STUDY OF ABLATED SURFACE SMOOTHNESS AND THERMAL PROCESSES IN RABBIT CORNEA TREATED WITH MICROSCAN-VISUM AND MICROSCAN-PIC EXCIMER LASER SYSTEMS

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In ophthalmology, excimer lasers are used for treating different refractive disorders. The performance of an excimer laser station can be assessed by a number of criteria, such as cornea surface smoothness after the ablation, differences between the diameter of the postoperative optical zone that received full correction and the diameter of the programmed optical zone, and cornea heating during the surgery. The article presents the results of the assessment of three Russian excimer laser systems: MicroScan-PIC 100 Hz, MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz (Optosystems Ltd.). The smoothness of the ablated surface was measured by New View – 5000 Zygo interferometer (Zygo Corporation, USA). Using PMMA plates, the ablated surface was formed tenfold with each laser as an imitation of the 3.0 D myopia surgical correction, with the optical zone diameter of 6 mm and the transition zone diameters of 2.3 mm for MicroScan-PIC 100 Hz and of 1.9 mm for MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz. Thermal processes in the cornea were studied in 15 grey chinchillas over 1 year old with a weight of 2–3 kg. With each of the laser systems, phototherapeutic keratectomy was performed on 5 eyes. The smoothest ablated surfaces were formed by MicroScan-Visum 500 Hz. Cornea temperature was the highest here (+ 3.95 °C by the end of treatment), but still within the range of values acceptable for modern scanning type lasers.

Keywords: excimer laser system, MicroScan-PIC 100 Hz, MicroScan-Visum 300 Hz, MicroScan-Visum 500 Hz, ablation, cornea, error of refraction

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ИССЛЕДОВАНИЕ ГЛАДКОСТИ АБЛЯЦИОННОЙ ПОВЕРХНОСТИ И ТЕРМИЧЕСКИХ ПРОЦЕССОВ В РОГОВИЦЕ КРОЛИКА ПРИ РАБОТЕ ЭКСИМЕРЛАЗЕРНЫХ УСТАНОВОК «МИКРОСКАН-ВИЗУМ» И «МИКРОСКАН-ЦФП»

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Эксимерные лазеры используют в офтальмологии для лечения различных аномалий рефракции. Качество работы эксимерлазерной установки можно оценить по нескольким критериям: гладкости формируемой ею абляционной поверхности роговицы, соответствию диаметра полученной оптической зоны полной коррекции диаметру расчетной оптической зоны и нагреву роговицы в процессе операции. В статье представлены результаты оценки трех российских эксимерлазерных установок: «МикроСкан-ЦФП 100 Гц», «МикроСкан-Визум 300 Гц» и «МикроСкан-Визум 500 Гц» («Оптосистемы»). Гладкость абляционной поверхности, которую формировали десятикратно для каждого лазера на пластинах полиметилметакрилата, имитируя операцию коррекции миопии в 3,0 дптр и задавая диаметр оптической зоны в 6 мм и диаметр переходной зоны — в 2,3 мм для «МикроСкан-ЦФП 100 Гц» и в 1,9 мм для «МикроСкан-Визум 300 Гц» и «МикроСкан-Визум 500 Гц», измеряли с помощью интерферометра New View – 5000 Zygo (Zygo Corporation, США). Термические процессы в роговице изучали на 15 кроликах породы шиншилла серая в возрасте старше одного года и живой массой 2–3 кг. Каждым лазером проводили фототерапевтическую кератэктомию на 5 глазах. Установка «МикроСкан-Визум 500 Гц» формировала наиболее гладкие абляционные поверхности. Нагрев роговицы при ее использовании был наибольшим (+ 3,95 °С к концу операции), но находился в пределах значений, допустимых для современных лазеров сканирующего типа.

