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Estimation of ultrasound attenuation coefficient of human diabetic cataract

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Introduction

Cataract is one of the earliest known disabling conditions of the eye. In most cases, the appearance of a cataract seems to be a result of certain biochemical changes in the lens, associated with aging, but the nature and mechanism of such changes is thus far unestablished, at least in humans. It is known that cataracts may also form as a consequense of certain inborn metabolic derangements, including diabetes mellitus. It would be fair to conclude that diabetes, especially when poorly controlled, does constitute a cataractogenic factor, either by itself or synergisticaly with other factors (nutritional status of the patient, age, genetic variations) known to participate in the formation of cataracts.

Diabetes is a disease characterized by an excessive increase in blood sugar (glucose) caused by a relative or absolute lack of insulin in the blood. Basically, there are two forms of diabetes:

- Insulin dependent diabetes mellitus (IDDM) or type I DM: appears at a relatively early age with hereditary and auto-immune components; characteristically with acute onset, and treatment with insulin is necessary.
- Non insulin dependent diabetes mellitus (NIDDM) or type II DM: appears later in life, associated with obesity and over-eating; often discovered by chance; controllable with proper diet, body weight, and oral anti-diabetic medicine.

Exposure to hyperglycemia can cause both reversible and, if prolonged, cumulative, irreversible changes to tissue metabolism and structure. All structures in the eye are impaired by hyperglycemia. Diabetic retinopathy is the most serious complication of the diabetic microvascular abnormalities. Microvascular changes are also found in the iris and ciliary body. Diabetes also induces metabolic disorders in the cornea, lens, muscles and nerves. Some of these impairments are of little consequence and go unnoticed by the patient or the doctor, but some changes may result in several complications following cataract surgery.

The identity of diabetic cataracts is well established in relatively younger diabetics. It is usually bilateral and consists initially of a characteristic band of subcapsular vacuoles extending to approximately one-third the depth of the superficial layers of anterior and posterior cortex. The vacuoles often are interspersed with white flaky opacities. There may also be a simultaneous appearance of water clefts and suture separations. These early stages of cataract development are ultimately followed by the appearance of more diffuse cloudiness and opacification.

In adult diabetics, cataracts are characterized by cortical and nuclear involvement and it is not possible to distinguish them morphologically from the garden variety of senile cataracts.

The crystallins are the main structure of the human lens and constitute approximately 90% of the total protein content [1]. Their structural function is to assist in maintaining the proper refractive index of the lens and its transparency [2]. According to molecular weight there are α-crystallins (over 200 kDa), β-crystallins (40-160 kDa) and γ-crystallins (about 20 kDa). Protein aggregation results in the development of high molecular weight aggregates of sufficient size to directly scatter the light and in the creation of protein rich and protein poor phases causing changes in refractive index and increased light scattering [1]. Rink H. and co-authors (1995) found the increased amount of water insoluble proteins in nuclear cataract lenses. This process was especially observed in the nuclear layers of cataract lenses. Redistribution of soluble crystallins from low molecular weight to high was observed in nuclear and cortical regions [3].

When examing the patient it is very important to describe the cataracts quantitatively, but it is difficult using only biomicroscopy.

Ultrasound examination is widely used in ophthalmology. Piezoelectric crystals generate ultrasound waves of 5-50 MHz. Short pulses of 2 to 3 cycles are send from transducer into the eye. These pulses go through the tissues of the eye with the speed that is proportional to elasticity and inversely proportional to the density and of the eye. Acoustic parameters of biologic tissues are described by velocity and attenuation coefficient of ultrasonic waves. It is known that in soft tissues the attenuation coefficient is approximately proportional to the frequency – high frequency components of echoes are attenuated more than the lower frequency components [4]. Ultrasound pulses are attenuated as the result of absorption and scattering as it goes through the tissue [5].

Normal lens is acoustically homogenous and clear. It's characteristics change according to the density of cataract that is due to the changes in tissue density and structure [5].

