Limitation, logic, and language

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In thinking about the process of innovation, I recognized that limitation, logic, and language have all played important roles in the development of my work. I would like to review the three areas of special interest for me: endolenticular phacoemulsification techniques, cortical cleanup, and the cataract incision.

What we all really seek is the perfect cataract procedure, for each case to end perfectly. That ideal may not be achievable, but in the 20-year history of the American Society of Cataract and Refractive Surgery, through incremental improvements, we have come a long way toward achieving that goal.

The man in Figure 1 was lying on my surgery table 10 minutes before this picture was taken. He had endolenticular phacoemulsification and foldable intraocular lens (IOL) implantation through a clear corneal incision under topical anesthesia. It is impossible to tell which eye was operated on, and the patient went to work upon leaving the surgery center.

Fig. 1. (Fine) Immediately after surgery, this patient (left) is ready to go to work.

This patient knows little of incremental improvement, but he knows about giant steps. Twenty years earlier, his mother had had intracapsular cataract extraction. She stayed in the hospital for a week after each eye surgery and then endured two months of visual disability until aphakic spectacles were prescribed.

I believe it is limitation that stimulates innovation. In some form we confront a difficulty, obstacle, or restriction in what we are trying to achieve, and this makes us seek an alternative path. That alternative path is usually logical.

In his earliest publication on the technique, Charles Kelman[1] called phacoemulsification an alternative technique for cataract surgery. He spoke specifically about the limitations large incision cataract surgery placed on visual and physical rehabilitation and how phacoemulsification could provide an alternative. At the same time, he gave the world small incision surgery.

The need to make a new incision in the globe limited our enthusiasm about opening opacified posterior lens capsules after cataract extraction and IOL implantation. Danièle Aron-Rosa[2] provided a wonderful alternative: the neodymium:YAG laser.

Many of us were frustrated by the inability to achieve routine in-the-bag IOL implantation and by the extension of anterior capsular tears over the equator and onto the posterior capsule. Thomas Neuhann[3,4] and Howard Gimbel[4] independently developed a solution: the continuous curvilinear capsulorhexis (CCC), which addressed the limitations of the can-opener capsulotomy. However, that advance, as is frequently the case with any advance, presented new limitations related to the loss of access to the nuclear equator.

ENDOLENTICULAR PHACOEMULSIFICATION TECHNIQUES

Limited in our access, we could no longer perform phacoemulsification from outside of the nucleus inward; an alternative technique had to be developed. Many endolenticular phacoemulsification techniques were developed in which phacoemulsification was performed from inside out. For me that initially meant

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sculpting with one hand, giving up the second hand I found so helpful, and reducing the nucleus to a posterior plate that was extremely difficult to mobilize predictably and remove from the eye.

By chance, at the Welsh Cataract Conference in 1988, Thomas Neuhann sat down beside me at breakfast. This man, whom I had admired but never met, told me of his method of hydrodissection in which fluid was injected not quite peripherally in the nucleus but a little more centrally, resulting in a thick layer of what he called cortex. The central portion of the nucleus was then emulsified and the thick cortical layer removed by mashing the cortex into the irrigation/aspiration (I/A) handpiece with a second handpiece.

I immediately saw the possibility of going not only a little centrally but as far centrally as I could to reduce the size of the nuclear mass, which would enable me to use a two-handed technique. If I could make the central portion of the nucleus small enough so that I had access to the equator of the reduced nuclear mass, I could perform phacoemulsification more like I used to. This circumferential division of the nucleus into a compact central mass surrounded by a soft outer epinuclear shell is now, in retrospect, recognizable as Aziz Anis' brilliant hydrodelineation and dry intracapsular cataract extraction technique (A.Y. Anis, M.D., "Dry ECCE Technique Reported to Reduce Endothelial Cell Loss," Ophthalmology Times, February 1, 1986, pages 1, 57).

Another advantage of circumferential division of the nucleus was that the epinuclear shell acted as a protective structure within which we could contain all of the phacoemulsification and mechanical forces. Also, the epinuclear shell kept the capsule stretched and, therefore, the posterior capsule was unlikely to prolapse during the phacoemulsification procedure, occlude the phaco tip, and rupture.

