·Clinical Research·

Standard coaxial phaco *vs* microincision cataract surgery: a corneal endothelium study

Alessandro Franchini[1], *Saverio Frosini*[1], *Vieri Boddi*[2]

[1] Optical Physiophathological Department, University of Florence, Florence, Italy

[2] Medical Statistics Department, University of Florence, Florence, Italy

Correspondence to: Alessandro Franchini. Eye Institute, University of Florence, Viale Morgagni 85-50134 Florence, Italy. alessandrofranchini@yahoo.it or oculist@unifi.it

Received: 2008-06-12 Accepted: 2008-11-10

Abstract

• AIM: To assess whether the new microincision cataract surgery (MICS) induces less endothelium damages than the standard coaxial phacoemulsification.

• METHODS: Two hundred consecutive patients affected by age-related cataract were randomly assigned to undergo phacoemulsification using either standard coaxial phaco (SCP) or MICS. Central cornea and 12 o'clock endothelial cell count, cell size variation coefficient, percentage of hexagonality and central cornea thickness were measured before and up to one year after surgery.

• RESULTS: One hundred and seventy-three patients completed the trial. At the one-year follow-up visit, the loss of endothelium cells was 6.5204% in the MICS group and 8.726% in the SCP group ($P<0.00005$). There were no significant differences between the two groups in terms of coefficient of variation in cell size, percentage of hexagonal cells, corneal thickness the day after surgery and variation of endothelial cell density measured both at the incision site and at the central cornea. In patients with hard cataracts, the increase in endothelial cell density loss was higher independently of the procedure.

• CONCLUSION: MICS induces a significant lower endothelial cell density loss than SCP.

• KEYWORDS: microincision cataract surgery; standard coaxial phacoemulsification; age-related cataract

Franchini A, Frosini S, Boddi V. Standard coaxial phaco *vs* microincision cataract surgery: a corneal endothelium study. *Int J Ophthalmol* 2008;1(4):344-350

INTRODUCTION

Since its introduction in 1967 [1], the ultrasonic phacoemulsification has represented the most effective and advanced technique for removing cataracts although many other alternative sources of energy had been advocated without reaching the efficiency and safety that ultrasounds offer. During the year 2000, the development of the software that introduced the ultra-pulse technology, ultrasonic cataract surgery has become even a safer procedure. With this new technology, a reduction of the effective phaco-time with a fantastic improvement of the followability check the spelling and reduction of the temperature raise of the tip [2-9] have been achieved. As a result, it is now possible to remove the lens through two incisions as small as one mm using a sleeveless phaco tip. Although there are several parameters that can be assessed to evaluate the quality of a cataract surgical procedure such as improvement in visual acuity or the increase in stromal thickness in the immediate postoperative time, the morphological and quantitative alterations of the endothelium are considered the most important [10,11]. In fact, since 1967 the percentage of endothelial cell loss, which can vary from 3.2% to 23.2%[12-15], has been considered as the most serious issue to consider for a successful outcome since endothelial cells do not regenerate significantly when damaged. However, some studies have also suggested that the morphometric analysis of the cell size and the morphological analysis of the cell shape could be in fact more relevant indicators of the endothelium viability [16,17]. The aim of this study was to verify whether modern Micro Incision Cataract Surgery (MICS) induces less damage of the corneal endothelium than standard coaxial phacoemulsification.

MATERIALS AND METHODS

This prospective clinical study was carried out in the Eye Institute of the Ophthalmic-Oto-Neurological Department of the University of Florence over a period of 2 years: from December 2001 to April 2003. Two hundred patients were enrolled in this study. Microincision cataract extraction was performed in 100 patients (average age 75.78 years ranging from 56 to 80) and a standard coaxial phaco was performed in 100 patients (average age 75.52 years ranging from 52 to 79). All cataract surgeries were preformed by the same surgeon (AF). The exclusion criteria were: Patients under the age of 40 or over 80. All eye pathologies that can compromise the visual recovery. The axial length was over

25mm and the eyes with any kind of corneal dystrophy or corneal scars. Patients with a preoperative endothelial cell density count less than 1 500 cells/mm^2. Before surgery, patients were divided in 4 groups according to hardness of their nucleus. To evaluate the cataract hardness, the Oxford Clinical Cataract Classification and Grading System [18] were used. In both procedures the same viscoelastic (Healon AMO Irvine, CA, USA) and the same balanced salt solution were used. All patients received topical anaesthesia. In 21 patients, a subtenonian injection of 1mL of lidocaine 2% was necessary in order to avoid pain.