Ultrasound attenuation by a biological medium is largely influenced by the presence of high-molecular-weight compounds and in cataract lenses increased protein aggregation contributes to the hardening of the lens and increased ultrasound attenuation [5]. Sugata Y. and co-authors (1992) examined normal and cataract lenses and suggested the possibility of diagnosing cataract by measuring the attenuation characteristics of the lens. The changes of ultrasound attenuation accordingly to the severity of cataract could make it possible to classify it to the stages and sound attenuation can be used as a criterion for the diagnosis of cataract. Sugata Y. and co-authors (1992) found the normal human lens to have normal lens attenuation 0.07-0.92 dB/cmMHz, while in different cataract types 1.6-7.3 dB/cmMHz, and expressed the idea about quantitative and early detection of cataract from echo signals [4]. Therefore, further developments for the lens examination in-vivo are needed.

In this work we intended to determine the types of lens opacities, their intensity and relation with the type of diabetes mellitus, duration of the illness and patients age, to evaluate the influence of diabetic cataract changes to ultrasonic attenuation and try to make quantitative description of human diabetic cataract.

Materials and methods

The sample consisted of 25 patients (27 eyes) who were scheduled for cataract surgery in Eye Clinic of Kaunas University of Medicine. 14 of them are type I diabetics (7 with hemophthalmus, 7 - without hemophthalmus) and 13 – type II diabetics without hemophthalmus. Patients age variates between 16 and 82 years. The duration of illness variates between 7 and 32 years.

Ultrasonic examination in-vivo

In-vivo examination of cataract lens by *Mentor*™ A/B ultrasonic imaging system (Advent, Norwell, MA) using 7 MHz A-mode probe was performed and the ultrasound attenuation coefficient was calculated. Radio frequency echo-signals from lens where digitized by TEKTRONIX 220 oscilloscope at the sampling rate 250 MHz and 8 bit amplitude resolution, bandwidth for analog signal was 100 MHz. Manual trigger of oscilloscope was used according to sound notice from system about the probe correct alignment to eye axis. Signal averaging was not used, but five single signals where acquired (Fig. 1). The selected signal from diabetic lens has been recorded. Digitized echo signals where used for off-line processing.

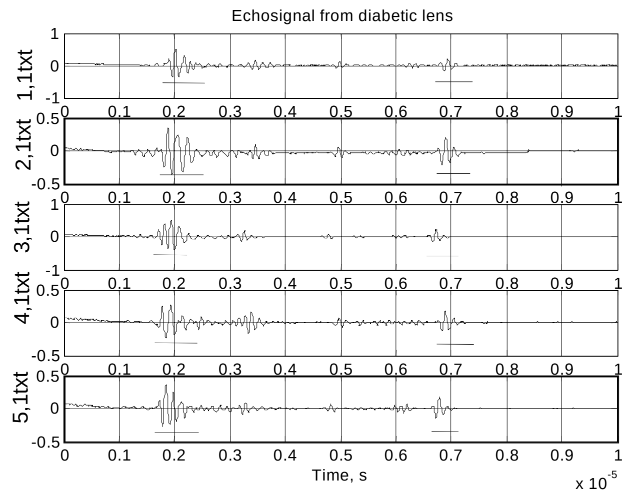

Fig.1. **Waveforms of echo signals received from anterior and posterior interfaces of cataract lens**

The assumption that the attenuation frequency function is linear $\alpha(f)=\beta\cdot f$ has been made. The attenuation coefficient β has been calculated from logarithmic spectra difference, taking into account spectra of echo signal from anterior $S_{AN}(f)$ (Fig. 2) and posterior $S_{PN}(f)$ (Fig. 3) nucleus interfaces, distance between interfaces d and frequency range f_2-f_1. To the frequency function of logarithmic spectrum difference $S_{AN}(f)$-$S_{PN}(f)$ least-squares straight line fit $\alpha_L(f)$ was applied. Finally the attenuation coefficient β was calculated as follows: $\beta=[\alpha_L(f_2)-\ \alpha_L(f_1)]/[2d\cdot\ (f_2-f_1)]$ (Fig. 4)

Thickness of the diabetic nucleus investigated was assessed taking into account the first zero-crossing instant in echo signals and the sound velocity in cataract lens c=1620 m/s [4; 5]. Echo-signals from anterior and posterior interfaces of lens nucleus where selected manually with the constant time window length of 1.024μs.