But again, a new limitation arose: how to deal with the thick epinuclear shell once we got rid of the endonucleus. We were, in a sense, in the same situation we used to describe as "phacoing oneself into a corner." How could we get rid of that epinucleus? For me, the thought of turning it upside down to mobilize it was very appealing because if I could turn it upside down, it would not be as close to the posterior capsule and I could more safely remove it from the eye. There was, however, another limitation: space. How does one turn this shell upside down within the confines of an intraocular environment?

To overcome this limitation, I returned to the fundamental, basic principles I learned during my training in engineering. If we exert a single force on a structure, such as pulling on the distal rim of the epinucleus, the proximal edge of which is being restricted at a pivot point like the capsular fornix 180 degrees away, and pull on it with the phaco handpiece in foot position 2 (Figure 2), we can only turn it upside down if we also move its position in space so that A is as far as it was from B but on the other side. We would need an eye that was twice as wide.

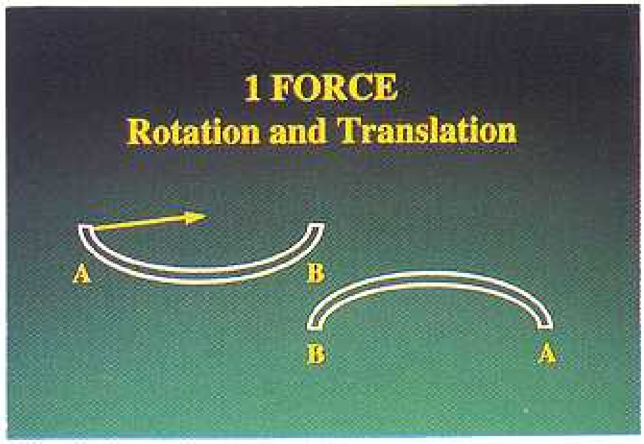

Fig. 2. (Fine) A single force produces rotation and translation.

Engineering has a mechanical concept called the couple. A couple results when equal antiparallel forces are applied, resulting in rotation without translation. Thus, one need not change position in space. By applying equal antiparallel forces, we could turn the shell upside down so that A now ended up where B was and B where A was without the need for additional space (Figure 3). In practice, this worked extremely well, and we were able to invert the epinucleus, remove it from the proximity of the capsule, and consume it either with low powers of phacoemulsification or aspiration.

Figure 4 illustrates the pull of the phaco tip toward the incision on the distal rim of the epinuclear shell in foot position 2. As the second handpiece pushes on the center of the bowl toward the distal periphery, it creates antiparallel forces and inverts the epinucleus.

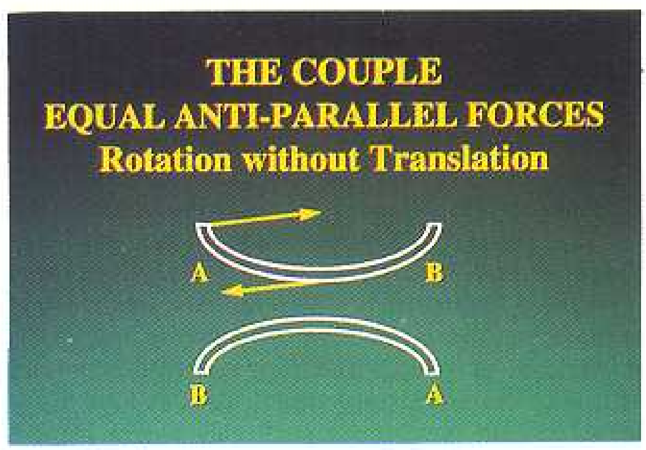

Fig. 3. (Fine) A couple creates rotation without translation.

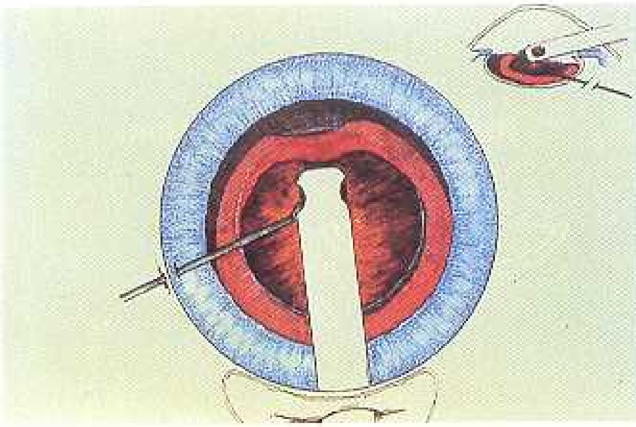

Fig. 4. (Fine) Purchase of the distal rim and the beginning of a flipping maneuver by antiparallel forces.

