SHORT THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (PHD)

Examinaton of factors influencing the outcome of cataract surgery – investigation of phacoemulsification tips ultrastructural changes and biometric parameters

by Ágnes Revák, MD

Supervisor: Zoltán Sohajda MD, PhD

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Supervisor: Zoltán Sohajda MD, PhD

Doctoral School of Clinical Medicine, University of Debrecen

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The PhD Defense takes place at the Lecture Hall of Building A, Department of Internal Medicine, Faculty of Medicine, University of Debrecen, 26th of February, 2026 at 13:00.

1. Introduction and literature review

Nowadays, cataracts, or clouding of the lens of the eye, are becoming more prevalent every year. It is the leading cause of blindness in both middle- and low-income countries. Approximately 35.5% of female patients and 30.1% of male patients becoming blind due to cataracts. According to one study, by 2050, the prevalence of cataracts per 100,000 people is estimated to be 1,232.33. Various studies have shown that 90% of people aged 80 and older develop cataracts. As the world's population continues to age, the incidence of cataracts is expected to rise from more than 10 million in 2010 to 40 million in 2025. Further growth is predicted by 2050, with an estimated 474 million visually impaired people worldwide, 61 million of whom will have vision loss due to cataracts.

Currently, cataract surgery is the most commonly performed eye surgery. In line with the expected increase in the incidence of cataracts in the coming decades, the rate of cataract surgery is expected to increase by between 72 and 144% by 2036.
One modern form of surgery is phacoemulsification. With this technique, the cataract is removed through a much smaller corneal incision of a few millimeters (currently around 2 mm), and the intraocular lens can also be implanted through the same incision. In the vast majority of cases, it is no longer necessary to close these clear corneal tunnel incisions with sutures, thus minimizing the possibility of postoperative astigmatism. During the operation, the phacoemulsificator fragments the lens nucleus into smaller pieces using a handpiece with a tube-like titanium tip controlled by ultrasound energy, and these pieces are then removed from the eye using the same device. The remaining pieces of the capsule are then suctioned out using an irrigating-aspirating head. During both the phacoemulsification and irrigation-aspiration phases, a closed system with infusion (BSS) maintains constant intraocular pressure and constant chamber depth thanks to the small corneal incision.

This surgery requires special instruments, for which several alternatives are available based on manufacturers' recommendations. During surgery, surgeons currently use single-use or reusable phacoemulsification tips. Mostly for financial reasons (off-label use), single-use tips are also used multiple times, and reusable tips are also used more often than recommended by the manufacturer.

With advances in cataract surgery and the reduction in the size of surgical incisions, the incidence of intra- and postoperative complications has decreased significantly. An early postoperative complication that may occur within 12 to 48 hours after surgery is toxic anterior segment syndrome (TASS), which is an acute, sterile inflammation. It is characterized by diffuse corneal edema due to damage to the corneal endothelium, fibrinous inflammation and hypopyon due to damage to the blood-aqueous barrier, and dilated pupils and secondary glaucoma due to dysfunction of the iris and trabecular meshwork. The inflammation is limited to the anterior segment and does not involve the posterior segment. The main complaints of patients are usually sudden, severe vision loss and severe eye pain. Many substances can cause TASS, including residues of substances used to clean and sterilize surgical instruments, rinsing solutions with incorrect pH or ion composition, preservatives, stabilizers, denatured ophthalmic viscous surgical instruments, and endotoxins, heavy metals, toxic doses of intraocular medications and ointments. In addition to the materials used during cleaning, organic residues present during surgery can also accumulate in the surface defects that appear in increasing numbers on ophthalmic surgical instruments after use and cause TASS.

In this study, we are looking for an answer to the question of how much the number of surgeries affects the abrasion of the tips, and whether it is possible to determine a limit for the use of the tips which would not result in a significant change in the morphology of the tips, and therefore would have no influence on the outcome and complications of the surgery. Furthermore, we also performed a comparison of the two currently most common surgical techniques (divide and conquer, chop) in terms of their effects on the phacoemulsification tips. In the course of this study, we examined and compared unused, sterilized-only, single-use and multiple-use phacoemulsification tips that underwent different number of surgeries based on atomic force microscopy and reflection light microscopy.

