Calculation Specifics for The Customized Contact Lenses

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Abstract— ***This paper presents the theoretical and practical aspects regarding the design and manufacturing of the customized contact lenses based on a proposal for a customized contact lens with a non-circular shape. Are proposed an oval shape and an approximate trapezoid shape for which arises the idea to calculate a coverage percentage that allows a comparison between the contour shapes of the contact lenses with regard to the direct oxygen transmission degree to the cornea. Another approach regards the possible combinations of surfaces of the customized contact lens, the determination of the curvature radiuses or the equation of the surfaces, while attempting to follow the closest shape to the geometry of the cornea and also the minimization of the aberration of the optical transfer function. Is presented an oval shaped contact lens manufactured in a fast-cast type system during laboratory conditions.***

Index terms— **contact** ***lens, customized, elliptical, coverage factor.***

I. INTRODUCTION

Among the optical devices that serve to compensate the various anomalies of the eyeball, the contact lens has a special place, due to the peculiarity of the usage position with regard to the eye media. The contact lens is directly adapted on the cornea using the lachrymal film as a lubricant. The contact lens is a method to correct the spherical ametropia, the ocular astigmatism, can act as an eye bandage and last but not least, it is used for its aesthetic value. The contact lens has reduced dimensions, compared to the ones of the cornea, observes its topography and ensures, most of the times, a proper correction and a good wearing comfort. The customized term regards a rigid contact lens, of spherical or non-circular shape, which is manufactured based on the measurements for a certain cornea. The optics of the contact lenses is not much different than the one for other correction systems, they just include some additional requirements: Restriction of some degrees of freedom when designing the lenses due to the fact that the posterior surface must be in agreement with the corneal topography of the anterior part of the eye; -Restricted variation for the refractive index of the material. The refractive index of the material is determined by its biocompatibility properties at the expense of its optical properties. -Oxygen permeability of the material. -Water absorption. These general requirements are completed with specific requirements for the rigid lenses:

-Optimal design for maximum comfort.

-Wettable materials, resistant to surface deposits, dimensionally stable and easy to process.

The lens must ensure a good centering, uniform movement and a very smooth edge contact with the upper eyelid.-They must be comfortable, ensure maximum acuity, maximum wearing time, must avoid the mechanical damage to the eye and ensure a normal appearance for the anterior pole. -Reduced weight and center of gravity of the lens displaced toward the inside of the eye.

In this context is proposed the execution of lens surfaces as close as possible to the shape of the corneal surface and contour shapes that will determine the highest direct oxygenation of the cornea allowing the selection of materials with lower oxygen transmission but with superior optical qualities.

II. CALCULATION SPECIFICS FOR THE CUSTOMIZED CONTACT LENSES [1],[2],[3],[4],[5],[6]

The design of a contact lens requires the selection of a material with a refractive index, the determination of the geometry of the anterior surface and the posterior surface, determination or imposition of a center thickness and selection or determination of its contour profile. In figure 1 is presented the geometry of a customized contact lens.

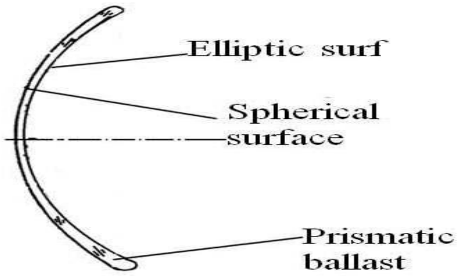

Fig. 1. Customized contact lens

For the material of the contact lens is selected the version with methyl methacrylate styrene copolymer (NAS). The tendency is to select refractive indexes with high values to obtain superior optical properties for the contact lens. This material, for the radiation of the maximum sensitivity of the human eye (555 nm) leads to a value of the refractive index n_{555}=1.56314. The variation curve of the refractive index was determined using the interpolation polynomial given by the Laurent series. The curve obtained is presented in figure 2.