Ключевые слова: эксимерлазерная установка, МикроСкан-ЦФП 100 Гц, МикроСкан-Визум 300 Гц, МикроСкан-Визум 500 Гц, абляция, роговица, аномалия рефракции

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According to the World Health Organization, the number of people with refractive errors has been steadily increasing in recent decades. Data obtained from various authors indicate that there is about 27 to 45 % prevalence of myopia and myopic astigmatism among people of working age in Russia, US and EU [1]. However, there has been an improvement both in the traditional (spectacle and contact lens correction) and in the surgical methods of correction of refractive errors.

Keratorefractive surgery with various lasers has improved rapidly [2–4].

In recent years, ophthalmologists from different countries have gained extensive clinical experience in the use of excimer laser for correction of refractive errors [3, 5–11]. In Russia, researchers are working to design excimer laser systems and introduce them into clinical practice. Since the late 1980s, Eye Microsurgery, an intersectoral research & technology complex, has created excimer lasers and deployed them into clinical practice. This complex has been doing this in cooperation with laser manufacturer – Physics Instrumentation Center of the General Physics Institute, Russian Academy of Sciences and Optosystems. Excimer laser system MicroScan-PIC was presented in 2000. Along with operations based on LASIK (laser in situ Keratomileusis) and TransPRK (transepithelial photorefractive keratectomy) standard technologies, the laser allows to perform personalized operations based on corneal topography and aberrometry data. Analysis of clinical and functional results of such operations showed that they are of high predictability, stability and safety [12].

Several criteria are used for objective assessment of the quality of excimer laser systems. One of them is the smoothness of corneal surface formed by the excimer laser. A smoother corneal surface facilitates normal course of corneal epithelialization after surgery and minimizes the likelihood of fibroplasia [13]. Quantitative characteristics of smoothness allow to obtain a measurement with interferometric microscopes from Zygo Corporation (USA). A number of investigators have shown that surface smoothness is higher in flying spot scanning lasers than in full-aperture lasers and lasers that use scanning slit and stopped down ablation formation system [14,15].

Another important criterion is the association of the diameter of the resulting optical zone of full correction with the computed optical zone diameter specified by the manufacturer in the computing program of the laser system. According to O'Donnel et al. [15], the ablation zone diameter obtained during excimer laser surgery using stopped down forming system is usually less than that indicated by the manufacturer. According to the researchers, the greater the optical and transition zone of influence, the better the functional outcome and the lesser the likelihood of regression of postoperative effect. A smaller optical zone can cause very unpleasant sensations in patients in lowered or increased illumination [16].

Another important indicator of the quality of excimer lasers is that there is no significant increase in corneal temperature during surgery. Despite the fact that excimer lasers are referred to as “cold”, they can break molecular bonds in cells and release energy that increases the corneal temperature [17,18]. The temperature increase cannot cause collagen denaturation but may affect the activity of keratocytes, postoperative healing and development of fibroplasia. Flying spot scanning lasers can significantly reduce possible heating of the cornea thanks to the small beam diameter and scanning algorithm in which the local areas of the corneal tissue, which are at a distance from each other, are ablated. Therefore, the cornea has no enough time to increase its temperature significantly [19, 20].

Efficiency in clinical practice is of course the main indicator of the quality of an excimer laser system. However, based on the criteria given above, the technical features and prospects for the use of the device at the pre-clinical study stage can be identified.

Next-generation device MicroScan-Visum is a modification of the MicroScan-PIC laser system and developed in two models — 300 and 500 Hz scanning frequencies. The aim of our study was to evaluate the surface ablation smoothness formed on polymeric materials and to investigate the thermal processes in a rabbit cornea treated with the studied laser systems during phototherapeutic keratectomy (PTK).

