

# The History, Present, and Future of Age-Related Cataracts Surgery

## ARTICLE INFORMATION

Received: 31 August 2019  
Accepted: 1 October 2019  
Published: 29 November 2019

**Senior Editor**  
Amama Khairzad

### Reviewers and Section Editors

Mohammed Inam Khan  
Isabel Dewey

**Layout Editor**  
Youssef El-Sayes

**Illustrator**  
Simran Kaur

Suhaila Abdelhalim<sup>1</sup> and Lyan Abdul Majeed Abdul Wadood<sup>2</sup>

1. *McMaster University, Honours Life Sciences, Class of 2020*

2. *McMaster University, Honours Life Sciences, Class of 2020*

## ABSTRACT

Twenty years ago, WHO and IAPB introduced an initiative called ‘The Right to Sight’, which set out to eliminate avoidable blindness universally by 2020. Age-related cataracts is a major contributor to treatable blindness worldwide and is increasing in global prevalence due to the growing proportion of individuals over 65 years of age. Cataracts refers to opacification of the lens inside the eye and clinically presents as a painless blurring and clouding of vision. From couching operations in 1200 B.C. to modern phacoemulsification, different approaches have been used to tackle this ancient disease over the centuries. Treatment today mainly involves surgery to replace the opaque lens with an artificial intraocular lens. Cutting-edge research into future therapies include investigating accommodating intraocular lenses, which hope to postoperatively restore accommodation. With the target year 2020 approaching, it is necessary to initiate discussion on age-related cataracts. This paper will provide a brief overview of this disease, discuss developments in treatment, and review innovations currently being pursued in the field.

**Keywords:** Age-related cataracts, ophthalmology, ROS, phacoemulsification, IOL, aging

## INTRODUCTION

Age-related cataracts refers to opacification of the lens inside the eye. It is a major cause of treatable blindness worldwide, and it is responsible for approximately 50% of the population’s visual impairment.<sup>1</sup> With an increasing global aging population, age-related cataracts is set to become more prevalent and exert a greater burden on health care resources.<sup>2</sup> In 1999, the International Agency for the Prevention of Blindness (IAPB) along with the World Health Organization (WHO) aimed to eliminate all avoidable blindness in the world by the year 2020. A large proportion of this blindness is due to age-related cataracts. They aimed to achieve this goal by investing in necessary infrastructure that would contribute to providing effective and accessible treatment, including greater investment in the equipment required to conduct treatments.<sup>3</sup> However, the proportion of individuals receiving cata-

ract surgery in developing countries remains low.<sup>4</sup> Cataracts has been surgically treated using different methods over the years. With an inequality of access to treatment and 2020 approaching, it is important to review the advances that have been made in cataract surgeries. This review will outline developments in cataract surgery over the centuries and compare the different surgical techniques. This paper benefited from the review article written by Asbell et al. (2005).<sup>5</sup>

## SYMPTOMS

Age-related cataracts is the most common form of cataracts and usually develops in individuals over the age of 50.<sup>5</sup> Symptoms develop gradually and are characterized by a painless blurring of vision and eventually functional blindness in mature white cataracts, where an individual may only discern light.<sup>5</sup> Symptoms may also include glare, monocular double vision, and near-

sightedness.<sup>5,6</sup> The type of cataract depends on its location in the lens fibres of the eye, which are the main cell type in the lens. Nuclear cataracts (NC) results from opacification in the centre of the lens due to hardening of the inner lens layers. Cortical cataracts involves newer lens fibres, and spoke-like opacities can form in the outer layers. Finally, posterior subcapsular cataracts (PSC) are grain-like opacities that form in the back of the lens.<sup>5</sup> This cataract type causes the greatest reduction in visual acuity.<sup>7</sup>

## PATHOPHYSIOLOGY

Cataracts refers to opacification of the lens within the eye. The lens is responsible for bending light to focus on near and far objects, accordingly. This function is facilitated by the lens structure. It is layered, with cells composed of a few organelles to keep it transparent and many proteins that are precisely arranged to bend light. These characteristics contribute to the formation of cataracts, where the lack of organelles prevents protein turnover and the layered structure results in the accumulation of older cells. Over the lifetime of an individual, exposure to reactive oxygen species (e.g. from diet or UV radiation) contributes to cellular and protein damage.<sup>8</sup> The lens cells have antioxidant defence mechanisms that can target these oxidative species. Specifically, superoxide dismutase, catalase, and glutathione peroxidase are enzymes that can neutralize molecules with the potential to form these harmful species.<sup>9</sup> When this damage overwhelms the lens' protective antioxidant defence mechanisms, proteins aggregate and form opacities in the lens.<sup>10</sup>