So, I now had a systemized approach to endolenticular phacoemulsification that involved hydrodelineation, sculpting of the endonucleus to a plate, elevation of the equator of the plate by the second handpiece and removal with phacoemulsification, and inverting and removing the epinucleus. This was a logical two-handed endolenticular technique for phacoemulsification within the confines of a small circular capsulorhexis.

I started to think about how I would communicate this to my colleagues. I realized it would be difficult, that I needed to be very precise in naming the procedure. I wanted the name to be descriptive enough so people could recognize what the technique entailed. And, to be perfectly honest, I wanted the name to rhyme, be alliterative, or to include some other linguistic catch. So, I called the plate "the chip" and reverting the epinucleus "flipping the epinucleus"; hence, the "chip and flip" technique.[5] I have always tried to invent clear, descriptive names (e.g., cortical cleaving hydrodissection,[6] self-sealing corneal tunnel incision,[7] chip and flip, crack and flip,[8] infinity suture,[8,9] millimeter marker[10]), which I think have helped communicate these concepts and methods.

Endolenticular phacoemulsification had a rapid progression. We are all familiar with cracking as Kelman demonstrated and with the spectrum of nucleofractis procedures that Howard Gimbel systemized with his divide and conquer techniques[11] and that John Shepherd modified.[12]

William Maloney and David Dillman found a way to combine the advantages of working within an epinucleus, as in chip and flip, with the enormous efficiency of cracking procedures, such as John Shepherd's in situ phaco-fracture.[12] This was a logical, brilliant idea. They called their procedure "fractional 2:4 phaco,"[13] a name that is a bit of a lyrical cripple. (Today, few people can tell you what that meant.)

This was one of the most productive periods of my life because I had an opportunity to work on a continuing basis for three years with Maloney and Dillman. Together, we made enormous technique refinements. Looking back, these refinements may seem small, but they were important incremental improvements.

We taught courses throughout the United States and the world. At night, after the courses ended, we would meet and ask such questions as, "Are we getting the point across and communicating well?" "Why aren't we communicating well?" "The questions at the end of the course indicate that we didn't make the point. Why?" We held how-to sessions and asked, "How should we describe these techniques?" "How should we teach these techniques?" What we came to learn was that language was the limitation.

These how-to sessions started us thinking about how to describe what we were doing. We took a more analytical look and as a result, we each altered our techniques. We altered them, yet we all ended up in the same place, independently almost, based on a desire to communicate.

The result was crack and flip phacoemulsification.[8] Although the technique drew heavily from the contributions of many others, we outlined specific steps and aids to the performance of each step. We recognized that withdrawing the cannula halfway out of the tract and injecting into an empty tract during hydrodelineation allowed the fluid to find the path of least resistance and produce a golden ring. We taught grooving as a shaving technique under low flow; we emphasized restricting grooving to central to the golden ring, with no need to violate the protective epinucleus. We looked at all of the physical forces and combinations of forces that were used in cracking, and we taught how to use cross action and parallel forces. We taught depth testing, which was a new concept that helped phacoemulsification surgeons become more comfortable with performing the cracking procedure.

Depth testing was based on the following concept: If one is afraid to sculpt more deeply, one should try to crack the groove. If it doesn't crack, the eye is stating that it is safe to go back and groove deeper. We looked at the fine details of quadrant removal, of elevating the quadrant apex, of occluding the phaco tip with the quadrant apex while the console is set at high vacuum with pulsed phaco mode, of using the second handpiece to contain the quadrant within the epinuclear shell and not allowing it to threaten either the corneal endothelium or the posterior capsule. Finally, we outlined all of the details of epinuclear management.

Figure 5 shows an empty epinuclear shell. The roof of the shell protects the peripheral endothelium, the fornices of the epinucleus protect the fornices of the capsule, and the posterior segment of the epinuclear shell protects the posterior capsule.

Fig. 5. (Fine) Intact epinuclear shell after all quadrants have been removed.

I think we helped many surgeons move toward endolenticular phacoemulsification that was less traumatic for their patients. I also think we helped them become more comfortable performing the procedure.