METHODS

An experiment to assess ablation surface smoothness was carried out using polymethylmethacrylate (PMMA) plates. In the control computer of each of the three test excimer lasers — MicroScan-PIC 100 Hz, MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz — myopia correction surgery was set in 3.0 diopter with the same optical zone diameter 6 mm but different transition zone diameters — 2.3 mm for MicroScan-PIC 100 Hz and 1.9 mm for MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz (this was due to different excimer laser light spot diameters — 1.15 and 0.95 mm respectively). Ten lenses for each of the lasers was formed on the plates, after which all the lenses were measured using interference microscope New View – 5000 Zygo. The following indicators characterizing the quality of the formed lens surface were identified:

RMS — root mean square deviation of the surface points relative to the average height across the study area;

PV — distance between the highest and lowest points of the study area;

Ra — average deviation of surface points from the middle surface.

Moreover, it was considered that the better the surface smoothness, the smaller the value of these indicators would be.

Thermographic analysis of corneal temperature changes was conducted in 15 gray chinchilla rabbits, more than one year old and with live weight of 2–3 kg. The experiment was approved by the Intercollegiate Ethics Committee (Minutes No 10–12 of 18 October 2012). Each of the three laser systems was used to operate on 5 eyes (one eye per animal). 15 min before the surgery, the rabbits were administered with 2 ml of relanium solution. The surgery was performed under local anesthesia (triple instillation of 1 % inokain solution). The estimated ablation depth during PTK was 52 microns.

Thermal imaging complex Thermo View Ti30 (Raytek, USA) was used to measure the corneal temperature. Imaging was carried out in a room with ambient temperature of 16.7 °C at a distance of 60–70 cm with frequency of 1 Hz and up to 0.1 °C accuracy. On the PC, thermal imager data were converted to thermographic map using a software tool supplied with the device, and the maximum and minimum corneal temperatures during the surgery were determined. Corneal emissivity was set at 0.93 (like water), i.e. it was considered that 0.93 of the total corneal radiation enters the device and the device adds 0.07 when calculating the temperature. For example, if the temperature is 37.3 °C for $k = 0.93$, then temperature will be equal to 36.1 °C for $k = 1$ for the same thermogram.

Data was statistically processed using software programs Statistica 6.0 (StatSoft, USA) and Excel 2003. Variation statistics methods were used. The results were presented as arithmetic mean (M) and standard deviation (σ). Student's t-test for independent cases was used to compare the means and evaluate the significance of differences ($p = 0.05$).

RESULTS

The results of comparative analysis of the quality of ablation surface of lens are presented in table 1. Laser system MicroScan-Visum 500 Hz yielded the best smoothness.

Table 1. Indicators of the ablation surface quality of lens formed on polymethylmethacrylate plates using radiation from MicroScan-PIC 100 Hz, MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz systems, nm (M ± δ, p <0.05)

Laser system	RMS	PV	Ra
MicroScan-PIC 100 Hz	392 ± 75	6454 ± 1752	311 ± 68
MicroScan-Visum 300 Hz	351 ± 35	2754 ± 298	282 ± 25
MicroScan-Visum 500 Hz	338 ± 25	2960 ± 51	268 ± 20

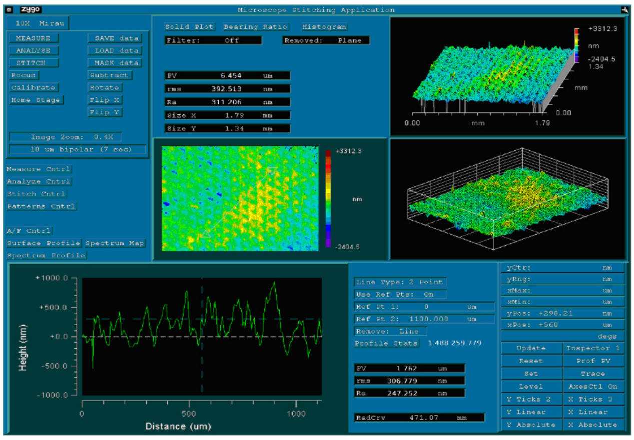

Fig. 1. Example of measurement of the smoothness of the ablation surface formed using MicroScan-PIC 100 Hz by interferometer New View – 5000 Zygo (Ra = 311 nm)