In addition, the success of cataract surgery is greatly influenced by the accuracy of preoperative intraocular lens planning, i.e., biometry. In recent years, several studies have shown that optical biometry provides more accurate and reproducible measurement results than A-scan ultrasound examination. This examination method measures the distance between the tear film covering the front surface of the cornea and the retinal pigment epithelium using low-coherence interferometry. The examination is non-contact and can be performed in a relatively short time, even in patients who are more difficult to cooperate with.

The measurable parameters of the human eye are not static throughout our lives. Biometric parameters change as we grow from childhood, and changes in refractive status also well described. Additionally, several parameters undergo age-related gradual changes in adulthood, such as the meridian of keratometric values, anterior chamber depth, crystalline lens thickness, and corneal white-to-white distances. In addition to slow, age-related changes, seasonal changes in axial length (AL) have also been observed in young adults and have been linked to changes in melatonin secretion.

Besides, it has shown for more than 30 years that some measurable parameters of the eye undergo diurnal changes. Such changes have been described for intraocular pressure (IOP), central corneal thickness (CCT) , topography, keratometry reading, higher order aberration (HOA) and AL, but it is known that anterior chamber depth (ACD), retinal nerve fiber layer (RNFL), retinal and chorioideal thickness and some tear parameters can also change. The diurnal variation in the measurable parameters of the eye was also significant in children, which the author suggests may have important implications for the development of myopia in children. In this study, axial length and IOP varied approximately in phase with each other and in antiphase with choroidal thickness.

Several of the parameters listed above are important in the calculation of intraocular lens power. It is unclear whether certain parameters, even if they change during the day, reach clinically significant levels that affect the accuracy of intraocular lens (IOL) calculation. As expectations for intraocular lens power calculation continue to grow, we must strive to make measurements and results as accurate as possible. This is also increasingly important because cataract surgery today must satisfy refractive goals in addition to improving vision. For this reason, any new information that can further improve measurement accuracy is of paramount importance.

The objective of our study was to investigate whether diurnal changes in biometric parameters measured by an optical biometer at different times of the day are visible, using a large cross-sectional database. Additionally, we aimed to analyze whether the observed changes could have clinical significance in the process of IOL power calculation. This would help determine whether we should take into account the time of measurement to increase accuracy.

2. Objective

During phacoemulsification, the tips used in vivo can be damaged microstructurally not only by intraoperative ultrasound energy, but also by physical contact during lens removal. Since these tips can be used multiple times, these changes can also affect the success of the surgery. In our study, we used a reflection light microscope and an atomic force microscope (AFM) to examine how the microstructural structure of phaco tips changes during cataract surgery.

The aim of our study was to assess how the surface roughness of single-use and reusable tips changes.
We also aimed to compare the effects of two surgical techniques on the microstructural structure of phacoemulsification tips and to investigate which technique is less damaging to the material.

In addition, we sought to determine whether there are changes in different biometric parameters at different times of the day and, if so, to what extent. We also sought to determine whether these changes have clinical significance in the design and calculation of intraocular lens (IOL) diopters.

3. Patients and methods

Ultrastructural examination of phacoemulsification tips

Patients

In our study, patients between the ages of 22 and 94 diagnosed with grade I-IV cataracts were included. The population was divided into two groups, one group was operated with the divide and conquer technique and the other with the chop technique. The operations were preceded by a comprehensive ophthalmological examination (visual acuity examination, intraocular pressure measurement, slit-lamp examination with narrow and dilated pupils, fundus examination) and intraocular lens planning. Then the operations were performed under topical anaesthesia.
The examinations and operations were carried out within the framework approved by the local ethics committee (Regional and Institutional Research Ethical Committee of the University of Debrecen) (BORS-12/2020, DEKGYEK, 10/2020).

Phacoemulsification tips

During our study, cataract surgeries were performed with Bausch and Lomb DP8230A (bent multiple-use) and Bausch and Lomb DP8230S (straight, single-use) phacoemulsification tips. For both tips, the measurements were made in the factory condition and after five, ten, twenty, thirty, fifty and ninety sterilization cycles. After performing the same number of surgeries, we also performed the measurements.

Surgical techniques

The surgeries were performed by two experienced physicians, one of them used divide and conquer, the other used the horizontal chop technique, so it was possible to compare the effects of these techniques on the phacoemulsification tips. During the operations, the age of the patients, grade of the cataract (grade I-IV), duration of the operation (case time), average phaco time (APT), effective phaco time (EPT), average phaco energy (US AVE%), the possible contact between the phaco tip and the auxiliary device during surgery were analyzed, as well as the possible surgical complications.