Standard coaxial phaco was performed through a self sealing 2.75mm clear corneal tunnel placed in the supero-temporal quadrant in the right eye and in the supero-nasal quadrant in the left eye. Capsulorhexis was done using suitable forceps. After hydrodissection, the lens was phacoemulsified (Sovereign WhiteStar AMO Irvine CA USA) using a standard "stop and chop" technique (after a central sculpture the nucleus was cracked and the two eminuclei were chopped and phacoaspirated). Ultrasound microincision cataract surgery (MICS) was performed through two stab incisions of 1.1mm. One incision was done in the supero-temporal quadrant and the other in the supero-nasal. A trapezoidal tunnel was created using a diamond blade (Janach Srl-Como Italia) which allowed an internal incision of 1.1mm and an external one of 1.3mm. We used a trapezoidal tunnel rather than a rectangular tunnel since the latter renders tools manipulation in the anterior chamber very difficult leading to eventual corneal shrinkage that can impair patient's vision. A continuous circular capsulorhexis was performed using either a needle or a forceps designed to be inserted through a one mm incision (Janach Srl-Como Italy). Then, a sleeveless phaco chop technique was performed (Sovereign WhiteStar AMO Irvine CA USA) using a 19-gauge open ended irrigating chopper (Janach Srl-Como Italia) with the same modalities as described for the standard coaxial phaco group. This irrigating chopper guarantees an irrigation of 65mL/min with the bottle placed at 110cm and an irrigation of 77.20mL/min with the bottle placed at 140cm. The same machine setting was used for all procedures: Phase 1-maximum flow 24mL/min, maximum vacuum 30mm Hg, power 60%; Phase 2-maximum flow unoccluded 24mL/min, maximum flow occluded 20cc/min, maximum vacuum 250mmHg, power 30%. The residual cortex was aspirated with a bimanual irrigation aspiration technique. An acrylic 3-piece 6mm foldable lens (AR40e AMO Irvine CA USA) was implanted using the Emerald injector (AMO Irvine CA USA). In the MICS group, an enlargement to 2.75mm of one of the two stab incisions was necessary. At the end of the operation a nylon monofilament single stitch was made in all patients.

Endothelial cell density was measured using the Confoscan (Nidek Tecnologies version 3). With also used this instrument to measure the coefficient of variation of cell size (polimegatism) and the percentage of hexagonal cells (pleomorphism) (Figure 1). Endothelial cell density count and cell morphology were assessed before surgery and at 1 month, 3-month, 6-month and 1 year after surgery. Corneal pachymetry was assessed using the Confoscan (through Z-scan analysis). In brief, Z-scan analysis consisted in calculating separately pachymetric values of the tear film, the epithelium, the anterior stroma, the posterior stroma and the endothelium by detecting the differences in light reflectivity at each interface (air-tear film, tear film-epithelium, epithelium-Bowman's membrane *etc*). Pachymetry of the cornea in toto is represented by the distance between the two major reflectivity spikes (air-tear film and endothelium-anterior chamber). Corneal pachimetry was evaluated at the preoperative examination and one day and three months post-surgery. Regarding the repeatability of the tests, the automatic lining up system of the Confo-Scan allowed us to successfully repeat scansions made along the patient's visual axis. This area is equivalent to 300×600 microns.

The corneal endothelium evaluation and the corneal pachymetry were not only performed in the central cornea but also within the incision area. With this instrument scansions in extra-axial areas, even when placed at the extreme corneal periphery, are feasible. To obtain peripheral scansions we created an instrument made of 8 red leds placed laterally on a 7cm diameter square. This square is attached externally to the Confo-scan microscope head. The leds are required as a fixation target for the patients and can be activated individually or in sequence (Figure 2).

To perform scansions on the clear corneal tunnel, the leds placed on the lower area of the square were used. The number of activated leds used for the scansion was indicated in the patient medical record. The number is assigned in a clockwise direction: 1=12 o'clock, 2= on the top left corner, 3= centre left and so on. The system of lining up, landing and scansion was used like a normal axial scansion and morphological and pachymetric data were archived as usual. The homogeneity of the two groups of patients regarding the nucleus hardness was evaluated using the Fischer test. The homogeneity in the average values of preoperative endothelial cell density in the two groups was evaluated using the Student t-test and the homoscedasticity test. The effect of the two procedures on endothelial cell density a year after surgery was evaluated with the homoscedasticity test and with the Wilcoxon test for independent data.

$P<0.05$ was considered as significant.