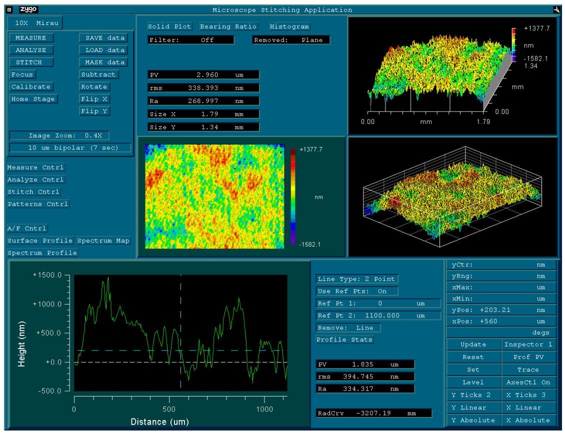

Fig. 2. Example of measurement of the smoothness of the ablation surface formed using MicroScan-Visum 500 Hz by interferometer New View – 5000 Zygo (Ra = 268 nm)

Fig. 1 and 2 show examples of measurement for MicroScan-PIC 100 Hz and MicroScan-Visum 500 Hz systems.

An example thermal map obtained during excimer laser ablation on MicroScan-PIC 100 Hz is shown in fig. 3, while the results of measurement of the transverse temperature profile for all the laser systems studied are presented in fig. 4.

For MicroScan-PIC 100 Hz, the average corneal temperature prior to laser exposure was 31.04 ± 0.63 °C, the maximum temperature at the end of surgery was 32.21 ± 0.68 °C, while the temperature change was 1.17 ± 0.05 °C (table 2). For MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz laser systems, the figures were 31.82 ± 0.87, 33.24 ± 1.21 and 1.42 ± 0.34 °C, and 31.02 ± 0.47, 34.97 ± 1.36 and 3.95 ± 0.89 °C, respectively.

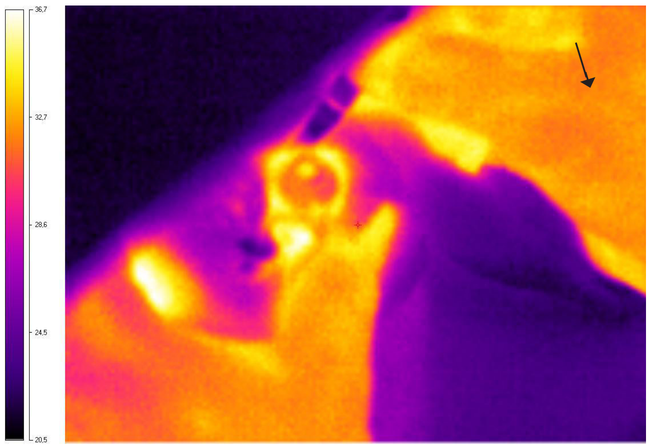

Fig. 3. Example of thermographic map during phototherapeutic keratectomy using MicroScan-PIC 100 Hz (rabbit cornea is marked by an arrow)

DISCUSSION

Laser system MicroScan-Visum 500 Hz yielded the smoothest ablative surfaces. Although corneal heating obtained with this laser was the highest (+3.95 °C by the end of surgery), the value was within acceptable range. For example, during LASIK surgery for treatment of high myopia Sph -9,25D using popular laser Schwind AMARIS 500 Hz (SCHWIND eye-tech-solutions, Germany), the corneal temperature increased by 3.73 °C [21].

CONCLUSIONS

All the three laser systems studied can create a high-quality ablation surface. However, the MicroScan-Visum 500 Hz system gave the best result. The laser yielded the highest corneal heating during phototherapeutic keratectomy in rabbits, but the value did not exceed the permissible values. After the study, MicroScan-Visum 500 Hz was recommended for clinical research.