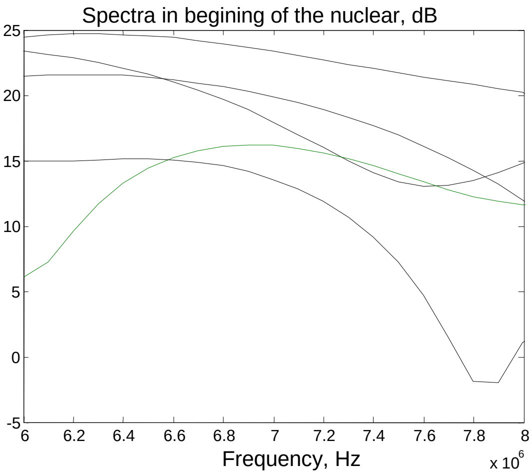

Fig. 2. **Spectra in the beginning of the diabetic lens $S_{AN}(f)$**

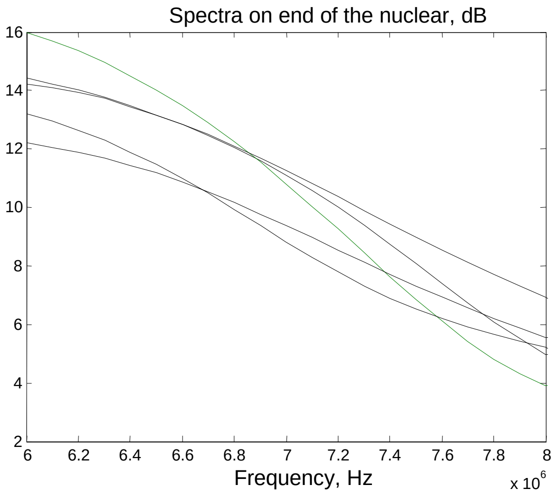

Fig.3. **Spectra in the end of the diabetic lens $S_{PN}(f)$**

Results

The thickness of lenses and the attenuation coefficient β were calculated for all patients in 3 groups using measurement method described above. We found that mean thickness of lenses is almost the same in all diabetics groups and it changes between 2,5 mm and 5,1 mm. In Fig.5 the results of mean thickness measurements in different diabetics groups are presented. The least mean

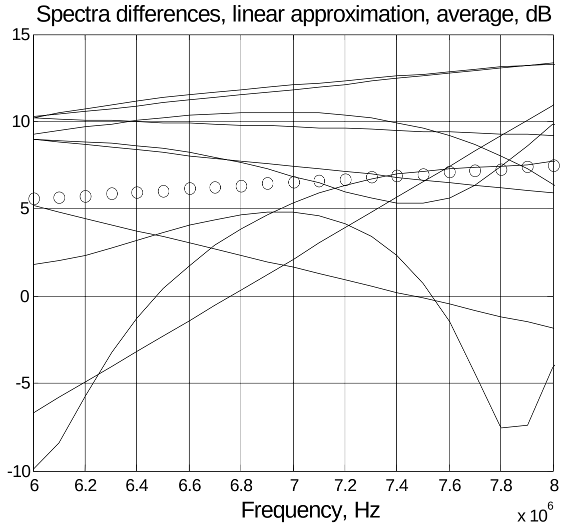

Fig.4. **Spectra differences, linear approximation and average, dB**

lens thickness of 3,57 mm was found in patients group with type I diabetics with hemophthalmus. The mean lenses thickness of 4,35 mm and 4,15 mm were found in groups with type I and type II diabetics without hemophthalmus respectively.