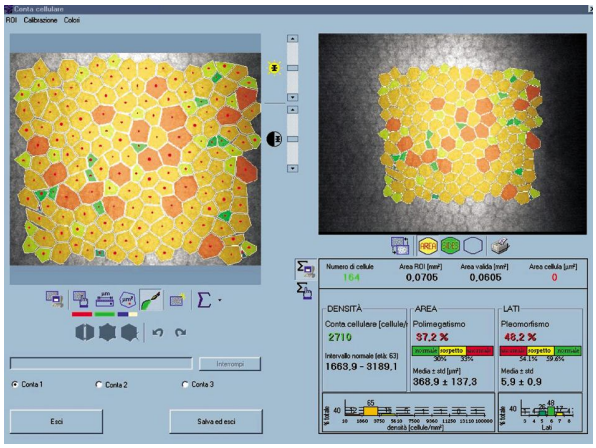

Figure 1 Polimegatism and pleomorphism values

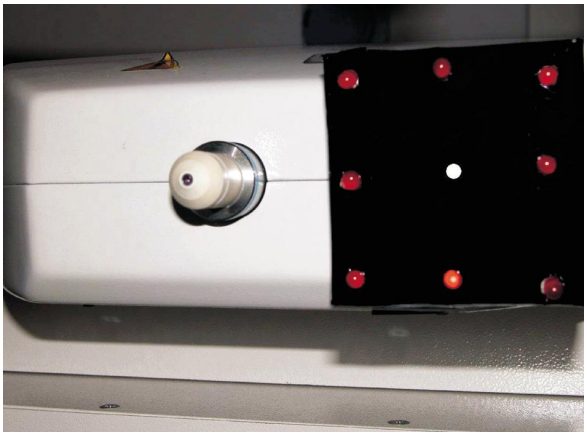

Figure 2 Instrument created to perform scansions in extra–axial area

RESULTS

Eighty-three patients of the MICS group and 90 of the standard coaxial phaco group completed the 1 year follow-up. The preoperative visit revealed a mean endothelial cell density count of 2570, 5081 in the group 1 and 2660, 3660 in the group 2. One year later, endothelium cells count decreased in both groups with an average loss of 6.5204% in the first group and 8.72632% in the second group (Table 1).

The corneal endothelial cells count before and after surgery is given in Figure 3. Comparison between the two groups was made by taking into account the variable "nucleus hardness" and data revealed a similar percentual distribution between the 2 groups(Fischer Exact test; P=0.719;Table 2). The variable ECDL in both groups was also characterized before surgery using the standard indexes (mean 2 570.51 *vs* 2 660.37, median 2 578 *vs* 2 672, standard deviation 326,6 415 *vs* 319). The distribution of ECDL frequency was also similar between the two groups as illustrated in Figure 4. Since the distribution of the 2 variables were almost normal, we also verified the homogeneity of the variances (homoscedasticity test; P= 0.83).

Table 1 Endothelial cell density loss in MICS group at the one year follow-up

	Preop	3mo	6mo	12mo
max	3328	3138	3148	3120
min	1860	1770	1765	1750
Av	2570,5081	2444,8360	2428,8196	2402,9016
% loss		-4,8897	-5,5191	-6,5204

(Av=average; Preop=Preoperation)

Table 2 Comparison of the two groups according to the variable nucleous hardness (Fischer Exact test)

nh	1	2	Total
1	8	10	18
	13.11	8.93	10.40
2	26	46	72
	42.62	41.07	41.62
3	18	41	59
	29.51	36.61	34.10
4	9	15	24
	14.75	13.39	13.87
Total	61	112	173
	100.00	100.00	100.00

Fisher's exact=0.719

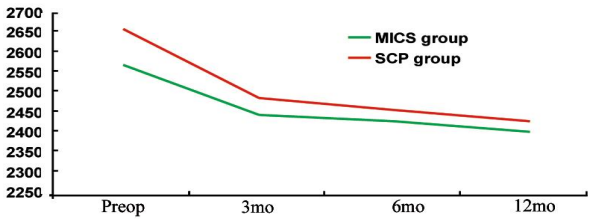

Figure 3 Corneal endothelial cell count before and after surgery in the two groups.