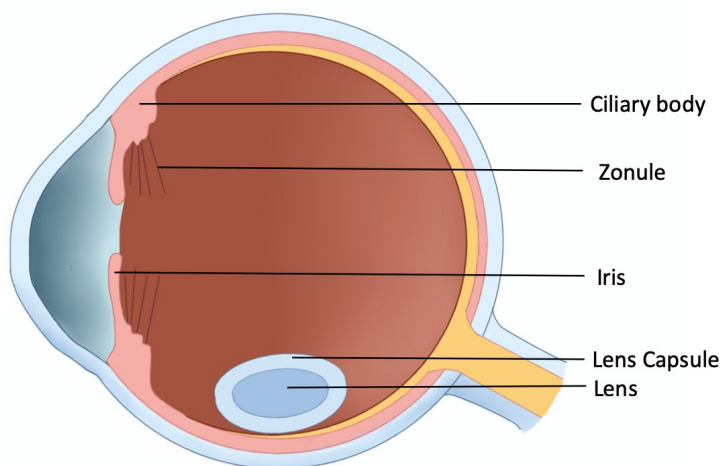
Both environmental factors and genetics play a role in age-related cataracts. The Age-Related Eye Disease study found that older individuals all had increased risk of cataracts, showing that older age is correlated with the development of cataracts.<sup>11</sup> In addition, smoking and UV exposure is associated with cataract formation.<sup>12,13</sup> Twin studies found that monozygotic twins had higher concordance of cataracts compared to dizygotic twins, suggesting a role of heritability in cataract development.<sup>14</sup>

## SURGICAL TREATMENTS - HISTORY

Age-related cataracts can only be treated surgically. However, if diagnosed early, a patient is recommended to postpone surgical treatment until their visual symptoms become severe enough to impair normal day-to-day function. Initially, there are smaller opacities in the eye that do not significantly interfere with light refraction. As the opacities become larger and the cataract further develops, reparative surgery is conducted. This helps patients avoid complications from surgeries that may only result in minimal improvements in vision.<sup>5</sup>

## Couching

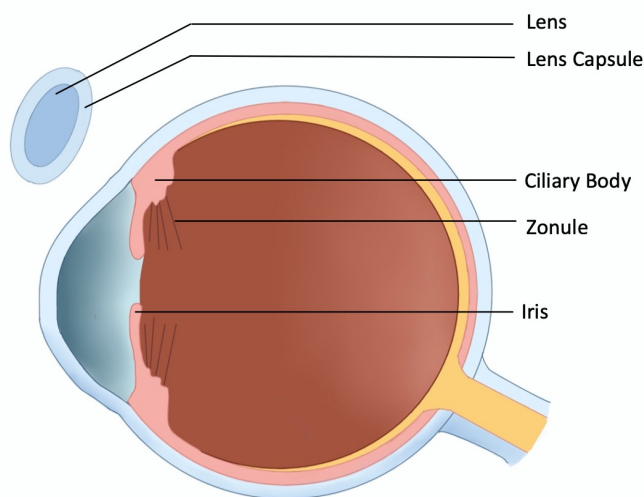
The earliest surgical method used to treat cataracts was couching.<sup>5</sup> A 1200 B.C. wall painting in an Ancient Egyptian tomb depicts what could be interpreted as a couching operation, where an individual is portrayed inserting a long, needle-like object into the eye of a worker. Another Ancient Egyptian temple constructed between 1479-1425 B.C. contains stone engravings that depict an array of long, sharp instruments, which many have speculated to be the tools used to perform couching surgeries.<sup>15</sup> Couching involves inserting a thin surgical instrument (e.g. a sharp needle) into a patient's pars plana and dislodging the capsule that the lens sits within. The lens falls from its original position, into the vitreous cavity, and out of the patient's visual field (Figure 1). Couching has also been non-invasively performed by repeatedly hitting a patient's affected eye, using the force of a blunt object to physically dislodge the lens.<sup>16</sup> Postoperatively, the characteristic symptoms of cataracts are eliminated and vision may improve. However, in many cases, vision still remains comparatively poor.<sup>16</sup> Preoperatively, a patient with mature white cataracts would only be able to differentiate between light and dark; however, postoperatively, they would be able to see how many fingers an individual is holding up, with blur. Couching is considered a dangerous and imprecise technique. Despite having low success and high complication rates, it is still used to treat cataracts in areas with limited access to medical resources. In one study, researchers surveyed individuals 40 years and older over a thirty-month period to determine which cataracts treatments they underwent.<sup>16,17</sup> They found that of 583 eyes that underwent cataract surgery in Nigeria, 249 (42.7%) were done by couching, and 73.1% of those couching eyes had poor visual acuity.<sup>16</sup>