Sterilization

The phacoemulsification tips were cleaned each time with distilled water and compressed air at a pressure of 2 bar. Sterilization was then carried out using an autoclave (Statim 5000, SciCan GmbH, Leutkirch im Allgäu, Germany), unpacked, for 3.5 minutes at 134°C.

Morphological examination

In this study, we used atomic force microscopy (AFM) and reflection light microscopy to examine the morphology of the phacoemulsification tips (Laboratory of Interfaces and Nanostructures, Eötvös Loránd University). With the help of light microscopy, we can obtain qualitative information about the abrasion of the edge and mantle of the tips. Atomic force microscopy can also be used to quantitatively monitor the morphological changes occurring at the tip and the mantle of the needles through the determination of the surface roughness. The measurements were performed on two parts of the needles: at the very end of the tip of the needles, which first comes into contact with the tissues (edge) and on the part of the outer mantle of the needles close to the tip (~50-100 μm distance) (mantle). At these locations, topographic images of $20 \times 20\ \mu m^2$ areas were taken using AFM. In addition, light microscopic images were taken from the edge around and from an area of approximately 1 mm on the mantle.

For the AFM measurements, we used a Park XE-100 device (Park System, Inc., Suwon, Korea), in tapping mode, with an NSC15 probe, at a resolution of 512×512 pixels. After evaluating the recorded images, we performed a roughness analysis. In the course of this, we determined the average surface roughness (S_a), the root mean square surface roughness (S_q) and the ten-point height (S_z):

$$S_a = \frac{1}{N}\sum_{j=1}^{N}\left|z_j - \bar{z}\right|$$

$$S_q = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(z_j - \bar{z}\right)^2}$$

Where N is the number of measurement points, $\bar{z}$ is the average height value and z_j is the height value at a given point.

The S_a value is a simple overview numerical value of the average roughness, while the S_q value is more sensitive to larger level differences occurring on the sample, and therefore more sensitively indicates the presence of a small number of large objects. The S_z value indicates the difference between the average of the 10 highest and 10 lowest points of the sample, it can be particularly sensitive if there are only localized but large level differences on the sample. The roughness values were determined according to the algorithm below. The representative AFM images were divided into 25 equal (4×4 μm^2) fields. We performed the roughness analysis on the image details separately. We took the average of the obtained 25 roughness data and determined the confidence interval. Based on the size of the confidence interval, we obtained additional information about the topographic homogeneity of the samples on the 4 μm size scale.

Edge abrasion was also examined by analyzing reflection light microscope images. To do this, we determined the length of the outer edge of the needle's edge, and then compared it to the length of the ideal elliptical profile. We also examined the change in the area of the edge of the needle. A circle was fitted to the outer edge of the needle tip and a mask was produced using the fitted profile. The length of the arc and the area of the mask were determined from the image. The length of the resulting arc (l_{id}) was compared to the ideally smooth edge line length. We also added a circular arc to the inner edge of the needle tip and created a mask in this way. We also determined the area of this mask, and, as the difference between the two masked areas, we obtained the area of the article of the ideal needle (A_{id}). After that, the image was converted

to binary after setting appropriate limits. We determined the length of the profile (l) and the area of the needle section (A) on the outer curve.
The obtained values are compared to the ideal curve values ($l/l_{id} \cdot 100\%$ and $A/A_{id} \cdot 100\%$).

Statistical analysis

Statistical analysis was conducted using Microsoft Excel software (version 2016, Microsoft Corp.). Descriptive statistics were computed, encompassing measures such as means, standard deviations (SDs), and measurement ranges. Additionally, the normality of the data was examined through the application of the Kolmogorov-Smirnov test. Wilcoxon test was used to compare the data between groups and the assessment of correlations between variables was performed using the Spearman rank test.

Examination of biometric parameters

Methods

All phakic eye measurements at office time in the database above the age of 16 years were indiscriminately included in the retrospective data collecting, the only exclusion being previous laser vision correction. We therefore used a database measured according to our daily routine, taking biometric data on the same individual only once a day.