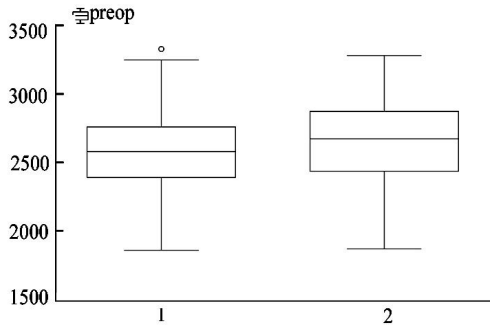

Figure 4 Distribution of the variability preoperative ECDC in the two groups

The impact of the two surgical techniques on endothelial cell loss pre-versus 12-month post-surgery was then evaluated. The percentual differences in both groups were calculated with the standard index (Table 3). The two distributions (pre and postoperative ECDL) were characterized by strong different standard deviations (1.73 *vs* 2.61, Figure 5).

Table 3 Percentual differences in the two groups calculated with the standard indexes (dif~100)

G	F	Mean	Med	Sd	Iqr
1	61	-6.535931	-6.503496	1.73156	1,777448
2	112	-8.814597	-8.678889	2.61143	3.346586

(G=group; F= Frequency)

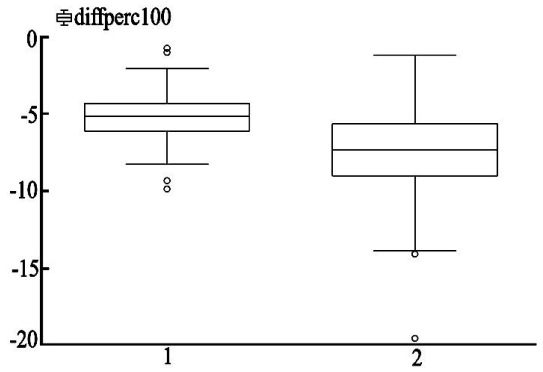

Figure 5 Distribution of the variability ECDL at one year follow-up in the two groups

The homoscedasticity test demonstrated a significant difference in variability (P=0.0006). Since the conditions necessary to use the Student t test were not satisfied, data were analyzed using a non parametric test (Wilcoxon test for independent data). A great statistical difference was shown between the 2 groups (P<0.00005).

As for the mean cell loss at different corneal positions, there were not significant differences between the 10 o'clock position and the center of the cornea (standard coaxial phaco group P=0.08; MICS group P=0.123). The coefficient of variation of cell size (polimegathism) and the percentage of hexagonal cells (pleomorphism) did not vary over time in each group and were not statistically different between groups as measured at the 12 month follow-up (Student t test, P=1.53). At the first post-operative day, corneal pachymetry increased in both groups with an average increase of 4.101% in the MICS group and of 4.420% in the standard coaxial phaco group. This difference was not significant (Student t test, P=1.45). Three months later, corneal thickness in both groups had returned to the preoperative levels.

Comparison of ECDL at the centre of the cornea and at the site of the incision showed significant differences in both groups (MICS P<0.001; Coaxial phaco P<0.0005). This difference was not significant between groups. However, the ratio between the 12 months ECDL and the nucleus hardness in both surgical groups showed some significances between patients with nuclei grade 4 and patients with nuclei grade 2 (Table 4). ECDL and the age of the patients in both surgical groups were not correlated.

Table 4 Ratio 12mo ECDL and nucleous hardness

Nucleous hardness		Number of patients	ECDL at 12mo follow-up	
MICS	1	8	- 4.926	
group	2	26	- 6.542	P<0.0005
	3	18	- 6.388	P<0.0005
	4	9	- 9.221	P<0.0005
Coaxial	1	10	- 5.228	
Phaco	2	46	- 8.612	P<0.001
group	3	41	- 9.315	P<0.001
	4	15	- 9.586	P<0.001

DISCUSSION

It is well known that during cataract surgery many different factors can generate endothelial damages[10,19-21] including the impact of the nuclear fragments, the turbulence generated in the anterior chamber and the volume of the liquid [22-25], air bubbles formation [26], the amount of the ultrasonic energy used [10,27,28] and the subsequent temperature increase [29], contacts with the surgical instruments and the IOL during implantation[30-32], the release of free radicals[33,34], the length and the features of the incision [27], the surgical techniques used [35-37] and the intraoperative complications such as posterior capsule rupture. The risk of endothelial cell density loss is further enhanced when surgeons have to deal with high-density cataracts, shallow anterior chambers [38,39], old age[38] and short eyes[39]. However, within the last few years, the improvement in technologies has allowed us to optimize many of these parameters. The introduction of new ultrasonic phacoemulsifiers has lead to a critical reduction in the ultrasounds and a great increase of the fluidics with the subsequent dramatic improvement of the followability and the holdability. In addition, the development of new viscoadaptive viscoelastic has provided significant endothelium protection [40-43] from turbulence, from nuclear fragments and contact with surgical tools as well as from chemical bonds[39,43,44].