**Figure 1. Couching Procedure.** This figure depicts the outcome of a couching operation used to dislodge a cataractous lens out of the visual field.

## Intracapsular Cataract Extraction

In the 18th century, the technique of intracapsular cataract extraction (ICCE) was introduced as a safer alternative to couching.<sup>5</sup> This involved the creation of a large incision at the limbus, which is the connection between the cornea and sclera. The whole lens and the capsule it sits in are then extracted without replacement, and the patient remains aphakic, or without a lens (Figure 2).<sup>18</sup> A set of suspensory ligaments called zonules hold the lens system in place by connecting the lens capsule to the eye's ciliary muscles. Alpha-chymotrypsin, a proteolytic enzyme, is sometimes injected into the eye during surgery in order to dissolve these zonules and facilitate capsular extraction.<sup>20</sup> Similar to couching, after severe cataracts, vision will improve compared to vision pre-surgery, but it will remain relatively poor. Therefore, thick aphakic glasses that negatively impact peripheral vision can be postoperatively provided to patients as part of the treatment.<sup>2,18</sup> A study by Schemann, Bakayoko, and Coulibaly (2000)<sup>19</sup> compared the outcomes of ICCE and couching in patients from Mali. Despite the two procedures being similar in cost, ICCE patients experienced better visual outcomes. 5.3% of ICCE patients compared to 0% of couching patients achieved good acuity, 76.8% compared to 29.1% had poor acuity, and 17.9% compared to 70.9% became blind. Approximately half of those patients who underwent couching were unaware of alternative or more effective options. This indicates that initiatives to educate surgeons and raise awareness within communities about the existence of other cataract surgery techniques are important to pursue. Intracapsular cataract extraction is still performed today but only when necessary, as in for instance, cases where the posterior capsule is unstable due to weakened zonules.<sup>5</sup>



**Figure 2. Intracapsular Cataract Extraction.** This figure depicts the outcome of the intracapsular extraction of a cataractous lens and its surrounding capsule.

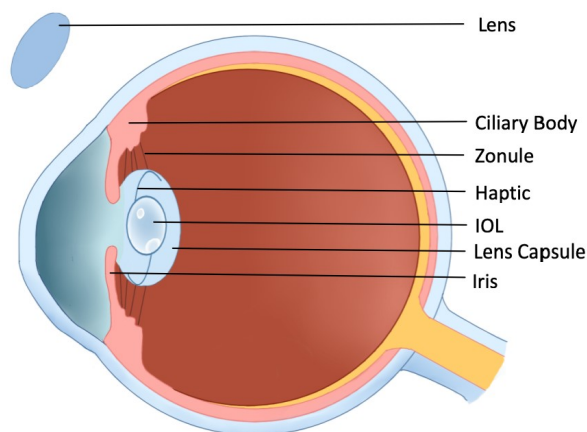
## SURGICAL TREATMENTS - PRESENT

### Extracapsular Cataract Extraction

During the late 20th century, the surgical technique of extracapsular cataract extraction became widespread. This method involved the removal of the aged, opaque lens and implanting an artificial intraocular lens (IOL) to replace it.<sup>21</sup> Therefore, the patient is no longer aphakic postoperatively, unlike with intracapsular cataract extraction or couching. In extracapsular cataract extraction, the surgeon creates an 11 mm limbal incision between the cornea and the sclera. Anterior capsulorrhexis, also known as anterior capsulotomy, is then performed, where the anterior capsule is removed, leaving behind the posterior capsule and the zonular attachments that hold it in place. The surgeon then extracts the lens nucleus and suctions out what is left of the lens cortex. In this manner, the integrity of the posterior lens capsule is maintained. An artificial IOL that has also been designed to correct for a patient's refractive errors can then be accurately maneuvered into place (Figure 3). This refractive correction provides patients with sharp acuity for distant vision, unlike with aphakic patients; reading glasses may be provided for near vision.<sup>5</sup>