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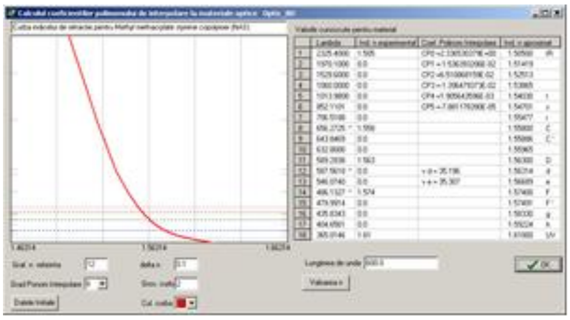

Fig. 2. Variation curve of the refractive index selected depending on the wavelength

II.1. Determination of the geometry of the posterior and anterior surfaces of the customized contact lens

Will be analyzed the most likely situations regarding the geometrical shape of the surfaces of the customized contact lens, as follows:

- Both surfaces as spherical diopters.
- Posterior surface elliptical and anterior surface spherical.
- Posterior surface as toric combined with a spherical or toric anterior surface.

II.1.1 Determination of the anterior surface of the contact lens for the hypothesis of the spherical corneal surface In the case when the cornea is spherical the radius of the posterior surface is imposed as equal to the radius of the anterior surface of the cornea of the human eye. For the determination of the anterior surface of the contact lens is proposed the applying of the theory of aberrations of optical systems. Specifically, was employed the optical transfer function (OTF), by its module, named the modulation transfer function (MTF).

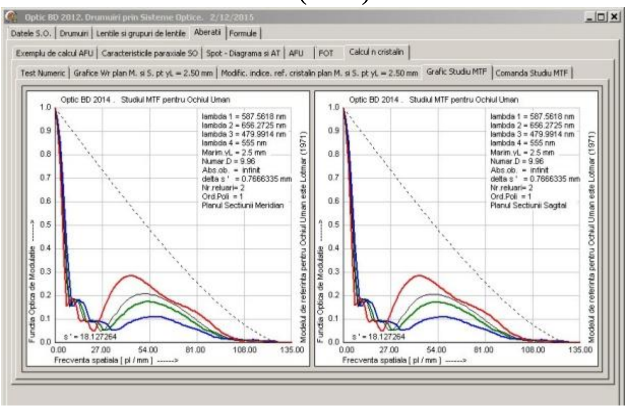

Fig 3. MTF curve for an ametropic eye with -2.0 diopters

The mathematical modeling is based on the Delphi 6 program in which was written the calculation software for the modulation transfer function (MTF). The MTF curve resulted for a myopic eye with 2 dpt. is presented in figure 3.The resulted contact lens must bring the MTF curves to the ideal value or as close as possible. To illustrate is selected a contact lens with the power of -2.00 dpt., corresponding to the correction of an ametropia with the refraction of -2.0 diopters. The central thickness of the contact lens is imposed as d = 0.15 mm. We will consider the thickness of the tear lens between the contact lens and the cornea as negligible. Is conducted a reversed paraxial tracing with the object abscissa as the retina of the human eye, as presented in table 1.

Table 1. Reverse paraxial tracing for the basic radiation having the object abscissa the retina of the human eye and the thickness of the contact lens as 0.15 mm

Tabel cu Drumuirea paraxiala inversa (5 .. 1) Abscisa obiect = -17.360651710000 mm

	Dioptrul 5	Dioptrul 4	Dioptrul 3	Dioptrul 2	Dioptrul 1
1. r	6.0000000	-10.2000000	-6.5000000	-7.8000000	
2. d	0.00000000	4.00000000	3.05000000	0.55000000	0.15000000
3. n	1.33606000	1.42007000	1.33746000	1.37716000	1.56314000
4. n'	1.42007000	1.33746000	1.37716000	1.56314000	1.00000000
5. s	-17.36065171	-26.55603660	-32.52540947	-29.70972259	-22.41776396
6. h	1.00000000	1.17733612	1.29916225	1.32366658	1.33258305
7. s'	-22.55603660	-29.47540947	-29.15972259	-22.26776396	

In table 1, for the last column, is not known the anterior radius of the contact lens, thus we cannot calculate the corresponding image abscissa. If we impose an infinite image abscissa, we can determine a formula which will generate the anterior radius of the contact lens.