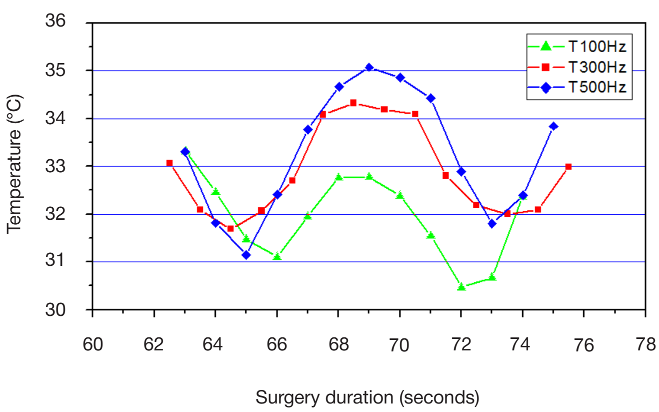

Fig. 4. Transverse temperature profiles for excimer laser systems MicroScan-PIC 100 Hz (green curve), MicroScan-Visum 300 Hz (red curve) and MicroScan-Visum 500 Hz (blue curve)

Table 2. Dynamics of thermal processes in a rabbit cornea during phototherapeutic keratectomy using laser systems MicroScan-PIC 100 Hz, MicroScan-Visum 300 Hz and MicroScan-Visum 500 Hz, °C (M ± δ, p<0.05)

Laser system	Initial corneal temp.	Maximum corneal temp. at the end of surgery	Increase in temp.
MicroScan-PIC 100 Hz	31,04 ± 0,63	32,21 ± 0.68	1,17 ± 0,05
MicroScan-Visum 300 Hz	31,82 ± 0,87	33,24 ± 1,21	1,42 ± 0,34
MicroScan-Visum 500 Hz	31,02 ± 0,47	34,97 ± 1,36	3,95 ± 0,89