IOLs are artificial lenses that are usually composed of polymethylmethacrylate if they are rigid and silicone or acrylic if they are foldable.<sup>5,22</sup> Hennig, Puri, Sharma, Evans, and Yorston (2014)<sup>22</sup> compared the use of rigid IOLs to the use of foldable IOLs in cataracts patients post-surgery. Visual outcomes in both groups were similar, but slightly better in the rigid IOL group. Furthermore, rigid IOLs are significantly cheaper than foldable ones. However, the incidence of posterior capsule opacification, a postoperative complication, was approximately 1.5 times higher in the rigid IOL group. Rigid IOLs require the creation of a 5 mm sclerocorneal tunnel incision that they can fit through. On the other hand, foldable IOLs allow for a smaller 2.5 mm corneal incision that is easier to create. Foldable IOLs are more widely used in developed countries, possibly due to the appeal of a smaller incision. However, in regions with limited access to medical resources, the low cost of rigid IOLs makes them preferable, especially when the visual outcomes are similar to those after the implantation of a foldable IOL. Two other types of IOLs currently exist: the posterior chamber IOL and the anterior chamber IOL. Usually, cataract surgery involves replacing the lens with a posterior chamber IOL. However, in cases where the posterior lens capsule is considered too unstable to hold the IOL in place or after an ICCE, an anterior chamber IOL is used instead. It is placed in front of the iris, where it can be held into place by attached "hooks" known as haptics.<sup>5</sup> Astigmatism is a condition characterized by an irregular corneal surface that prevents the sharp focus of light on the

retina and results in blurred vision. Toric IOLs that correct for astigmatism are also available and implanted in patients when necessary.<sup>23</sup>



**Figure 3. Extracapsular Cataract Extraction.** This figure depicts the outcome of extracapsular extraction of a cataractous lens without its capsule and its replacement with an artificial IOL.

### Phacoemulsification

Currently, the most commonly-used cataract surgical technique is phacoemulsification: an altered form of extracapsular cataract extraction that was introduced by Kelman in 1967.<sup>24-26</sup> Similar to the traditional ECCE, phacoemulsification involves the creation of a corneal incision, an anterior capsulotomy, and the replacement of the cataractous lens with a new IOL. Phacoemulsification differs from ECCE in the introduction of the phacoemulsification probe. After capsulorrhexis is performed, this probe is inserted into the opaque lens through a corneal incision. Instead of extracting the lens nucleus as one solid mass, the probe is used to transmit high-frequency ultrasound waves that emulsify the lens nucleus and allow for its suction through the same probe.<sup>2,24</sup> This is more colloquially known as the “divide and conquer” step. Once the old lens is suctioned out, a new IOL is inserted into the posterior lens capsule. With the advent of thinner phacoemulsification tools that can extract the lens in pieces and foldable IOLs, the corneal incision was significantly reduced to a size of 3 mm that does not require stitches. This may reduce complications such as suture-induced astigmatism.<sup>5</sup> De Silva, Riaz, and Evans (2014)<sup>2</sup> conducted a meta-analysis of studies that compared patient outcomes after phacoemulsification and patient outcomes after ECCE. Patients who underwent phacoemulsification achieved better uncorrected and corrected visual acuity than patients who underwent ECCE. Complication rates, such as iris prolapse, cystoid macular oedema and posterior capsular opacification, were also lower in the phacoemulsification groups. While phacoemulsification is surgically more expensive, ECCE may cost more overall, including the costs of extra postoperative follow-ups and treatments