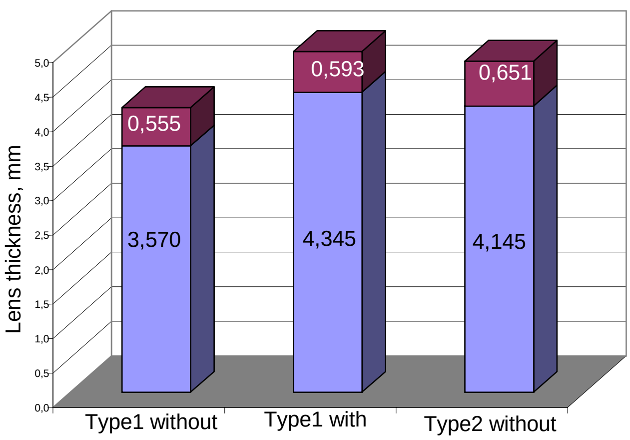

Fig.5. **Mean lens thickness distribution in three diabetics groups**

The ultrasound attenuation coefficients in all diabetics groups were measured as well. Distribution of the attenuation coefficients β in all three groups is presented in Fig. 6. There are shown that the ultrasound attenuation coefficient is higher in the group with II-nd type diabetic cataracts, where β changes between 5,7 dB/(cm MHz) and 15,7 dB/(cm MHz). The smallest attenuation coefficient β is observed in I-st type diabetics with hemophthalmus, in this case β = 2,27 - 7,6 dB/(cm MHz). The results of the mean ultrasound attenuation coefficient calculation are presented in Fig.7.

Results of the highest mean attenuation coefficient of 9,37 ± 3,40 dB/(cm MHz) was found in type II diabetics without hemophthalmus. Significantly lower mean values of attenuation coefficients have been found in other two cases - in type I diabetics without and with hemophthalmus – 5,82 ± 1,22 dB/(cm MHz) and 3,86 ± 1,89 dB/(cm MHz) respectively. According to these results we decided that hemophthalmus does not influence the lens ultrasound attenuation. We linked all type I diabetic cases (without and with hemophthalmus) into the same group – type I diabetics. After that the values of ultrasound attenuation

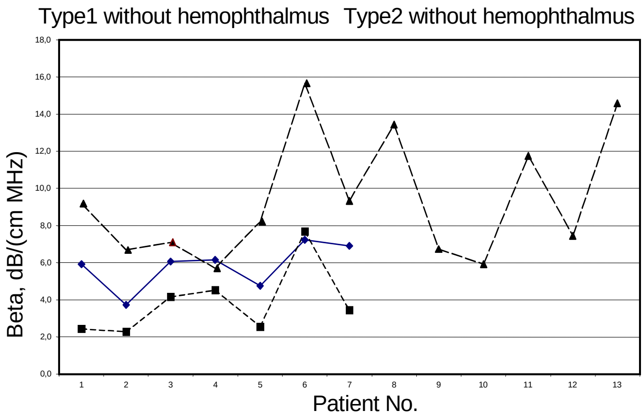

Fig.6. **Distribution of ultrasound attenuation coefficients in diabetics groups**

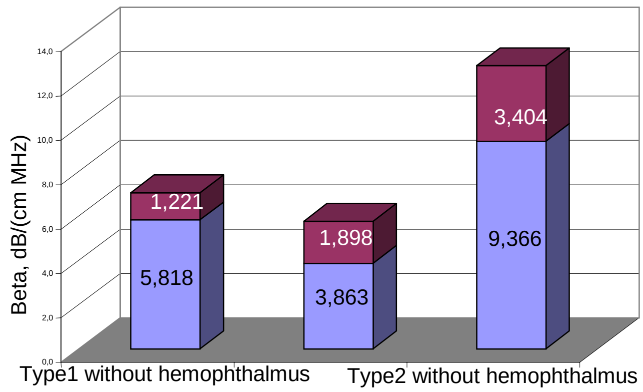

Fig.7. **The results of mean attenuation coefficients calculations in diabetics groups with different types of cataracts**

coefficients β for both groups (type I and type II) were calculated. These calculations are presented in Fig.8.

Significantly lower mean value of attenuation coefficient have been found in group with type I diabetics – 4,84 ± 1,84 dB/(cm MHz), compare with 9,37 ± 3,40 dB/(cm MHz) in group with type II diabetics. So we found that the ultrasound attenuation coefficient significantly is higher in the group of type II diabetic cataracts. It may be assumed that the alteration in the properties of crystalline, increased scattering and absorption of echo- signals are related to the decrease of lens transparency.

