Current State of Cataract Surgery

Today, with the use of small incisions and foldable intraocular lenses (IOLs), cataract extraction has become a safer and more effective surgery. However, despite the many advances over the years, the current state of cataract surgery still has safety concerns and refractive limitations. Complications such as endophthalmitis, posterior capsule rupture and cystoid macular edema still arise. The refractive accuracy remains suboptimal and true accommodating IOLs are first generation with much advancement still to come. In the next ten years, the use of the femtosecond laser will help reduce or eliminate these shortcomings in cataract surgery. In addition, the femtosecond laser will perform surgery that is simply impossible to perform manually.

Limitations

Wound Integrity

Current cataract surgery employs the use of manually created clear corneal incisions with ultra-sharp blades. Although recovery time has improved, the advent of this approach in 1992 has perhaps led to an increase rate of endophthalmitis. (Taban 2005). Laboratory studies have shown that these incisions are potentially unstable, leading to an increased risk of endophthalmitis. (McDonnell 2003) In a large meta-analysis, Taban et al demonstrated decrease in the rate of post cataract endophthalmitis from the 1960s until 1992, at which point there was a statistically significant increase in the rate of endophthalmitis. This has largely been accounted for by the integrity of the wound, and subclinical wound leaks. (Maxwell 1994, Montan 1998) Additionally, Wallin et al in 2005 determined that wound leak was the worst risk factor, leading to a forty-fold increase in the development of endophthalmitis post cataract extraction.

Capsulorhexis creation

The capsulorhexis creation is one of the most important and difficult steps in cataract surgery. It ensures proper centration of the IOL and its durability allows for complicated movements during phacoemulsification. (Colvard 1990) However, its creation is variable depending on the experience of the surgeon and patient specific factors such as pupil dilation and anterior chamber depth. If there is a single radial tear in the capsulorhexis, there is a significant risk of extension to the
posterior capsule. (Marques 2006) The rate of anterior capsular tears ranges from, 0.5% to 5.6%, depending of the experience of the surgeon. (Marquez 2006, Muhtaseb 2004, Unal 2006, Olali 2007) When a tear does occur, in the largest reported study, Marques et al had 48% association with extension to the posterior capsule and 19% required an anterior vitrectomy.

Additionally, capsule size plays a significant role in determining outcomes post procedure. Various studies have shown that a small capsulorhexis has been associated with fibrosis of the anterior capsule and a hyperopic shift with single piece IOLs, while a large capsulorhexis can lead to tilt and decentration of the lens, posterior capsular opacification formation and a myopic postoperative error. (Sanders, Wallace, Ravalico, Walkow). Additionally, with the increased use of accommodating IOLs, capsulorhexis size is critical. A dual optic accommodating IOL necessitates complete overlap of the capsulorhexis to maintain proper optic positioning, while the other accommodating IOLs require a larger rhexis in order to allow for full movements of the lens. (McLeod 2007, Ossma 2007, Vargas 2005)

Ultrasound time and Endothelial Cell Loss

Another limiting aspect of current cataract surgery is the amount of phacoemulsification time required and its impact on endothelial cell count. Phacoemulsification has been known to decrease endothelial cell count, and the use of the phaco chop method has been shown to require less ultrasound energy than the traditional divide and conquer approach. (Debry 1998, Pirazzolli 1996) While the impact on endothelial loss between these techniques varies in the literature, Pirazzoli et al demonstrated less endothelial loss with the phaco chop method. (Pirazzoli 1996) Additionally, it has been shown that chopping decreases phaco time for dense lenses (Park 2010) and less energy is consumed when the lens is presliced. (Pereira 2006)

Relaxing Incisions

Following cataract surgery, limbal relaxing incisions can be used to correct astigmatism by flattening the steepest axis of the cornea. (Nichamin 2006). A recent study of 4,540 eyes of 2,415 patients showed that corneal astigmatism is present in the majority of patients undergoing cataract surgery, with at least 1.50 D measured in 22.2% of study eyes. (Ferrer-Blasco 2009). Approximately 38% of eyes undergoing cataract surgery have at least 1.00 D of preexisting corneal astigmatism, and 72% of patients have 0.5 D or more. (Hill 2008). However, their utilization has been minimized, given the technical demands of the manual procedure, concern with anterior chamber perforation, and variability of results, as an axis misalignment of five degrees can result in a 17% reduction in effect of the incision. (Nichamin 2006)