CORTICAL CLEANUP

If there was ever a limitation in my life, it was cortical cleanup. I hated to accomplish a good phacoemulsification and then rupture the capsule and occasionally even lose vitreous doing cortical cleanup. I became inordinately motivated to do away with I/A. Each time I performed a CCC and elevated the central flap to tear it, I looked at the flap and asked myself, "Why is that flap so clean? There is no cortex on it. Why can't we have a bag that looks like that flap after we are done with phacoemulsification?"

I decided I would elevate the anterior capsule rim before hydrodissection and inject against the capsule, between the capsule and the cortex. The first four or five times I did this, I blew the nucleus out of the bag.

It finally occurred to me what was happening: The gentle, continuous irrigation allowed the fluid to flow posteriorly, peripheral to the cortex, around the lens. The fluid became trapped in the capsular fornices, where the cortical capsular connections are the most adherent. This resulted in pressure from behind the nucleus, which brought the nucleus forward. Continued irrigation of the trapped fluid expressed the lens out of the bag.

By watching the capsulorhexis enlarge, I recognized that fluid was being trapped posteriorly. By depressing the lens with the cannula, I could force the posteriorly loculated fluid to come circumferentially around the equator of the lens, rupture capsular cortical connections at the equator, and exit the capsule through the capsulorhexis.

Once I understood this phenomenon, I was able to reproduce and refine it. I named it cortical cleaving hydrodissection.[6] This technique enabled me to do away with I/A. In 70% of the cases, the cortex came out with the epinucleus. When some or all of the cortex was left behind, I was able to viscodissect it, draping the anterior extension of the cortex on top of the capsule and then forcing the posterior cortex into the capsular fornices (Figure 6). I would then implant the lens and mobilize the residual cortex along with residual viscoelastic. The logic was wonderful: It is pretty hard to rupture the posterior capsule with the optic in the way.

THE CATARACT INCISION

Self-sealing corneal tunnel incisions remain somewhat controversial. We heard several opinions on these incisions at this meeting (see Appendix). To me, the incision is less invasive than others. In addition, these incisions overcame what I viewed to be definite limitations of scleral tunnel incisions: the need to do a conjunctival incision and a scleral dissection, resulting in bleeding and the need for cautery; a long scleral tunnel resulting in oarlocking of the phaco handpiece in the incision and a compromised view of intraocular structures; and finally, an occasional hyphema from vessels in scleral tunnel incisions.

My own involvement with corneal incisions goes back to 1979, when I was performing secondary anterior chamber IOL implantations in eyes that years before were operated on by surgeons who viewed incisions only as a means of access to the cataract. These incisions were so unpredictable, I had difficulty working around them. So, I moved to the corneal periphery temporally. I closed the incisions with three 10-0 nylon sutures. To my amazement, after suture removal three months later, these eyes had inordinately stable refractions. They did not drift against the

Fig. 6. (Fine) Viscoelastic being injected through the side port. The anterior cortex, seen to the left and inferiorly, has already been draped over the capsulorhexis and the posterior cortex is now being forced into the capsular fornices.

rule, as did my superiorly incised eyes that had cataract extraction.

In 1986 I began investigating silicone lenses and foldable lenses for several manufacturers. At that time, I began to use clear corneal incisions in all patients who had functioning filtering blebs before cataract surgery. The incisions were 3 mm long for phacoemulsification and I/A. The incisions were enlarged with a keratome to 4 mm for lens implantation, and two 10-0 nylon radial sutures were used to close. These patients had rapid visual rehabilitation. The promise that small incision cataract surgery would decrease surgically induced astigmatism was immediately realized.

In 1990, I implanted in a rabbit eye the prototype of what is now the AMO SI30. When finished, I told the project manager that when that lens became available, I was going to move to the clear cornea for my incision site.

Indeed, in 1992, I began clear corneal cataract surgery from the temporal periphery using a Shepherd single stitch. Within a month, I abandoned the stitch in favor of self-sealing incisions.[7]

Figure 7 shows a clear corneal tunnel incision closed by a Shepherd single stitch; Figure 8 shows photokeratoscopy of the same eye immediately after surgery. There is some flattening of the sutured incision site, but the central mires are clear and regular, indicating that this patient would enjoy excellent visual acuity soon after surgery.

Figure 9 shows one of my first self-sealing corneal tunnel incisions on the first postoperative day. There is a bit of edema over the tunnel temporally and the immediate photokeratoscopy (Figure 10) shows minor disturbance at the incision itself. However, the central mires are regular and extend to the edge of the cornea, documenting that this patient, too, should have excellent visual acuity immediately.

