally it may need further security to assure water-tight closure.[1] This may be due to faulty technique in the incision creation, or secondary to tissue damage sustained during phacoemulsification and/or IOL implantation.

Stromal Hydration:
At the conclusion of phacoemulsification, stromal hydration is the most frequently used methods to close the CCIs.[56,57] This technique was first described by Fine et al.[19] Mifflin showed that greater than 50% of incisions leaked pre-hydration, but none leaked post-hydration.[58] Calladine demonstrated that the patients with stromal hydration had higher IOPs one hour PO than the patients without it.[59] He suggested that it was likely due to less early micro- leakage owing to the sealing effect of stromal hydration. Furthermore, Vasavada demonstrated that the ingress of Trypan-blue was decreased several-fold by stromal hydration.[57] Nevertheless; inflow of surface fluid has been described even despite stromal hydration.[53] Many studies have shown that the integrity of the CCI may be compromised immediately after surgery allowing ingress of ocular surface bacteria. Surgeons have also pointed out its possible effect on distorting of the incision.[4,47,60] It has also been suggested that leaks may occur as the effect of stromal hydration wears off, which may take anytime between one day to one week.[22,61,62] It has been suggested that the duration of stromal hydration varies due to its dependence on the endothelial pumping mechanism which is different for every eye.[61] Other potential negative effects include an increase in IOP, corneal staining, corneal edema, Descemet's membrane detachment, anterior chamber reaction and decrease visual acuity.[59,61,63] Surgeons described a variation in the hydration technique, by creating an anterior or supra-incisional stromal pocket overlying the incision, and hydrating the stromal pocket instead of the roof and walls of the incision, which was shown to be associated with significantly less leaking, however carrying an additional risk of epithelial damage and/or increased SIA.[58] OCT imaging demonstrated that the posterior compression of the internal lip by hydrating this 'Wong' incision presumably created greater wound apposition.[58]

While stromal hydration is the standard of care today, further study is required to elucidate its role in incision closure. If the wound's integrity is in question even after stromal hydration, the next option is to secure the incision with suture.

Sutures:
Owing to their historical use and time-tested efficacy, sutures have been the gold standard to close the incisions. However, it still remains debatable whether sutured incisions allow a better or similar seal when compared with stromal hydration.[26,64] Likewise, while some studies suggest that sutured corneal incisions were protective of endophthalmitis, others found no such protective benefit from suture placement.[65,66] Sutures have some other considerable adverse effects too. On one hand, loose or broken sutures are more susceptible to leaks and infections, on the other hand tight sutures may distort the incision, increase astigmatism, and reduce visual acuity.[26,67-71] Other complications include subconjunctival hemorrhage, eye irritation, foreign body sensation, corneal tissue injury and vacuole development, neovascularization, suture breakage, and suture abscess.[26,72-74] Sutures have also been shown to change wound architecture to the point where they render the incision more prone to infections.[75,76] These evidence based studies strongly advocate for early removal of non-absorbable sutures as soon as epithelialization has occurred.[70,73]

The standard of care remains to place a suture to stem leakage if the surgeon thinks that the stromal hydration is ineffective in adequately sealing the CCI, but routine suture placement for theoretical endophthalmitis prevention is not advocated.

Tissue Adhesives:
An ideal means of incision closure should be biocompatible,

biodegradable, non-toxic, non-inflammatory, and non-disruptive to surrounding tissue which would not induce astigmatism, create opacities, or cause neovascularization.[77-79] It should be optically clear, easy to prepare, easy to apply and efficient to close the incision securing a watertight seal until re-epithelialization occurs.[26,77-79] Studies have found few candidates for such ideal tissue-adhesive, viz. cyanoacrylate, fibrin glue and polyethylene glycol (PEG). Cyanoacrylate has been used for quite some time in ophthalmology, mostly for sealing corneal perforations.[64,80] The more elastic 2-octyl cyanoacrylate (Liquid Bandage), which also exhibits bacteriostatic activity, has been used in vivo for sealing phacoemulsification CCIs.[81] However, cyanoacrylate has been demonstrated to be brittle, toxic, opaque, non-absorbable and pro-inflammatory.[64,80] Other adverse-effects include necrosis, fibrosis, foreign body sensation, irritation, discomfort, and hyperemia.[81,82]