References

1. Libman ES, Shakhova EV. Slepota, slabovidenie i invalidnost' po zreniyu v rossiyskoy federatsii. In: Likvidatsiya ustranimoy slepoty: Vsemirnaya initsiativa VOZ: Materialy Rossiyskogo mezhregional'nogo simpoziuma; 2013 Apr 22–; Ufa, Russia. p. 38–42.
2. Avetisov SE, Mamikonyan VR. Keratorefraktsionnaya khirurgiya. Moscow: IPO "Poligran"; 1993. 120 p.
3. Balashevich LI. Tekhnika eksimerlazernoy keratektomii. Refraktsionnaya khirurgiya. 2002; 93–4.
4. Fedorov SN, Semenov AD, Kharizov AA, et al. Opyt ispol'zovaniya eksimernogo lazera v refraktsionnoy khirurgii blizorukosti. In: Tezisy dokladov Mezhdunarodnogo simpoziuma po refraktsionnoy khirurgii, implantatsii IOL; 1991; Moscow. p. 12.
5. Alisov IA. Eksimernyy lazer "Profil'-500" v korrektsii slozhnogo miopicheskogo astigmatizma [dissertation]. Moscow; 2002.
6. Kachalina GF. Khirurgicheskaya tekhnologiya transepitelial'noy fotorefraktivnoy keratektomii pri miopii na eksimerlazernoy ustanovke "Profil'-500" [dissertation]. Moscow: IRTC Eye Microsurgery; 2000.
7. Kishkin YuI. Eksimernyy lazer v korrektsii ostatochnoy blizorukosti posle radial'noy keratotomii [dissertation]. Moscow: IRTC Eye Microsurgery; 1998.
8. Kurenkov VV. Fotorefraktsionnaya keratektomiya i intrastromal'naya keratektomiya: Rukovodstvo po eksimerlazernoy khirurgii rogovitsy. Moscow: Izdatel'stvo RAMN; 2002. p. 197–200.
9. Tarutta EP, Smirnova TS, Khodzhabekyan NV. Dvukhletniy opyt FRK s pomoshch'yu eksimernogo lazera MEL-60. In: Materialy VII S"ezda oftal'mologov Rossii; 2000 May 16–20; Moscow. p. 298–9.
10. Esquenazi S, Mendoza A. Two-year follow-up of LASIK for hyperopia. J Refract Surg. 1999; 15 (6): 648–52.
11. Knorz M, Wiesinger B, Liermann A, Seiberth, Liesenhoff H. Laser in situ keratomileusis for moderate and high myopia and myopic astigmatism. Ophthalmology. 1998; 105 (5): 932–40.
12. Doga AV. Eksimerlazernaya refraktsionnaya mikrokhirurgiya rogovitsy na baze skaniruyushchey ustanovki «Mikroskan» [dissertation]. Moscow: IRTC Eye Microsurgery; 2004.
13. Liang FQ, Geasey SD, del Cerro M, Aquavella JV. A new procedure for evaluating smoothness of corneal surface following 193-nm excimer laser ablation. Corneal Surg. 1992; 8 (6): 459–65.
14. Argento C, Valenzuela G, Huck H, Cremona G, Cosentino MJ, Gale MF. Smoothness of ablation on acrylic by four different excimer lasers. J Refract Surg. 2001; 17 (1): 43–5.
15. O´Donnel F., Tang F., Han X., Chen D., Hwang M. PRK ablation zone anatomy. In: Book of abstract American Society of Cataract and Refractive Surgery Meeting; 1995 Apr 1–5; San Diego, USA.
16. O´Brart D, Corbett M, Verma S, et al. An investigation to determine the effects of ablation diameter, depth and profile on the outcome of excimer laser photorefractive keratectomy Invest. Ophthalmol Vis Sci. 1995; 36 (Suppl): S1063.
17. Bende T, Seiler T, Wollensak J. Side effects in excimer corneal surgery: corneal thermal gradients. Graefes Arch Clin Exp Ophthalmol. 1988; 226 (3): 277–80.
18. Berns MW, Liaw LH, Oliva A, Andrews JJ, Rasmussen RE, Kimel S. An acute light and electron microscopic study of ultraviolet 193-nm excimer laser corneal incisions. Ophthalmology. 1988; 95 (10): 1422–33.
19. Kornilovskiy IM, Dorri AM, Pavlenko VV. Izmeneniya temperatury rogovitsy pri FRK i lokal'noy gipotermii. In: Materialy IV mezhdunarodnoy konferentsii «Klinicheskie rezul'taty primeneniya eksimernogo lazera EC-5000 (NIDEK)». 1999; Moscow. p. 8.
20. Chatterjee A, Shah S, Bonshek R, et al. Relationship of histological change to corneal temperature change following PRK. J Refract Corneal Surg. 1997; 13 (Suppl): S462–3.
21. Schwind Press Release. Thermodynamic measurements confirm high safety of the SCHWIND AMARIS' intelligent thermal effect control. Kleinostheim, Germany; 2010 Apr. Available from: http://www.eye-tech-solutions.com/en/home/information-centre/press-centre.