Along with these technological improvements, the concomitant development of new surgical techniques has further minimized the risks of endothelial damages. This includes the transition from intracapsular to extracapsular technique and then from extracapsular to phacoemulsification. Later on, the introduction of the ultrasonic pulses has lead to the so-called microincision cataract surgery. Despite many attempts and interesting results [45-49], none of the machines tested could achieve the same efficiency, safety and corneal microincision than standard coaxial ultrasonic phacoemulsification offers.

Microincision cataract extraction seems to present many advantages in comparison to the standard coaxial phaco

although the lack of intraocular lenses that fit through microincision is still a limiting factor. This procedure provides an amount of energy that is inferior to what is traditionally used with the coaxial technique. This is due to the increase in fluidics which provokes an increase in followability and holdability. Another advantage of the technique is the possibility to keep irrigation separate from aspiration allowing the utilization of the flow like a tool. The flow can be used to flush nuclear fragments trapped under the tunnel but also to press down the posterior capsule in order to avoid the anterior chamber to collapse when the chopper is pulled back to the incision site. Furthermore the separated irrigation flow can be helpful in complex cases such as in patients with a small pupil or in patients with a floppy pupil that moves during aspiration with a big risk of nicking the pupil margin. By directing the irrigation flow directly to the iris, the surgeon can hold the floppy pupil in place. Patients with a limited zonular dialysis can also benefit from this procedure. The bag can be maintained in position by holding the irrigation flow in the direction of the dialysis, thus increasing the safety of the surgical procedure.

In this present study, we compared the performance of MICS and standard coaxial phacoemulsification with respect to endothelial cell loss and morphology. One year post-surgery, our data revealed that MICS induced significantly less endothelial cell loss than standard coaxial phaco although no morphological and morphometric differences were found between the two groups. This finding in favour of the MICS technique can be explained by the significant reduction of the infusion volume due to the reduction of the wound leakage. In fact, the insignificant temperature increase of the tip allowed us to perform the procedure through two perfectly water tight incisions. The reduction of the fluid movements in the anterior chamber led to a reduction of the particle chatter thereby minimizing the impact on endothelial cells.

There is accumulating evidence that ultrapulse technology is effective in reducing the temperature of the tip during phacoemulsification [51-54]. In agreement with these data, we also showed in a study partially presented at the 2005 ASCRS congress in Washington ("Microphacoemulsification versus standard coaxial phacoemulsification: *in vivo* temperature study"), that ultrapulse technology prevented the development of high temperatures in the cornea and therefore corneal damages were minimized. This is likely the result of the increase of the fluidics that reduces the ultrasonic energy used and the fact that sleeveless phaco tips reduce the frictional heat at the incision site. Our study also showed that some alterations in the coefficient of variation in cell size and the percentage of hexagonal cells were present in both groups but only in the immediate postoperative phase to finally return to pre-operative levels a month later. These results are particularly relevant since it has been suggested by several authors that polymegathism and pleomorphism were the most important indicators of endothelial damage[17,19,55-58].

The greatest ECDL at the site of the supero-temporal tunnel in the right eye and at the supero-nasal tunnel in the left eye was related to the strongest mechanical damage caused by the surgery. However, at the three-month follow-up, ECDL values were similar between the different corneal sites. The fact that there was no difference between the two surgical groups is probably linked to the need to enlarge the incision at the end of the operation in the MICS group. We also observed a significant statistical correlation between the nucleus hardness and ECDL at one year follow-up in both surgical groups. This relationship is consistent with what has been previously reported in the literature [10,27,38,39] and confirms that a hard nucleus should be considered as an important risk for ECDL as a consequence of increased surgical time, greater amount of delivered ultrasounds and a larger infusion volume which may damage the endothelium. Interestingly, we did not find a significant correlation between the patient age and ECDL. Similar data were reported by Schultz[59]. In contrast, other studies[10,38] reported that older age is associated with higher ECDL independently of the hardness of the nucleus. We also did not find a correlation between ECDL and axial length in our groups of patients as previously reported by others[39]. The consistency of our surgical procedure is likely due to the excellent anterior chamber stability guaranteed by the microincision. Working without leakage and with a software which amends the post-occlusion surge provides a continuous anterior chamber pressure control, an approach that ensures complete safety also in patients with a shallower anterior chamber. As reported by others [41,60], the day after cataract surgery we noticed a significant increase in the central corneal thickness in both groups that was not significantly different between the two surgical techniques. Typically, the corneal thickness increases when the barrier function of the endothelium is damaged and provides a mean to measure endothelium alteration. A few authors found a statistical significance correlation between the increase in stromal thickness the day after surgery and the endothelial cell density loss three and six months after the operation [61]. In the present study, the increase in the corneal thickness was temporally and gradually decreased within the weeks following surgery to finally returned to baseline values 3-month later.