for complications.<sup>2</sup>

### Femtosecond Laser-Assisted Cataract Surgery

The most recent development in cataract surgery is the more expensive and less commonly used Femtosecond Laser-Assisted Cataract Surgery (FLACS) technique. FLACS differs from phacoemulsification in that lasers largely automate the surgery by performing the incision, anterior capsulotomy, and fragmentation of the aged, opaque lens before its ultrasound emulsification and suction with the phacoemulsification probe.<sup>21</sup> Compared to previous techniques, FLACS lends the surgeon more precision and can reduce the risk of complications. Chen, Chen, He, and Yao (2016)<sup>25</sup> conducted a meta-analysis of studies that investigated FLACS outcomes and found multiple advantages associated with the technique compared to phacoemulsification. Specifically, FLACS was found to be a safer option that presents better visual outcomes, more accurate surgical performance, and reduces complications caused by surgical damage to the corneal endothelium. FLACS patients also experienced a faster recovery time, and consequently, better uncorrected distant visual acuity. Corrected distant visual acuity was also found to be better one-week post-surgery in the FLACS group. However, in the long-term, no significant difference was detected between the two groups. Nevertheless, FLACS is expensive, and the benefits it lends can be considered marginal in comparison to the cost of implementing it.<sup>25</sup> It is less commonly widespread compared to traditional phacoemulsification.<sup>25</sup>

### Viscoelastics

The introduction of viscoelastics to intraocular surgery in 1980 significantly contributed to the safety and efficacy of modern cataract surgeries.<sup>27</sup> Viscoelastics are transparent, fluid substances that are regularly injected into the eye throughout the duration of modern cataract operations. The main purpose behind the use of viscoelastics in cataract surgery is protection. Corneal edema presents one of the more common early postoperative complications to cataract patients.<sup>28</sup> Normally, corneal endothelial cells help regulate the fluid content of the cornea and maintain transparency by transporting excess fluid into the aqueous humor of the eye.<sup>29,30</sup> During surgery, some of these corneal endothelial cells can become damaged or lost, which reduces function and results in corneal swelling or corneal edema. This interferes with corneal transparency and results in poor vision.<sup>31</sup> Viscoelastics minimize friction and damage to the corneal endothelium while removing and replacing the lens, and therefore, they significantly reduce the incidence of complications such as bullous keratopathy, a severe form of corneal edema.<sup>32-34</sup> Additionally, they serve to fill the eye so as to hold ocular structures in place. This allows the surgeon more space to accurately maneuver tools and im-

mensely facilitates the surgery.<sup>34</sup>

## SURGICAL TREATMENTS - FUTURE

### *Accommodating Intraocular Lenses*

The lens capsule is connected to ciliary muscles that regularly relax and contract, causing the lens to alter its convexity. This process, known as accommodation, is crucial for the functioning of the natural lens and accurately focuses light on the retina to allow for sharp vision at all distances, according to Helmholtz's theory.<sup>35</sup> However, because extracapsular cataract extraction involves performing an anterior capsulotomy, the capsule and the entire lens system is unable to partake in accommodation.<sup>36</sup> Furthermore, cataracts patients are fitted with artificially constructed and comparably stiff IOLs, which additionally limit their ability to accommodate.<sup>36</sup> To compensate for this, IOLs are corrected in a manner that would allow the patient to have focused distant vision, and they are then provided with reading glasses that aid with near vision.<sup>5</sup> Alternatively, multifocal IOLs that are engineered to confer focused vision at different distances may be used. While they allow for a certain degree of accommodation, they do not possess the same range of focus that a natural lens does and may reduce contrast sensitivity.<sup>37</sup> Moreover, these multifocal "pseudoaccommodating" lenses are not as financially accessible as regular, unaccommodating IOLs.<sup>38</sup>

Due to these limitations in accommodation, current research efforts are focused on creating a transparent, optical substance that can be injected into the capsule once the opaque lens has been removed - without performing a capsulorrhexis.<sup>39</sup> Ideally, the liquid would be malleable enough to adequately and dynamically respond to the shifting capsule as it changes shape. This would accommodate for focused vision at all distances, provided that the ciliary muscles have not compromised their contractile function, as may be the case in older patients.<sup>39,40</sup> These lenses are known as accommodating IOLs and could potentially replace regular IOLs as the standard treatment for cataracts and revolutionize ocular surgery.