Литература

1. Либман Е. С., Шахова Е. В. Слепота, слабовидение и инвалидность по зрению в российской федерации. В сборнике: Ликвидация устранимой слепоты: Всемирная инициатива ВОЗ: Материалы Российского межрегионального симпозиума; 22–23 апреля 2003 г.; Уфа. с. 38–42.
2. Аветисов С. Э., Мамиконян В. Р. Кераторефракционная хирургия. М.: ИПО «Полигран»; 1993. 120 с.
3. Балашевич Л. И. Техника эксимерлазерной кератэктомии. Рефракционная хирургия. 2002; 93–4.
4. Федоров С. Н., Семенов А. Д., Харизов А. А. и др. Опыт использования эксимерного лазера в рефракционной хирургии близорукости. В сборнике: Тезисы докладов Международного симпозиума по рефракционной хирургии, имплантации ИОЛ; 1991; Москва. с. 12.
5. Алисов И. А. Эксимерный лазер «Профиль-500» в коррекции сложного миопического астигматизма [диссертация]. Москва; 2002.
6. Качалина Г. Ф. Хирургическая технология трансэпителиальной фоторефрактивной кератэктомии при миопии на эксимерлазерной установке «Профиль-500» [диссертация]. Москва: Межотраслевой научно-технический комплекс «Микрохирургия глаза»; 2000.
7. Кишкин Ю. И. Эксимерный лазер в коррекции остаточной близорукости после радиальной кератотомии [диссертация]. Москва: Межотраслевой научно-технический комплекс «Микрохирургия глаза»; 1998.
8. Куренков В. В. Фоторефракционная кератэктомия и интрастромальная кератэктомия: Руководство по эксимерлазерной хирургии роговицы. М.: Издательство РАМН; 2002. с. 197–200.
9. Тарутта Е. П., Смирнова Т. С., Ходжабекян Н. В. Двухлетний опыт ФРК с помощью эксимерного лазера MEL-60. В сборнике: Материалы VII Съезда офтальмологов России; 16–20 мая 2000 г.; Москва. с. 298–9.
10. Esquenazi S, Mendoza A. Two-year follow-up of LASIK for hyperopia. J Refract Surg. 1999; 15 (6): 648–52.
11. Knorz M, Wiesinger B, Liermann A, Seiberth, Liesenhoff H. Laser in situ keratomileusis for moderate and high myopia and myopic astigmatism. Ophthalmology. 1998; 105 (5): 932–40.
12. Дога А. В. Эксимерлазерная рефракционная микрохирургия роговицы на базе сканирующей установки «Микроскан» [диссертация]. Москва: Межотраслевой научно-технический комплекс «Микрохирургия глаза»; 2004.
13. Liang FQ, Geasey SD, del Cerro M, Aquavella JV. A new procedure

for evaluating smoothness of corneal surface following 193-nm excimer laser ablation. Corneal Surg. 1992; 8 (6): 459–65.

14. Argento C, Valenzuela G, Huck H, Cremona G, Cosentino MJ, Gale MF. Smoothness of ablation on acrylic by four different excimer lasers. J Refract Surg. 2001; 17 (1): 43–5.
15. O´Donnel F., Tang F., Han X., Chen D., Hwang M. PRK ablation zone anatomy. In: Book of abstract American Society of Cataract and Refractive Surgery Meeting; 1995 Apr 1–5; San Diego, USA.
16. O´Brart D, Corbett M, Verma S, et al. An investigation to determine the effects of ablation diameter, depth and profile on the outcome of excimer laser photorefractive keratectomy Invest. Ophthalmol Vis Sci. 1995; 36 (Suppl): S1063.
17. Bende T, Seiler T, Wollensak J. Side effects in excimer corneal surgery: corneal thermal gradients. Graefes Arch Clin Exp Ophthalmol. 1988; 226 (3): 277–80.
18. Berns MW, Liaw LH, Oliva A, Andrews JJ, Rasmussen RE, Kimel S. An acute light and electron microscopic study of ultraviolet 193-nm excimer laser corneal incisions. Ophthalmology. 1988; 95 (10): 1422–33.
19. Корниловский И. М., Дорри А. М., Павленко В. В. Изменения температуры роговицы при ФРК и локальной гипотермии. В сборнике: Материалы IV международной конференции «Клинические результаты применения эксимерного лазера EC-5000 (NIDEK)». 1999; Москва. с. 8.
20. Chatterjee A, Shah S, Bonshek R, et al. Relationship of histological change to corneal temperature change following PRK. J Refract Corneal Surg. 1997; 13 (Suppl): S462–3.
21. Schwind Press Release. Thermodynamic measurements confirm high safety of the SCHWIND AMARIS' intelligent thermal effect contro. Kleinostheim, Germany; 2010 Apr. Доступно по ссылке: http://www.eye-tech-solutions.com/en/home/information-centre/press-centre.