Our study shows that both standard coaxial phacoemulsification and ultrasound microincision cataract surgery are reliable and safe methods for the removal of cataracts. MICS has the main advantage of allowing corneal incision

smaller than 1.5mm. This advanced technology will become even more popular when intraocular lenses that can fit through such microincision become available.

REFERENCES

1 Kelman CD. Phacoemulsification and aspiration: a new technique of cataract removal. A preliminary report. *Am J Ophthalmol*1967;64(1):23-25

2 Donnenfeld ED, Olson RJ, Solomon R, Finger PT, Biser SA, Perry HD, Doshi S. Efficacy and wound-temperature gradient of whitestar phacoemulsification through a 1.2mm incision. *J Cataract Refract Surg*2003;29(6):1097-1100

3 Soscia W, Howard G, Olson RJ. Microphacoemulsification with WhiteStar: a wound temperature study. *J Cataract Refract Surg*2002;28(6):1044-1046

4 Fine IH, Packer M, Hoffman RS. Use of power modulations in phacoemulsification: choo-choo chop and flip phacoemulsification. *J Cataract Refract Surg* 2001; 27(2):188-197

5 Olson RJ. Clinical experience with 21-gauge manual microphaco using Sovereign WhiteStar Technology in eyes with dense cataract. *J Cataract Refract Surg*2004;30(1):168-172

6 Olson RJ, Jin Y, Kefalopoulos G, Brinton J. Legacy AdvanTec and Sovereign WhiteStar: a wound temperature study. *J Cataract Refract Surg* 2004;30 (5): 1109-1113

7 Tsuneoka H, Shiba T, Takahashi Y. Feasibility of ultrasound cataract surgery with a 1.4mm incision. *J Cataract Refract Surg*2001;27(6):934-940

8 Tsuneoka H, Shiba T, Takahashi Y. Ultrasonic phacoemulsification using a 1.4mm incision: clinical results. *J Cataract Refract Surg*2002;28(1):81-86

9 Tsuneoka H, Hayama A, Takahama M. Ultrasmall-incision bimanual phacoemulsification and AcrySof SA30At implantation through a 2.2mm incision. *J Cataract Refract Surg*2003;29(6):1070-1076

10 Bourne R, Minassian DC, Dart J, Rosen P, Kaushal S, Wingate N. Effect of cataract surgery on the corneal endothelium: modern phacoemulsification compared with extracapsular cataract surgery. *Ophthalmology* 2004;111 (4): 679-685

11 Minassian DC, Rosen P, Dart JK, Reidy A, Desai P, Sidhu M, Kaushal S, Wingate N. Extracapsular cataract extraction compared with small incision surgery by phacoemulsification: a randomized trial. *Br J Ophthalmol*2001;85(7):822-829

12 Miyata K, Maruoka S, Nakahara M, Otani S, Nejima R, Samejina T, Amain S. Corneal endothelial cell protection during phacoemulsification: low- *vs* high-molecular weigh sodium hyaluronate. *J Cataract Refract Surg* 2002;28 (9): 1557-1560

13 Zetterstrom C, Laurell CG. Comparison of endothelial cell loss and phacoemulsification energy during endocapsular phacoemulsification surgery. *J Cataract Refract Surg*1995;21(1):55-58

14 Davison JA. Endothelial cell loss during the transition from nucleous expression to posterior chamber-iris plane phacoemulsification. *Am Intra-Ocular Implant Soc J*1984;10(1):40-43

15 Holzer MP, Tetz MR, Auffarth GU, Welt R, Volcker HE. Effects of Healon5 and 4 other viscoelastic substances on intraocular pressure and endothelium after cataract surgery. *J Cataract Refract Surg*2001;27(2):213-218

16 Schultz RO, Matsuda M, Yee RW, Edelhauser HF, Schultz KJ. Corneal endothelial changes in type I and type II diabetes mellitus. *Am J Ophthalmol*1984;98 (4):401-410

17 Rao GN, Aquavella JV, Goldberg SH, Berk SL. Pseudpèhakic bullous keratopathy: relationship to pre-operative corneal endothelial status. *Ophthalmology* 1984;91(10):1135-1140

18 Sparrow JM, Bron AJ, Brown NA. The oxford clinical cataract classification and grading system. *Int Ophthalmol*1986;9(4):207-225