$$s^{`} = \frac{-n^{`}}{\frac{n}{s}+\frac{n^{`}-n}{r}} \Rightarrow r = \frac{n^{`}-n}{-\frac{n^{`}}{s^{`}}-\frac{n}{s}} \qquad (1)$$

Thus is obtained the radius of the anterior diopter,

$$r = \frac{-(n'-n)s'}{n} = \frac{-(1-1.56314)\cdot(-22.41776396)}{1.56314} = 8.076\,mm \qquad (2)$$

The contact lens with the radii r_0=7.8 mm and anterior radius r=8.076 mm brings the image on the retina as presented in figure 4.

The influence of the spatial frequency on the contrast of the eye for the image formed on the retina, and for the 4 basic radiations, is presented in figure 3.

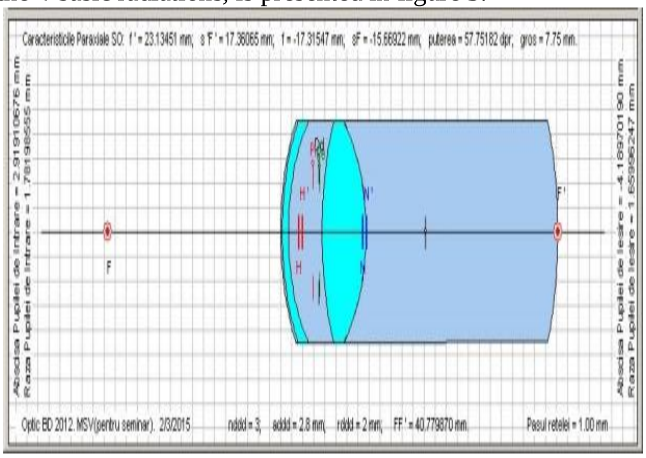

Fig.4. The eye corrected with the contact lens brings the image on the retina

Introducing the value of the anterior radius in the MTF analysis is obtained the correction of the myopic eye with ideal aberrations (figure 5).

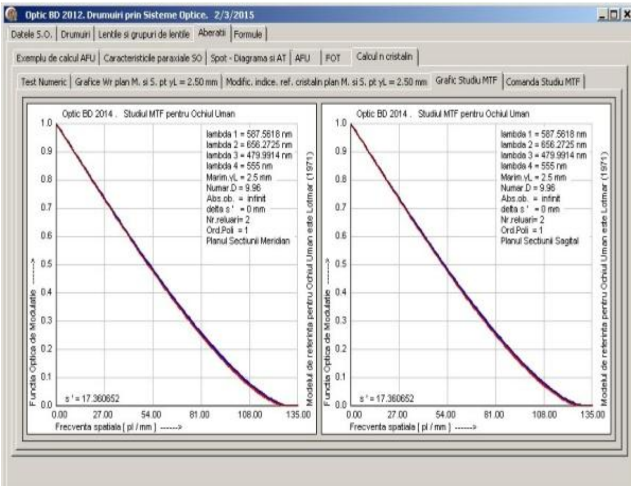

Fig.5. MTF function for a human eye corrected for a myopia of two diopters in the presence of a corrective lens with the thickness of 0.15 mm.

We can observe that the contact lens brings the contrast to the ideal value.

The shape of the customized spherical contact lens is presented in figure 6.

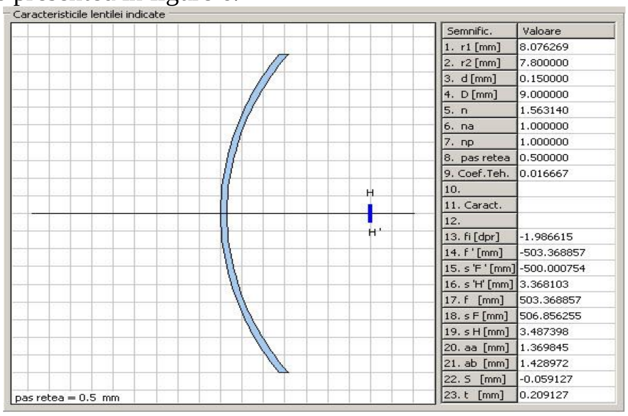

Fig.6. Shape of the contact lens with spherical surfaces -2.00 dpt.