For the measurements, the Zeiss IOLMaster 700 (Carl Zeiss Meditec AG Jena, Germany) (software version 1.50.7.40411) was used. Measurements were taken between 09 July 2016 and 14 November 2023. The office hours were defined in the GMT+1.0 time zone between 7:00 and 15:00 hours and the data were treated in hourly groups within this range. The median time for biometric measurements was 10:44:12.
For data collection, anonymized patient data such as age, biological sex and biometric parameters (axial length, anterior chamber depth, central corneal thickness, corneal white-to-white distance, keratometry readings, lens thickness), obtained from IOLMaster 700, were used. The biometric values in this exported csv file include the exact hour:minute time of the examination. The measurement data for the whole population were thus sorted by the hour:minute data and groups were created according to the test hour intervals. Data from these groups, i.e., eyes measured in one-hour intervals, were used for further analysis.

The study protocol complied with the principles of the Declaration of Helsinki, revised in 2013, and was approved by the Regional/Institutional Scientific and Research Ethics Committee of the Central Hospital and University Teaching Hospital of Borsod-Abaúj-Zemplén County, Miskolc, Hungary with the identification number BORS-03/2024. Due to the retrospective nature of the study, the requirement to obtain written informed consent was waived.

Statistical analysis

Descriptive statistics were performed to determine mean, median, standard deviation (SD) and range. The distribution of the data was estimated using the Shapiro-Wilk test and normality was excluded for all variables included ($p<0.001$), so we used the Mann-Whitney test to compare groups of data, the Kruskal-Wallis test to compare three or more non-matched groups and Spearman correlation test to quantify the relationship between two variables.

For data management and statistical data processing, we used Microsoft Excel 2021 and MedCalc Statistical Software version 13.0.6 (MedCalc Software BvBA, Ostend, Belgium). A P-value below 0.05 was considered significant.

4. Results

Ultrastructural examination of phacoemulsification tips

During our study, 2 surgeons performed unilateral cataract surgery on 820 eyes. Average age of patients was 69.67, and the mean of cataract grade was 2.65 (in scale I-IV). There was no significant difference in cataract grade between the two groups of patients operated with different surgical techniques ($p=0.52$). The average grade of cataract was 2.58 in the case of the divide and conquer technique, and 2.70 of patients who were operated with the chop technique.

Based on the analysis of our data, significant correlations were found between age and cataract grade ($r=0.87$, $p=0.0045$), between area percentage and absolute phaco time (APT) ($r= -0.9$, $p=0.03$), and between the area percentage and EPT ($r=-0.9$, $p=0.03$). According to the negative correlation between the area % and APT and EPT data, the longer the phaco energy is used, the greater the reduction of the area %, thus the abrasion of the tip will also be greater. However, in the case of profile length %, we found a significant difference in only one roughness index ($r=0.9$, $p=0.03$). We found a significant difference between the two surgical techniques in terms of the percentage of the area ($p=0.04$) and the average US energy (US ave %) used during the operation ($p<0.01$).

With the exception of one roughness index (Sz_conf: p=0.03), the values obtained in the case of operations performed with the divide and conquer technique are higher compared to the chop technique. On average, higher ultrasound energy was required during operations performed using the chop technique. The difference in area % indicates that the surface abrasion of the tips is less with the divide and conquer technique.

Unused single-use and multiple-use tips differed in several edge and mantle parameters (Edge: Sa p=0.04, Sq p=0.04, Sz p=0.02, Mantle: Sa p=0.01, Sq p=0, 01).
Differences were also found between the sterilized-only but not used single-use and multiple-use tips in several data of the edge and mantle (Edge Sa p=0.03, Sq p=0.05 Sz p=0.04, Sz and Mantle Sa p<0.01, Sq p=0.01, Sq p=0.01). In the parameters of the multiple-use tips, the edge while in the values of the single-use tips, mantle indicators were higher, but sterilization had no significant effect on the parameters of the edge and the mantle.

A gradual decrease in area % and an increase in profile length % were observed for both single-use and multiple-use tips, which is also confirmed by the change in roughness indicators.

The analysis of the data revealed that the roughness of the samples increased significantly after 5 operations, which shows a gradual decrease with further use, and then for both tip types, a jump is visible after the twentieth operation, which is followed by another gradual decrease.