19 Beltrame G, Salvetat ML, Driussi G, Chizzolini M. Effect of incision size and site on corneal endothelial changes in cataract surgery. *J Cataract Refract Surg* 2002;28(1):118-125

20 O'Brien PD, Fitzpatrick P, Kilmar DJ, Beatty S. Risk factors for endothelial cell loss after phacoemulsification surgery by a junior resident. *J Cataract Refract Surg* 2004;30(4):839-843

21 Ishikawa A. Risk factors for reduced corneal endothelial cell density before cataract surgery. *J Cataract Refract Surg*2002;28(11):1982-1992

22 Kosrirukvongs P, Slade SG, Berkeley RG. Corneal endothelial changes after divide and conquer versus chip and flip phacoemulsification. *J Cataract Refract Surg* 1997;24(7):1006-1012

23 Edelhauser HF, Van Horn DL, Hyndiuk RA, Schultz RO. Intraocular irrigating solut their effect on the corneal endothelium. *Arch Ophthalmol* 1975;93 (8): 648-657

24 Joussen AM, Barth U, Cubuk H, Koch HR. Effect of irrigating solution and irrigation temperature on the cornea and pupil during phacoemulsification. *J Cataract Refract Surg*2000;26(3):392-397

25 Oki K. Measuring rectilinear flow within the anterior chamber in phacoemulsification procedures. *J Cataract Refract Surg*2004;30(8):1759-1767

26 Kim EK, Cristol SM, Kang SJ, Edelhauser HF, Yeon DS, Lee JB. Endothelial protection: avoiding air bubble formation at the phacoemulsification tip. *J Cataract Refract Surg*2002;28(3):531-537

27 Dick HB, Kohnen T, Jacobi FK, Jacobi KW. Long-term endothelial cell loss following phacoemulsification through a temporal clear corneal incision. *J Cataract Refract Surg*1996;22(1):63-71

28 Frohn A, Dick HB, Fritzen CP. Corneal impact of ultrasound and bevel position in phacoemulsification. *J Cataract Refract Surg*2002;28(9):1667-1670

29 Ernest P, Rhem M, McDermott M, Lavery K, Sensoli A. Phacoemulsification conditions resulting in thermal wound injury. *J Cataract Refract Surg* 2001;27(11): 1829-1839

30 Mc Carey BE, Polack FM, Marshalln W. The phacoemulsification procedure I. The effect of intraocular irrigating solutions on the corneal endothelium. *Invest Ophthalmol*1976;15(6):449-457

31 Roper-Hall MJ, Wilson RS. Reduction in endothelial cell density following cataract extraction and intraocular lens implantation. *Br J Ophthalmol*1982;66(8): 516-517

32 Sandoval HP, Al Sarraf O, Vroman DT, Solomon KD. Corneal endothelial cell damage after lens extraction using the fluid-based system compared to ultrasound phacoemulsification in human cadaver eyes. *Cornea*2004;23(7):720-722

33 Craig MT, Olson RJ, Mamalis N, Olson RJ. Air buble endothelial damage during phacoemulsification in human eye bank eyes: the protective effects of Healon and Viscoat. *J Cataract Refract Surg*1990;16(5):597-602

34 Cameron MD, Poyer JF, Aust SD. Identification of free radicals produced during phacoemulsification. *J Cataract Refract Surg*2001;27(3):463-470

35 Vargas LG, Holzer MP, Solomon KD, Sandoval HP, Auffarth GU, Apple DJ. Endothelial cell integrity after phacoemulsification with 2 different handpieces. *J Cataract Refract Surg*2004;30(2):478-482

36 Can I, Takmaz T, Cakici F, Ozgül M. Comparison of Nagahara phaco-chop and stop-and-chop phacoemulsification nucleotomy techniques. *J Cataract Refract Surg*2004;30(3):663-668

37 Fine IH, Hoffman RS, Packer M. Optimizing refractive lens exchange with bimanual microincision phacoemulsification. *J Cataract Refract Surg* 2004;30 (3): 550-554

38 Walkow T, Anders N, Klebe S. Endothelial cell loss after phacoemulsification: relation to preoperative and intraoperative parameters. *J Cataract Refract Surg* 2000;26(5):727-732

39 Hayashi K, Hayashi H, Nakao F, Hayashi F. Risk factors for corneal endothelial injury during phacoemulsification. *J Cataract Refract Surg*1996;22(8):1079-1084

40 Harfstrand A, Molander N, Stenevi U, Apple D, Schenholm M, Madsen K. Evidence of hyluronic acid and hyaluronic acid binding sites on human corneal endothelium. *J Cataract Refract Surg*1992;18(3):265-269