II.1.2. Determination of the posterior surface for the elliptical shape hypothesis Equation of the ellipsis of the posterior surface of the contact lens:

$$y^2 = 2r_0 z - \left[1 - 4\left(1 - \frac{(r_h + r_v)^2}{(r_1 + r_2 + r_3 + r_4)^2}\right)\right] z^2 \qquad (3)$$

For the example we consider that the radius of the cornea in the center of the optical area is of r_0=7.80 mm and the eccentricity is $E_n = 0.50$.

The equation of the posterior surface of the contact lens, according to formula 3, in order to result a parallel adaptation, will be:

$$y^2 - 15\,z + 0.75z^2 = 0 \qquad (4)$$

For this example z=2 mm ***z*** (cornea arrow), and y=D_V /2= 4.275 mm. Results the shape of the posterior surface of the contact lens as shown in figure 7.

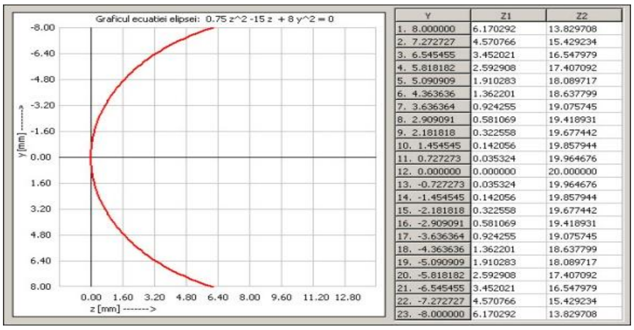

Fig. 7. Graphical representation of the ellipsis of the posterior surface of the contact lens

For the determination of the radius of the anterior diopter when the posterior surface is elliptical is analyzed, for the start, the influence of the tear lens. If we consider the thickness of the tear lens d_l=0.02 mm, between the contact lens and the cornea, we can obtain a parallel adaptation.

The parallel adaptation represents the situation when the radius of the anterior cornea surface is equal to the posterior central radius of the contact lens.

The power of the tear lens participates to the ocular correction with the power:

$$\Phi'_l = \varphi_{la} + \varphi_{lp} - d_l/n\ \varphi_{la} \cdot \varphi_{lp} = -\ d_l/n\ \varphi_{la} \cdot \varphi_{lp} \qquad (5)$$

Because $\varphi_{la} = \varphi_{lp}$=7.80 mm

$$\Phi'_l = \frac{0{,}00002}{1{,}336} \cdot \left(\frac{0{,}336}{0{,}0078}\right)^2 = 0{,}027 dpt$$

The value obtained for the chosen example is negligible, thus the influence of the power of the tear lens is also negligible. The determination of the anterior surface starts from the hypothesis that the optical area of the contact lens is of approximately 3 mm. In this area the elliptical posterior surface becomes the osculation circle of the respective ellipsis. The calculation involves the applying of the methodology proposed at 2.1.2.

II.1.3. Determination of the posterior surface for the toric diopters hypothesis

In the case of rigid lenses with spherical, elliptical surfaces, the regulated astigmatism of the optical area of the cornea is compensated by the tear lens.

The resulted corneal astigmatism is:

$$A = (n_l - 1) \cdot \left(\frac{1}{r_v} - \frac{1}{r_h}\right) \qquad (6)$$

Usually the corneal astigmatism has a value between 0.25 dpt. and 1.50 dpt.

We will show the phenomenon of the compensation of the corneal astigmatism by the tear lens by employing a practical example.

We assume a toric cornea that, in the optical area, in the horizontal section has a radius measured on the keratometer as r_h = 7.5 mm, and in the vertical section has a radius r_v = 7.3 mm. The refractive index for the cornea is n=1.336. In this situation, by applying formula 6, the corneal astigmatism has the value A=1.227 dpt.