Examination of biometric parameters

Biometric data from 30657 eyes were used (38.89% males, 61.11% females).
There were no statistically significant differences in mean age between the different office-hour groups (Kruskal-Wallis p>0.05), nor were ACD, LT, CCT, and WTW statistically different between the different groups (Kruskal-Wallis p>0.05). The largest average age difference between the subgroups of office hours in the male group was 2.28 years and 1.46 years for women.

Age and AL were significantly correlated in both the male and female populations (r=-0.12; p<0.001 and -0.147; p<0.001, respectively), and this correlation was also observed when the office-hours groups were separated.

The AL difference between the end (15:00 h) and the beginning (7:00 h) of the office day was 0.223 mm for the total population, 0.198 mm for the male group and 0.197 mm for the female group.

The IOL power calculation was performed based on the change in the diurnal variation of the AL, using the Barrett Universal II formula (calc.apacrs.org/barrett_universal2105).

When using an A-constant of 118.9, only the difference in axial lengths during office hours shows a difference in IOL diopter of up to 1.0 D.

If the database is split by gender, the data in Table 3 and 4 is obtained for the IOL power calculation. Calculated using the AL value for the male population, the IOL diopter value for conventional calculation varies between 21.0 and 20.0 D, for the female population these values are between 21.5 D and 20.5 D.

5. New results and conclusions

1. Our study was the first to examine phacoemulsification tips using atomic force microscopy. It was conducted in vivo, under real surgical conditions, and involved the largest number of cases to date. We found that tips used with the chop technique showed greater roughness and surface damage.

2. Our results may also have clinical significance in that reusable tips can be used for up to 20 surgeries without significant complications, instead of the 10 uses recommended by most manufacturers. The repeated use of single-use tips should also be considered. All of these factors may play a significant role in cost-effectiveness and environmental protection in the future.

3. According to our results, in the case of less mature cataracts, the divide and conquer technique causes less damage to the needle surface and requires less average ultrasound energy during surgery.

4. Among the multiple biometric parameters (CCT, ACD, K, WTW, LT, AL) determined with a swept-source biometer, we found significant daily changes in axial length in the case of AL in a large cross-sectional database.

5. During our investigations, we concluded that there is a methodological and/or device-dependent factor behind the daily change in axial length, which is much greater than the diurnal change described above. All of these factors may have a clinically significant impact on the determination of the intraocular lens power, which may result in an intraocular lens power difference of up to 1.0 D, thus leading to a significant deviation from the postoperative target refraction.

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Registry number: DEENK/553/2025.PL
Subject: PhD Publication List

Candidate: Ágnes Revák
Doctoral School: Doctoral School of Clinical Medicine

List of publications related to the dissertation

1. Németh, G., **Revák, Á.**, Vámosi, P., Elekes, Á., Módis, L., Sohajda, Z.: The variation in axial length in office hours causes a diopter change in the intraocular lens power calculation.
   Eur. J. Ophthalmol. 35 (4), 1162-1168, 2025.
   DOI: http://dx.doi.org/10.1177/11206721241304154
   IF: 1.4 (2024)
2. **Revák, Á.**, Németh, G., Korizs, J., Gyulai, G., Ábrahám, Á., Kiss, É., Sohajda, Z.: Examination of phacoemulsifcation tips after diferent numbers of cataract surgeries.
   Sci. Rep. 14 (1), 1-9, 2024.
   DOI: http://dx.doi.org/10.1038/s41598-024-67891-0
   IF: 3.9

List of other publications

3. Sohajda, Z., Széll, N., **Revák, Á.**, Papp, J., Tóth-Molnár, E.: Morfológiai és funkcionális változások CO2-lézer-asszisztált mély sclerectomia után.
   Szemész. 158 (2), 107-112, 2021.
4. Sohajda, Z., Széll, N., **Revák, Á.**, Papp, J., Tóth-Molnár, E.: Retinal Nerve Fibre Layer Thickness Change After CO2 Laser-Assisted Deep Sclerectomy Surgery.
   Clin. Ophthalmol. 14, 1749-1757, 2020.

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5. **Revák, Á.**, Szendi, M., Sohajda, Z.: Recklinghausen-kórban szenvedő betegek szemészeti gondozása. Esetismertetés.
   Szemész. 153 (3), 137-142, 2016.

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The Candidate's publication data submitted to the Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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