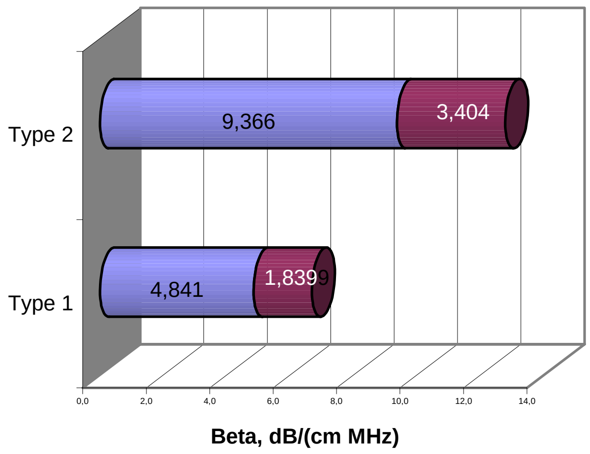

Fig.8. **The results of mean attenuation coefficient calculations in two groups with I type and II type diabetics**

Discussion

In 1985 there were about 30 million people with diabetes all around the world. In 1995 this number has roused until 135 million. The prognosis is that in 2025 will be 300 million of people, suffering from this disease. About a half of all type II diabetes cases are not diagnosed in most of countries.

According to the National register, there are about 400 of children and 3000 of adults with type I diabetes and about 30000 people suffer from type II diabetes in Lithuania. According to data of Medical Social Expertise Commission more than 10% of people with diabetes are already established as invalids, every year we have 700 new cases of invalidity due to diabetes, vision disorders develop in about 10% of diabetics. Each year about 10 patients suffering from diabetic cataract need cataract extraction, and about 300-350 patients suffering from diabetic retinopathy need vitrectomy. While checking the blood prophylacticaly, from 7 to 14.7 % of people are found too high glucose level. It seems that it is crucial to encourage healthy lifestyle and inform people about the danger of complications.

Improvements in the medical management of diabetes mellitus during the last 50 years have increased the life expectancy of a large number of diabetic patients. This increase has resulted in a significant rise in diabetic complications, including diabetic cataract and diabetic retinopathy. These complications are leading causes of visual dysfunction and blindness in patients with DM, and, therefore, for both diagnostic and therapeutic reasons, cataract extraction is recommended in these persons. About 10-15% of patients undergoing cataract surgery are diabetics, and this number is increasing [6].

Despite extensive research, the mechanisms responsible for diabetic cataract formation are still unknown. Although modern cataract extraction and IOL implantation have become a routine procedure with a low complication rate in senile cataract, the decision to remove the cataract in patients with diabetes involves many considerations. Cataract extraction in diabetic patients may lead to several complications during surgery as well as during the postoperative period. Proliferative retinopathy may develop rapidly after cataract surgery despite relatively short duration and acceptable metabolic control of diabetes. That's why the researches should work towards developing new strategies of rational drug design to prevent or delay cataract.

Conclusions

There is significant difference between ultrasound attenuation in lenses with type I and type II diabetic cataracts was found.

Hemophthalmus does not influence the lens ultrasound attenuation.

The analysis of the results suggests the possibility for investigating non-invasively diabetic cataract by measuring the ultrasound attenuation characteristics of the lens.

The value of ultrasound attenuation coefficient can be used for diabetic cataract differentiation.

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Ultragaro slopinimo koeficiento įvertinimas esant diabetinei kataraktai

Reziumė

Įvertinta diabetinės kataraktos subrendimo įtaka ultragarso slopinimui. Ištirti dvidešimt septyni diabetu sergančių žmonių lęšiukai. Pagal diabeto tipą jie buvo suskirstyti į I tipo (7 su hemoftalmu ir 7 be hemoftalmo) ir II tipo. Lęšiukas ištirtas ultragarso A sistema, naudojant 7 MHz dažnio jutiklį. Ultragarso slopinimo lęšiuko branduolyje koeficientas apskaičiuotas skaitmenizuotų ultragarso signalų spektrinės analizės būdu.

Nustatyta, kad ultragarso slopinimo koeficientas didesnis II tipo diabetinės kataraktos grupėje. Manoma, kad taip yra dėl to, kad II tipo diabetu sergančių žmonių lęšiuko drumstumą sąlygoja ne tik diabetiniai, bet ir senatviniai pakitimai.

Ultragarso slopinimo koeficiento įvertinimas padeda objektyviau išreikšti diabetinės kataraktos drumstumo laipsnį.

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