41 Kiss B, Findl O, Menapace R, Petternel V, Wirtitsch M, Lorang T, Gengler M, Drexler W. Corneal endothelial cell protection with a dispersive viscoelastic material and an irrigating solution during phacoemulsification: low cost versus expensive combination. *J Cataract Refract Surg*2003;29(4):733-740

42 Miyata K, Maruoka S, Nakahara M, Otani S, Nejima R, Samajima T, Amano S. Corneal endothelial cell protection during phacoemulsification: low versus high

molecular weight sodium hyaluronate. *J Cataract Refract Surg* 2002;28 (9): 1557-1560

43 Goa KL, Benfield P. Hyaluronic acid. A review of its pharmacology and use as a surgical aid in ophthalmology, and its therapeutic potential in joint disease and wound healing. *Drug* 1994;47(3):536-566

44 Oshika T, Eguchi S, Oki K, Yaguchi S, Bissen-Miyajima H, Ora I, Sugita G, Miyata K. Clinical comparison of Healon 5 and Healon in phacoemulsification and intraocular lens implantation: randomized multicenter study. *J Cataract Refract Surg* 2004;30(2):357-362

45 Verges C, Lievat E. Laser cataract surgery: technique and clinical results. *J Cataract Refract Surg* 2003;29(7):1339-1345

46 Fine IH, Packer M, Hoffman RS. New phacoemulsification technologies. *J Cataract Refract Surg* 2002;28(6):1054-1060

47 Kannellopoulos AJ. Laser cataract surgery: a prospective clinical evaluation of 1000 consecutive laser cataract procedures using the Dodick photolysis Nd:Yag system. *Ophthalmology* 2001;108(4): 649-654

48 Huetz WW, Eckhardt HB. Photolysis using the Dodick-ARC laser system for cataract surgery. *J Cataract Refract Surg* 2001;27(2):208-212

49 Fugo RJ. Focused electromagnetic field technology. *J Cataract Refract Surg* 1998;24(1):9-10

50 Mackool RJ, Sirota MA. Thermal comparison of the AdvanTec Legancy, Sovereign WhiteStar and Millenium phacoemulsification systems. *J Cataract Refract Surg* 2005;31(4):812-817

51 Olson RJ, Jin Y, Kefalopoulos G, Brinton J. Legacy AdvanTec and Sovereign WhiteStar: a wound temperature study. *J Cataract Refract Surg* 2004;30 (5): 1109-1113

52 Donnenfeld ED, Olson RJ, Solomon R, Finger PT, Biser SA, Perry HD, Doshi S. Efficiency and would temperature gradient of WhiteStar phacoemulsification through a 1.2mm incision. *J Cataract Refract Surg* 2003;29(6):1097-1100

53 Soscia W, Howard JG, Olson RJ. Microphacoemulsification with WhiteStar. a wound-temperature study. *J Cataract Refract Surg* 2002;28(6):1044-1046

54 Soscia W, Howard JG, Olson RJ. Bimanual phacoemulsification though two stab incisions: a wound temperature study. *J Cataract Refract Surg* 2002;28 (6): 1039-1043

55 Schultz RO, Matsuda M, Yee RW, Edelhauser HF, Schultz KJ. Corneal endothelial changes in type I and type II diabetes mellitus. *Am J Ophthalmol* 1984;98 (4):401-410

56 Matsuda M, Miyake K, Inaba M. Long-term corneal endothelial changes after intraocular lens implantation. *Am J Ophthalmol* 1988;105(3):248-252

57 Bourne WM, Brubaker RF, O'Fallon M. Use of air to decrease endothelial cell loss during intraocular lens implantation. *Arch Ophthalmol* 1979;97(8):1473-1475

58 Sweeney DF, Holdon BA, Vannas A. The clinical significance of corneal endothelial polymegathism. ARVO abstract 8. *Invest Ophthalmol Vis Sci* 1985;26 (suppl):53

59 Schultz RO, Glasser DB, Matsuda M, Yee RW, Edelhauser HF. Response of the corneal endothelium to cataract surgery. *Arch Ophthalmol* 1986;104 (8): 1164-1169

60 Davis EA, Lindstrom RL. Corneal thickness and visual acuity after phacoemulsification with 3 viscoelastic materials. *J Cataract Refract Surg* 2000;26 (10): 1505-1509

61 Tuft SJ, Coster DJ. The corneal endothelium. *Eye* 1990;4(Pt 3):389-424