Fibrin glue is commonly used for conjunctival and amniotic membrane transplantation. Fibrin is considered flexible, non-toxic, non-inflammatory and biodegradable.[80-83] It has been shown to be a relatively weaker adhesive than cyanoacrylate.[82-83] When compared to cyanoacrylate, fibrin can resist only mild to moderate increase in IOP.[74,84] On the downside, fibrin is expensive, requires preparation, and may increase the potential risk of viral and prion disease transmission.[77,80,82]

The newer class of tissue adhesives based on PEG hydrogel polymers are either polysaccharide-attached bio-synthetics such as chondroitin sulfate-PEG and dextran aldehyde-PEG or pure synthetic PEG polymers.[79,85,86] They are applied as a liquid and then polymerize to form a hydrogel over the incision in 30-45 seconds. The hydrogel acts as a pseudoepithelium and is subsequently replaced by healing epithelium. They do not carry a risk of viral transmission due to their synthetic nature, and if necessary, they can be easily removed with forceps without damaging the corneal tissue.[72] The commercially available ReSure® Adherent Ocular Bandage (Ocular Therapeutix) is currently FDA-approved PEG for the management of CCI leaks and the prevention of aqueous leakage after phacoemulsification.

Biodendrimers are experimental synthetics that either photo-activate with an argon laser or self-polymerize into a hydrogel sealant.[87] An in vivo study demonstrated that when compared to sutures, the biodendrimer adhesive have lesser chances of long term corneal scarring.[88]

Corneal soldering and tissue welding:

Corneal soldering and tissue welding have been described as the latest techniques of incision closure after phacoemulsification. The advantages of these techniques is that it takes just 25–45 seconds to weld and induces minimal inflammation.[89] These are shown to be as strong or in some cases stronger than sutures; however they require activation with a laser and may induce astigmatism. Another disadvantage is that the dye used in these techniques is toxic if allowed to enter the anterior chamber.[74] They act by inducing tissue shrinkage of the cornea which may distort the cornea and reduce visual acuity.[90]

Discussion

Creating a perfect incision is the foremost step toward an uncomplicated successful phacoemulsification. Over last decade phacoemulsification incisions have moved from sclera to CCIs. A well-crafted tri-planar, near square-shaped CCI of adequate size is usually self-sealing if not watertight, with minimal augmentation needed for its closure.[25] There is increased risk of aqueous egress and conjunctival fluid ingress, and subsequent endophthalmitis if the CCI is not watertight at the conclusion of the surgery.[5,7,72] Currently popular methods of incision closure seem inadequate and do not provide adequate wound closure.[2,42,47,67] The effectiveness of stromal hydration is variable depending on the patient's corneal endothelial function.[17,62] Sutures, although better in securing the incision than stromal hydration, may not always prevent leaks and are associated with other complications including SIA and increased risk of infections.[26,68-72,75,76] The tissue adhesives are the newer means of incision closure, which promise better results over previous techniques with improved safety profile.[72] By avoiding the potential adverse events associated with sutures and stromal hydration, these tissue adhesives are very promising to the patients who desire the best refractive results.[61,72] An inadequately closed incision may increase the risk of IOL decentration, potentially affecting the clinical outcome, especially in case of premium IOLs such as toric, multifocal, accommodative or presbyopia-correcting IOLs.[26,48]

Conclusion

As the modern investigation tools and techniques evolve, our understanding of corneal structure and function continues to improve. The surgical experience of decades and the advantage of newer tools such as femtosecond laser, high resolution SEM imaging, fourier-domain anterior segment OCT, and India ink dynamic studies, combine to help the cataract surgeons move closer to the goal of the perfect wound. With the more reproducible and highly customizable incision designs and with novel corneal sealants, the safety profile and the satisfaction levels of phacoemulsification surgery will rise even higher for the surgeons as well as the patients.

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