The challenges facing the successful development and application of accommodating IOLs include the optical material leaking through the opening made in the capsule and postoperative capsule opacification. Posterior capsule opacification is the most common late postoperative complication.<sup>41</sup> After extracapsular cataract extraction is conducted, whether phacoemulsification was performed or not, lenticular fibers may not have been completely extracted and remain in the periphery of the posterior lens capsule. These cells then proliferate and migrate into the center of the posterior capsule before undergoing opacification. This results in symp-

toms that echo those experienced when the individual was suffering from cataracts (e.g. low visual acuity). For this reason, posterior capsule opacification is also known as "secondary cataracts". To treat this complication, a neodymium: YAG laser-automated posterior capsulotomy is performed as a way to clear the patient's visual field and allow a transparent passage for light to enter the eye. Currently, there are no established ways to prevent posterior capsule opacification from occurring.<sup>41</sup> With an accommodating IOL, posterior capsule opacification would reduce visual acuity and prevent effective accommodation. Furthermore, a laser capsulotomy to treat posterior capsule opacification might result in the leaking of the optical substance and a compromise of the accommodating IOL structure.<sup>42</sup>

Another goal for these accommodating IOLs is to correct for a patient's refractive errors and eliminate the need for visual correction with glasses or contact lenses, also known as emmetropia.<sup>42</sup> Multiple accommodating IOL designs and methods of administration have been proposed and remain under research investigation. In a study by Hao et al. (2012)<sup>36</sup>, researchers tested the effectiveness of a polysiloxane gel as an alternative to traditional IOLs and found that the gel fully recovers the accommodation range of human cadaver eyes. Ideally, this research aims to achieve a point where accommodating IOLs can be clinically utilized in human cataract surgeries, and patients can postoperatively enjoy sharp, uncorrected vision at all distances. More research on accommodating IOL design, application, and long-term outcomes is needed.

## CONCLUSION

Approximately 50% of the world's blindness is caused by age-related cataracts, and people across the globe and across centuries have been faced with the disease. Technological advances over time have allowed the treatment of cataracts to evolve: from the couching method used in ancient times to phacoemulsification, the most common surgical method used to treat cataracts today. Research into future therapies remains active and looks into developing accommodating IOLs to replace regular ones and lend the patient emmetropia through restoring lens accommodation.

With a greater understanding of age-related cataracts and more research into viable therapeutics, the disease can be effectively combated. Strategies to make treatments more cost-effective, accessible and convenient will bring us closer to the Right to Sight Initiative of eliminating avoidable blindness. However, this goal is far from being reached. A large number of individuals in developing countries are unaware of cataract treatment options available to them and tend to undergo couching, which is the least safe and least effective technique. Without disseminating the relevant infor-

mation and advocating for access to safe treatments in developing countries, surgical advances in the field are inconsequential in these regions. Therefore, it is integral to train specialists on these surgical techniques and inform potential patients on their treatment options. Implementing these measures along with providing the equipment required to conduct these surgeries can help reduce inequalities in treatment.

## ACKNOWLEDGEMENTS

This work did not receive funding. There are no conflicts of interests.