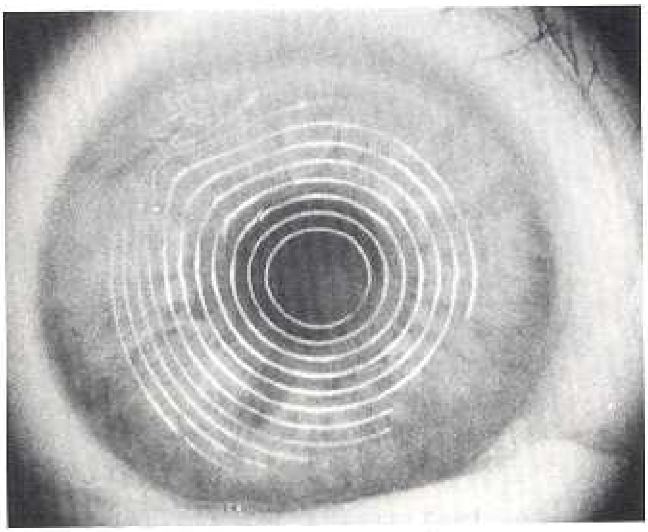

Fig. 8. (Fine) Photokeratoscopy of the eye in Figure 7 immediately after surgery.

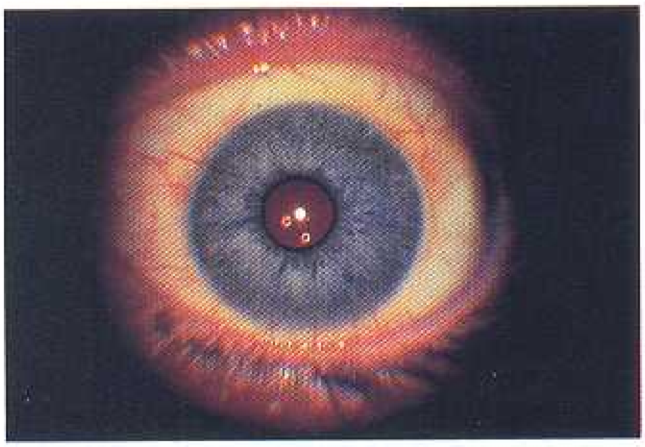

Fig. 9. (Fine) A self-sealing corneal tunnel incision immediately after surgery.

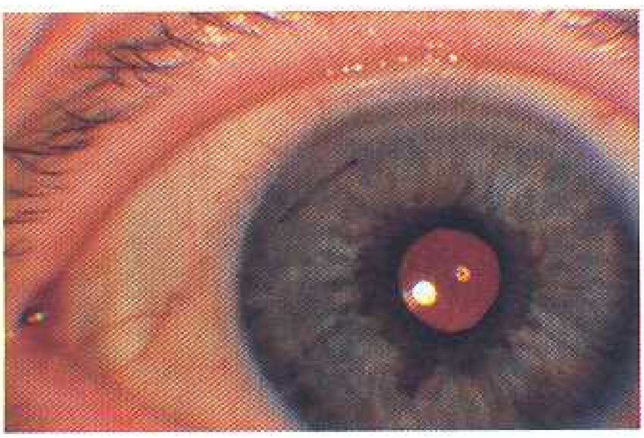

Fig. 7. (Fine) A self-sealing corneal tunnel incision closed by Shepherd's single stitch in the absence of a filtration bleb.

I went temporally because I was bucking the flow of convention. We had a 15-year history of moving peripherally for our incision locations, and I was going back centrally. Certainly, the distance between the visual axis and the temporal corneal periphery was the largest distance in the cornea between the visual axis and corneal periphery. Flattening at the corneal incision temporally was less likely to be transmitted to the corneal apex from that location. This phenomenon was later documented with elegant studies by Cravy[14] and by Masket.[15]

These experiences led me to understand why my earlier patients who had anterior chamber secondary implantations in the temporal periphery didn't have against-the-rule drift. I believe that lid blink and gravity are the culprits that create most of the change in the cornea, not only in patients who have had surgery, but