Refractive accuracy
Although safety plays a major role in the efficacy of a procedure, patients also have refractive expectations that must be met or exceeded. The predictability and accuracy of the cataract procedure are assuming greater importance with the emergence of refractive cataract surgery. Murphy and colleagues reported an outcome within 0.50 D of emmetropia in only 45% of patients and within 1.00 D in only 72%. (Murphy 2002). A more recent article that evaluated refractive success using the IOLMaster (Carl Zeiss Meditec, Inc.) found that only 75% of patients achieved an outcome within 0.50 D of emmetropia. (Landers, 2009). These results pale in comparison to those achieved with LASIK for mild and moderate refractive errors: 95% of patients’ results are within 0.50 D of emmetropia. (Solomon, 2009). The practical consequence of the cited statistics is that approximately one-quarter to one-half of the patients undergoing cataract surgery today (about 750,000 to 1.5 million patients per year) will require distance correction.

Femtosecond laser assisted cataract surgery

The advent of the femtosecond laser for cataract surgery should help alleviate some of these shortcomings in the years to come. Initially developed for LASIK flap creation for refractive surgery (Nordan 2003), its benefits have now expanded to cataract surgery. Femtosecond lasers are photodisruptive lasers with extraordinarily short pulse durations of less than 800 femtoseconds (one femtosecond is $10^{-15}$ seconds). This extremely short pulse duration allows femtosecond lasers to cut tissue with considerably less energy than traditional lasers used in ophthalmic surgery. Per-pulse energies can be reduced approximately 1,000-fold, from around $1-10$ millijoules for nanosecond lasers (neodymium-doped yttrium aluminum garnet [Nd:YAG]) to $1-10$ microjoules for femtosecond lasers leading to less energy output and less destruction of surrounding structures with its focused depth of action. (Sugar 2002, He 2011)

Initial Results

Porcine eyes, ex vivo

Nagy et al performed ex vivo studies on porcine eyes, comparing accuracy, reproducibility and capsular edge strength of capsulotomies created by LensSx laser system ($n=10$) and by manual continuous curvilinear capsulorhexis ($n=12$). They showed that the femtosecond laser produced a more reproducible ($P<0.001$), uniform, and accurate capsulotomy ($p<0.001$) when compared to the manual procedure. Scanning electron microscopy demonstrated comparably smooth edges and the capsule aperture had a significantly higher stretching ratio ($P<0.001$) in the laser group. Additionally, average phaco power was reduced by 43% ($P<0.001$) and effective phaco time by 51% ($P<0.001$) (Nagy 2009).
Initial in vivo studies

Nagy et al also performed laser treatments on nine patients. Three received capsulotomies, three received lens fragmentation, and three received both. Seven patients had trace to mild corneal edema on post op day 1 and 6 had a trace anterior chamber reaction at post op day 1 with complete resolution by day 7. All patients had corrected visual acuity of 20/20 by month 1 post procedure. No complications or adverse were noted in any case. (Nagy 2009)

Capsulotomies

He et al summarized the initial clinical data on size, shape and position of the capsulotomy from three femtosecond laser systems – OptiMedica, LensAR, and LenSx. (He 2011) Each system produced a capsulotomy diameter closer to the intended diameter than the manual capsulorhexis. OptiMedica reported diameters within 27 μm of intended compared to 339 μm for manual; 183 μm for the LensAR compared to 500 for the manual; and the LenSx reported all laser capsulotomies were within 250 μm of intended. In terms of ideal shape, OptiMedica capsulotomities measured 0.942 with 1 being completely circular. LensAR produced a 6 fold increase in circularity compared to manual and LenSx capsulotomies were "significantly rounder" when compared to manual capsulorhexis. Placement of the capsulotomy was also significantly closer to the intended location for laser group when compared to a manual approach. (Battle, Nichamin, Nagy)

In a larger study, Nagy et al compared the laser technique (n=54) to manual capsulorhexis creation 1 week after surgery. They found that the capsulorhexis created by the femtosecond laser was more regularly shaped, had better overlap with the IOL, and had better IOL centration than manual capsulorhexis. Additionally, there was no correlation with femtosecond capsulotomies and pupil size or axial, as compared to the manual group where a statistically significant correlation existed. (Nagy 2011)

Longer-term studies have also shown the benefit from using the femtosecond laser. Kranitz et al compared sizing and positioning of femtosecond laser capsulotomies with manual continuous curvilinear capsulorhexis at 1 week, 1 month, and 1 year after surgery. They found the type of capsulorhexis and the amount of overlap with the IOL to be a significant predictor of horizontal lens decentration. The manual group was six times more likely to have lens decentration and had significantly less overlap at all time periods. Out of 20 eyes in the manual group, 15 had decentration of >0.4mm at 1 year. None of the eyes in the laser group had that level of decentration at any time point in the study. (Kranitz 2011). Femtosecond laser capsulotomies have now been show to result in a more reproducible and accurate
effective lens placement and better refractive results than manually performed surgeries. (Cionni 2012).