## REFERENCES

- (1) Khairallah M, Kahloun R, Bourne R, Limburg H, Flaxman SR, Jonas JB, Keeffe J, Leasher J, Naidoo K, Pesudovs K, Price H. Number of people blind or visually impaired by cataract worldwide and in world regions, 1990 to 2010. *Investigative ophthalmology & visual science*. 2015 Oct 1;56(11):6762-9.
- (2) De Silva SR, Riaz Y, Evans JR. Phacoemulsification with posterior chamber intraocular lens versus extracapsular cataract extraction (ECCE) with posterior chamber intraocular lens for age-related cataract. *Cochrane Database of Systematic Reviews*. 2014(1).
- (3) The International Agency for the Prevention of Blindness. What is VISION 2020? [Internet]. United Kingdom: The International Agency for the Prevention of Blindness; [cited 2019 Aug 26]. Available from: <https://www.iapb.org/vision-2020>
- (4) Sapkota YD, Pokharel GP, Nirmalan PK, Dulal S, Maharjan IM, Prakash K. Prevalence of blindness and cataract surgery in Gandaki Zone, Nepal. *British journal of ophthalmology*. 2006 Apr 1;90(4):411-6.
- (5) Asbell PA, Dualan I, Mindel J, Brocks D, Ahmad M, Epstein S. Age-related cataract. *The Lancet*. 2005 Feb 12;365(9459):599-609.
- (6) Thompson J, Lakhani N. Cataracts. *Primary Care: Clinics in office practice*. 2015 Sep 1;42(3):409-23.
- (7) Chua BE, Mitchell P, Cumming RG. Effects of cataract type and location on visual function: the Blue Mountains Eye Study. *Eye*. 2004 Aug;18(8):765.
- (8) Sorte K, Sune P, Bhake A, Shivkumar VB, Gangane N, Basak A. Quantitative assessment of DNA damage directly in lens epithelial cells from senile cataract patients. *Molecular vision*. 2011;17:1.
- (9) Ohrloff C, Hockwin O, Olson R, Dickman S. Glutathione peroxidase, glutathione reductase and superoxide dismutase in the aging lens. *Current eye research*. 1984 Jan 1;3(1):109-15.
- (10) Lin D, Barnett M, Grauer L, Robben J, Jewell A, Takemoto L, Takemoto DJ. Expression of superoxide dismutase in whole lens prevents cataract formation. *Mol Vis*. 2005 Oct 11;11(11):853-.
- (11) Chang JR, Koo E, Agrón E, Hallak J, Clemons T, Azar D, Sperduto RD, Ferris III FL, Chew EY, Age-Related Eye Disease Study Group. Risk factors associated with incident cataracts and cataract surgery in the Age-related Eye Disease Study (AREDS): AREDS report number 32. *Ophthalmology*. 2011 Nov 1;118(11):2113-9.
- (12) Flaye DE, Sullivan KN, Cullinan TR, Silver JH, Whitelocke RA. Cataracts and cigarette smoking: the City Eye Study. *Eye*. 1989 Jul;3(4):379.
- (13) Taylor HR. The biological effects of UV-B on the eye. *Photochemistry and photobiology*. 1989 Oct;50(4):489-92.
- (14) Hammond CJ, Snieder H, Spector TD, Gilbert CE. Genetic and environmental factors in age-related nuclear cataracts in monozygotic and dizygotic twins. *New England Journal of Medicine*. 2000 Jun 15;342(24):1786-90.
- (15) Asacaso FJ, Huerva V. The history of cataract surgery. chapter; 2013 Feb 7.
- (16) Gilbert CE, Murthy GV, Sivasubramaniam S, Kyari F, Imam A, Rabiun MM, Abdull M, Tafida A. Couching in Nigeria: prevalence, risk factors and visual acuity outcomes. *Ophthalmic epidemiology*. 2010 Oct 1;17(5):269-75.
- (17) Dineen, B., Gilbert, C. E., Rabiun, M., Kyari, F., Mahdi, A. M., Abubakar, T., ... & Faal, H. (2008). The Nigerian national blindness and visual impairment survey: Rationale, objectives and detailed methodology. *BMC ophthalmology*, 8(1), 17.
- (18) Beare NA, Bastawrous A. Ophthalmology in the Tropics and Sub-tropics. In *Manson's Tropical Infectious Diseases* 2014 Jan 1 (pp. 952-994). WB Saunders.
- (19) Schémann JF, Bakayoko S, Coulibaly S. Traditional couching is not an effective alternative procedure for cataract surgery in Mali. *Ophthalmic epidemiology*. 2000 Jan 1;7(4):271-83.
- (20) Harris GS. Alpha-Chymotrypsin in Cataract Surgery. *Canadian Medical Association journal*. 1961 Jul 22;85(4):186.
- (21) Minassian DC, Rosen P, Dart JK, Reidy A, Desai P, Sidhu M. Extracapsular cataract extraction compared with small incision surgery by phacoemulsification: a randomised trial. *British Journal of Ophthalmology*. 2001 Jul 1;85(7):822-9.