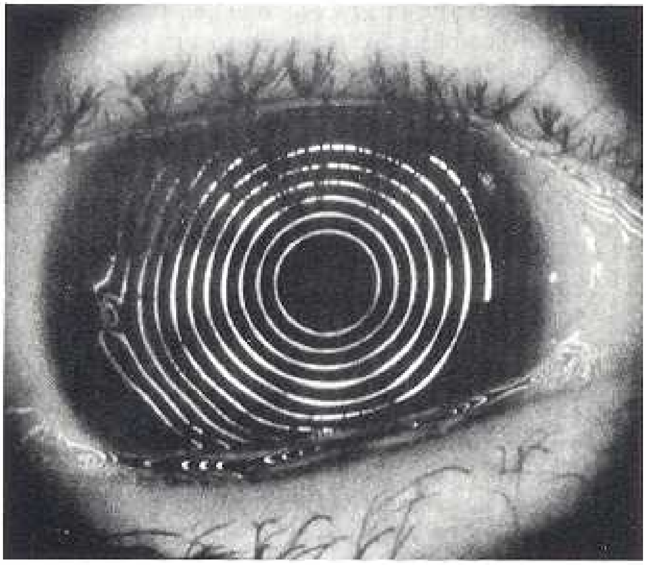

Fig. 10. (Fine) Photokeratoscopy of the eye in Figure 9 immediately after surgery.

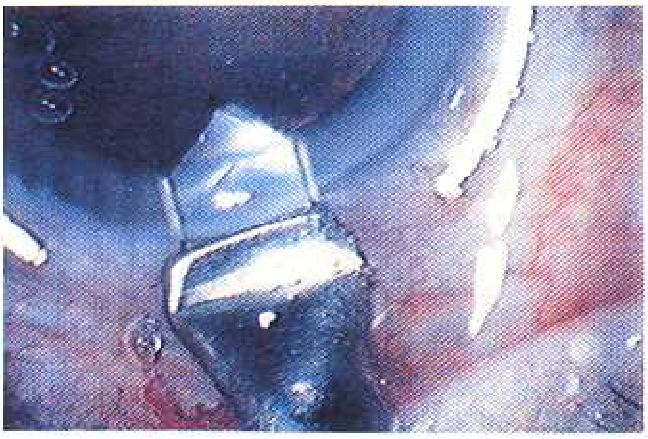

Fig. 11. (Fine) The Howard Fine clear corneal diamond knife (Huco Co., Hauterville, Switzerland).

even in older patients who have not yet had surgery. They all tend to develop against-the-rule astigmatism over time. A temporal cataract incision neutralizes lid blink and gravity because the vector forces are parallel rather than perpendicular to the incision. I believe this results in less against-the rule shift postoperatively.

I discovered other advantages as well. The lateral canthal angle is under the incision; therefore, we had natural drainage and never had to work under water. Ergonomically, temporal clear corneal cataract surgery is easier. By operating from the temporal periphery, our view is unobstructed by the brow; thus, it is not necessary to turn the eye down or place a bridle suture. There is such an enhancement of the red reflex that visualization of intraocular structures is markedly enhanced. Access to the incision for implantation is enhanced, making the surgery a lot easier. Finally, the surgery is less costly, quicker, and lends itself to topical anesthesia.

I developed or participated in the development of several instruments to systematize the temporal clear corneal approach and make it workable and reproducible. I designed an atraumatic fixation device, modifying Spencer Thornton's ring by taking 8 mm of chord length out of the arc of the ring to give access to the globe for an incision. I participated in the design of specific diamond blades, which I still prefer (Figure 11). I downsized some other instruments to allow implantation of three-piece lenses, and I beveled the cartridge of the plate haptic injector so it could be inserted into the corneal incision without the surgeon holding the superior lip of the incision with forceps.

Frequently, we are impressed with what has gone on previously when we find out about it. As Harry Truman said, "The only thing that is new under the sun is the history you never read."

At a 1993 symposium in Bonn, Germany, my good friend Eric Arnott from London gave me a couple of slides documenting that 20 years ago he was doing a clear corneal technique. That reminded me that I must recognize other innovators who had interest in cornea as the site for the cataract incision. Harms and Mackensen,[16] Kelman,[1] Troutman and coauthors,[17] Arnott,[18] Galand,[19] Stegmann (personal communication, December 3, 1992), and Shimizu (K. Shimizu, M.D., "Pure Corneal Incision," Phacos and Foldables, vol. 5, 1992, pages 6–8) have all worked with clear corneal incisions since cataract surgery became microsurgery with the 1967 publication of *Ocular Surgery Under the Microscope*.[16] They have all been innovators in and advocates of corneal cataract surgery. However, they faced a major limitation that I did not because I had access to foldable lenses. It is for this reason that clear corneal cataract surgery seemed, to me, to be the logical next step. All it really needed was language; somebody to talk about it.