Lens Fragmentation

Another benefit of femtosecond laser assisted cataract surgery would be the reduction of ultrasound energy and phaco power required to fragment the lens following pretreatment with the laser. Aside from Nagy’s initial work on porcine eyes, Batlle et al demonstrated a 40% reduction in cumulative dispersive energy with pretreated eyes, as compared with the traditional approach. (Batlle 2011) Edwards et al has also shown an absolute decrease in energy required proportional to the grading of the cataract, with a statistically significant decrease for grades 1 and 2. (Edwards 2011)

Corneal Incisions

To this point, limited research has been performed evaluating clear corneal incisions using the femtosecond laser for cataract surgery, although it has been used successfully for penetrating keratoplasty. (Chamberlain 2011) Masket et al in a pilot studied constructed reproducible and stable corneal incisions, with no leakage for the 3mm x 2mm incision, regardless of IOP and ophthalmodynamometer readings. (Masket 2010).

Discussion

Since the introduction of phacoemulsification, cataract surgery has evolved into an efficient procedure with excellent visual results. However, with these advancements have come an increase in patient expectation and the need for even faster recovery times. The limitations and shortcomings of today’s procedure can be improved with the use of femtosecond laser assistance.

Although still in its infancy, femtosecond laser assisted cataract surgery has already been shown to produce more reliable and accurate capsulorhexis, while at the same time reducing phaco energy and phaco time. This is just the beginning. Lee et al in 2009 described a technique for performing femtosecond laser assisted lamellar keratoplasty to remove corneal opacities to allow for better visualization prior to cataract extraction with no complications. (Lee 2009) Nishimoto el al described a technique for treating vertical strabismus by intentionally decentering the IOL. Although their technique was with manual capsulorhexis creation, the use of femtosecond laser would allow for more accurate and better control of the procedure. (Nishimoto 2007) Finally, the role of the femtosecond laser may be to reverse the cataract entirely. Kessel et al in 2010 performed infrared pulsed femtosecond laser treatments on nine donor eyes and found a marked increase of the transmission of light following the procedure. (Kessel 2010)
The future of cataract surgery will lie in our ability to correct the limitations we currently have and produce a more optimized cataract extraction procedure. That future will begin with the increased utilization of the femtosecond laser. Cost considerations will resolve over time as the effectiveness of femtosecond laser cataract surgery improves. Femtosecond laser cataract surgery has already been established as superior to conventional phacoemulsification in several parameters and the potential for improvements is limitless. Aspects of the cataract procedure will be performed with the femtosecond laser that are simply impossible with conventional phacoemulsification. The ability to produce true self sealing cataract incisions with reverse side cuts should reduce the incidence of endophthalmitis. Atraumatic capsulotomies and lens disruption can be performed in cases of trauma with zonular dehiscence through vitreous in the anterior chamber. Refractive incisions are now computer-controlled and do not rely on surgeon skill or experience. The use of a femtosecond laser system will provide faster, safer, easier, customizable, adjustable, and fully repeatable astigmatic incisions. Removing the inconsistencies in the astigmatic procedure will improve our understanding and accuracy of astigmatic incisions and should provide improved refractive results and patient satisfaction. The ability to perform intrastromal ablations for astigmatism management cannot be achieved with manual incisions. The optimal placement of the capsulotomy on the center of the capsular bag, over the pupil, or centered on the visual axis will be possible with image guided laser surgery. Finally IOL design will be revolutionized by the ability to create regular, reproducible capsulotomies and lens disruption. The concept of creating a 1 mm or smaller hinged capsulotomy, emulsifying the lens and removing it through a small incision opens the possibility of refilling the capsular bag with a polymer that maintains the ability of the patient’s own lens to accommodate and then resealing the capsule.

We are now witnessing the natural progression of cataract surgery from intracapsular, to extracapsular, to phacoemulsification and now to the femtosecond laser. In conclusion, the femtosecond for cataract surgery is a novel technique that provides the precision of image-guided laser technology that will dramatically elevate cataract surgery and will be the standard form of cataract surgery in ten years.

References:


comparative analysis of phaco-chop and stop-and-chop techniques according to the degree of nuclear density. Ophthalmic Surg Lasers Imaging 2010;41:236-241