- (22) Hennig A, Puri LR, Sharma H, Evans JR, Yorston D. Foldable vs rigid lenses after phacoemulsification for cataract surgery: a randomised controlled trial. *Eye*. 2014 May;28(5):567.
- (23) Ruhswurm I, Scholz U, Zehetmayer M, Hanselmayer G, Vass C, Skorpik C. Astigmatism correction with a foldable toric intraocular lens in cataract patients. *Journal of Cataract & Refractive Surgery*. 2000 Jul 1;26(7):1022-7.
- (24) Kelman CD. Phaco-emulsification and aspiration: a new technique of cataract removal: a preliminary report. *American journal of ophthalmology*. 1967 Jul 1;64(1):23-35.
- (25) Chen X, Chen K, He J, Yao K. Comparing the curative effects between femto-second laser-assisted cataract surgery and conventional phacoemulsification surgery: a meta-analysis. *PLoS One*. 2016 Mar 21;11(3):e0152088.
- (26) Leaming DV. Practice styles and preferences of ASCRS members—2003 survey. *Journal of Cataract & Refractive Surgery*. 2004 Apr 1;30(4):892-900.
- (27) Miller D, Stegmann R. Use of Na-hyaluronate in anterior segment eye surgery. *American Intra-Ocular Implant Society Journal*. 1980 Jan 1;6(1):13-5.
- (28) Iqbal Y, Zia S, Baig Mirza AU. Intraoperative and early postoperative complications of manual sutureless cataract extraction. *J Coll Physicians Surg Pak*. 2014 Apr 1;24(4):252-5.
- (29) Hodson S. The regulation of corneal hydration by a salt pump requiring the presence of sodium and bicarbonate ions. *The Journal of physiology*. 1974 Jan 1;236(2):271-302.
- (30) Hull DS, Green K, Boyd M, Wynn HR. Corneal endothelium bicarbonate transport and the effect of carbonic anhydrase inhibitors on endothelial permeability and fluxes and corneal thickness. *Investigative ophthalmology & visual science*. 1977 Oct 1;16(10):883-92.
- (31) Yi DH, Dana MR. Corneal edema after cataract surgery: incidence and etiology. In *Seminars in ophthalmology* 2002 Jan 1 (Vol. 17, No. 3-4, pp. 110-114). Taylor & Francis.
- (32) Claesson M, Armitage WJ, Stenevi U. Corneal oedema after cataract surgery: predisposing factors and corneal graft outcome. *Acta ophthalmologica*. 2009 Mar;87(2):154-9.
- (33) Glasser DB, Osborn DC, Nordeen JF, Min YI. Endothelial protection and viscoelastic retention during phacoemulsification and intraocular lens implantation. *Archives of Ophthalmology*. 1991 Oct 1;109(10):1438-40.
- (34) Storr-Paulsen A, Nørregaard JC, Farik G, Tårnhøj J. The influence of viscoelastic substances on the corneal endothelial cell population during cataract surgery: a prospective study of cohesive and dispersive viscoelastics. *Acta Ophthalmologica Scandinavica*. 2007 Mar;85(2):183-7.
- (35) Glasser A, Kaufman PL. The mechanism of accommodation in primates. *Ophthalmology*. 1999 May 1;106(5):863-72.
- (36) Hao X, Jeffery JL, Le TP, McFarland G, Johnson G, Mulder RJ, Garrett Q, Manns F, Nankivil D, Arrieta E, Ho A. High refractive index polysiloxane as injectable, in situ curable accommodating intraocular lens. *Biomaterials*. 2012 Aug 23;56(59):71.
- (37) Montés-Micó R, Alió JL. Distance and near contrast sensitivity function after multifocal intraocular lens implantation. *Journal of Cataract & Refractive Surgery*. 2003 Apr 1;29(4):703-11.
- (38) Lin JC, Yang MC. Cost-effectiveness comparison between monofocal and multifocal intraocular lens implantation for cataract patients in Taiwan. *Clinical therapeutics*. 2014 Oct 1;36(10):1422-30.
- (39) Findl O, Leydolt C. Meta-analysis of accommodating intraocular lenses. *Journal of Cataract & Refractive Surgery*. 2007 Mar 1;33(3):522-7.
- (40) Strenk SA, Semmlow JL, Strenk LM, Munoz P, Gronlund-Jacob J, DeMarco JK. Age-related changes in human ciliary muscle and lens: a magnetic resonance imaging study. *Investigative ophthalmology & visual science*. 1999 May 1;40(6):1162-9.
- (41) Schaumberg DA, Dana MR, Christen WG, Glynn RJ. A systematic overview of the incidence of posterior capsule opacification. *Ophthalmology*. 1998 Jul 1;105(7):1213-21.
- (42) Nishi Y, Mireskandari K, Khaw P, Findl O. Lens refilling to restore accommodation. *Journal of Cataract & Refractive Surgery*. 2009 Feb 1;35(2):374-82.