APPENDIX

Some presentations on clear corneal incisions presented at the Symposium on Cataract, IOL and Refractive Surgery, Boston, April 1994.

- "Minimizing Incision Size in Clear Corneal Surgery," Jay I. Lippman, M.D.
- "5.0 mm Clear Corneal Incision with Topical Anesthesia: Proposal for a Safe Incision," Matteo Piovella, M.D.
- "Temporally Oriented Corneal Incision Cataract Surgery: Ergonomics and Astigmatics," Samuel Masket, M.D.
- "Stability of Temporal Corneal Incisions: Six-Month Follow-up of the Three-Step Versus the One-Step," Alexander Lebuisson, M.D.
- "Comparison of Induced Astigmatism After Temporal Clear Corneal Tunnel Incisions of Different Sizes," Thomas Kohnen, M.D.

- "Stability of Clear Corneal Incisions in a Cadaver Eye Model," Paul H. Ernest, M.D.
- "Comparison of Scleral and Clear Corneal Temporal Incisions in Cataract Surgery," Howard V. Gimbel, M.D.

REFERENCES

1. Kelman CD. Phaco-emulsification and aspiration; a new technique of cataract removal; a preliminary report. Am J Ophthalmol 1967; 64:23–35
2. Aron-Rosa D, Aron J-J, Griesemann M, Thyzel R. Use of the neodymium-YAG laser to open the posterior capsule after lens implant surgery: a preliminary report. Am Intra-Ocular Implant Soc J 1980; 6:352–354
3. Neuhann T. Theorie und Operationstechnik der Kapsulorhexis. Klin Monatsbl Augenheilkd 1987; 190:542–545
4. Gimbel HV, Neuhann T. Development, advantages, and methods of the continuous circular capsulorhexis technique. J Cataract Refract Surg 1990; 16:31–37
5. Fine IH. The chip and flip phacoemulsification technique. J Cataract Refract Surg 1991; 17:366–371
6. Fine IH. Cortical cleaving hydrodissection. J Cataract Refract Surg 1992; 18:508–512
7. Fine IH. Corneal tunnel incision with a temporal approach. In: Fine IH, Fichman RA, Grabow HB, eds, Clear-Corneal Cataract Surgery and Topical Anesthesia. Thorofare, NJ, Slack Inc, 1993; 5–26
8. Fine IH, Maloney WF, Dillman DM. Crack and flip phacoemulsification technique. J Cataract Refract Surg 1993; 19:797–802
9. Fine IH. Infinity suture: modified horizontal suture for 6.5 mm incisions. In: Gills JP, Sanders DR, eds, Small-Incision Cataract Surgery; Foldable Lenses, One-Stitch Surgery, Sutureless Surgery, Astigmatic Keratotomy. Thorofare, NJ, Slack Inc, 1990; 191–196
10. Fine IH. Architecture and construction of a self-sealing incision for cataract surgery. J Cataract Refract Surg 1991; 17:672–676
11. Gimbel HV. Divide and conquer nucleofractis phacoemulsification: development and variations. J Cataract Refract Surg 1991; 17:281–291
12. Shepherd JR. In situ fracture. J Cataract Refract Surg 1990; 16:436–440
13. Dillman DM, Maloney WF. Fractional 2:4 phaco. In: Koch PS, Davison JA, eds, Textbook of Advanced Phacoemulsification Techniques. Thorofare, NJ, Slack Inc, 1991; 241–255
14. Cravy TV. Routine use of a lateral approach to cataract extraction to achieve rapid and sustained stabilization of postoperative astigmatism. J Cataract Refract Surg 1991; 17:415–423
15. Masket S. Temporal incision for astigmatic control in secondary implantation. J Cataract Refract Surg 1986; 12:179–181
16. Harms H, Mackensen G. Ocular Surgery Under the Microscope. Stuttgart, Germany, Georg Thieme Verlag, 1967; 144–153
17. Troutman RC, Paton D, Ryan S. Present trends in incision and closure of the cataract wound. Highlights Ophthalmol 1975–76; 14:176–204
18. Arnott EJ. Intraocular implants. Trans Ophthalmol Soc UK 1981; 101:58–60
19. Galand A. La Technique de l'Enveloppe. Liege, Belgium, Pierre Mardaga, 1988