To evaluate the effect generated by the tear lens we will calculate the astigmatic difference between its two sections.

If we employ a spherical posterior surface of the contact lens of 7.50 mm, the thickness of the tear lens d_l = 0.02 mm and the refractive index of the tears n = 1.336, are obtained the powers of the tear lenses in the two sections from the formula of the total power of a lens, as follows:

$$\Phi'_{lh} = \frac{0{,}336}{0{,}0075} + \frac{-0{,}336}{0{,}0075} + \frac{0{,}00002 \cdot (0{,}336)^2}{1{,}336 \cdot (0{,}0075)^2} = 0{,}035 \text{ dpt}$$

$$\Phi'_{lv} = \frac{0{,}336}{0{,}0075} + \frac{-0{,}336}{0{,}0073} + \frac{0{,}00002 \cdot (0{,}336)^2}{1{,}336 \cdot (0{,}0075)(0{,}0073)} = -1{,}196\,dpt$$

The astigmatic difference is equal with:

$$\grave{\Phi}_{lh} - \grave{\Phi}_{lv} = 1{,}237 dpt. \qquad (7)$$

The corneal astigmatism is equal with the astigmatic difference of the tear lens, thus it compensates the corneal astigmatism.

If the corneal astigmatism is higher, the problem of the stability of the lens on the cornea arises, and a ballast prism must be introduced.

If a crystalline lens astigmatism is also present, the tear lens cannot compensate it and we must employ a lens with a toric anterior surface.

For the calculation of the curvature radii of the lens in this case we will employ another practical example. Several prior assumptions are reinstated, with regard to the geometrical and optical parameters of the system contact lens - eye.

If we consider a residual astigmatism of +1.00 dpt in the horizontal section and the power of the lens in the vertical section $\grave{\Phi}_{lv} = -10.00 dpt.$ and in the horizontal section $\grave{\Phi}_{lh} = -9.00 dpt.$

The posterior surface of the contact lens can have the radius r_0 =0.0078 m and thus the power of this diopter will be:

$$\varphi_0 = \frac{1 - n_l}{r_0} = -\frac{0{,}56314}{0{,}0078} = -72{,}197 \text{dpt} \qquad (8)$$

The toric anterior surface will have the following vertical and horizontal radii:

$$r_{1v,h} = (n_l - 1)\left(\frac{1}{\Phi'_{lv,h} - \varphi_0} + \frac{d}{n_l}\right) \qquad (9)$$

For the considered example the calculated values are r_{lh}=8.964 mm and r_{lv}=9.06 mm.

The lens resulted in this situation presents a combination of surfaces, spherical posterior and toric anterior.

If a precise correction is desired in the case of mixed astigmatism (cornea and crystalline lens), the contact lens resulted from the perspective of the diopter surfaces will be bi-toric.

If the eye has the cornea with the geometrical characteristics from the prior example and a residual astigmatism of +1.50 dpt., the axis of the cylinder being oriented at 120°. In the section located at 30° from the horizontal the power of the cylinder is +1.50 dpt. The horizontal component of this astigmatism will be 1.5 cos 30° = 1.3 dpt. and the vertical component is 1.5 sin 30° = 0.75 dpt.

The powers of the lens in the horizontal and vertical sections:

$$\Phi'_h = -10 + 1{,}3 = -8{,}7 \text{ dpt}$$

$$r_{1h} = 0{,}5\left[\frac{1}{-8{,}7 + 6{,}25} + 0{,}0001\right] = 9{,}344 \text{ mm}$$

$$\Phi'_v = -12{,}8 + 0{,}75 = -12{,}05 \text{ dpt}$$

$$r_{1v} = 0{,}5\left[\frac{1}{-12{,}05 + 66{,}667} + 0{,}0001\right] = 9{,}205 \text{ mm}$$

II.2. Calculation of the weight of the contact lens

The weight is equal with the product between the volume of the body and its specific weight.

$$G = V \cdot \rho \qquad (10)$$

In the case of the lens with surfaces with axial symmetry (fig. 8) the calculation of the volume is made like in the following example:

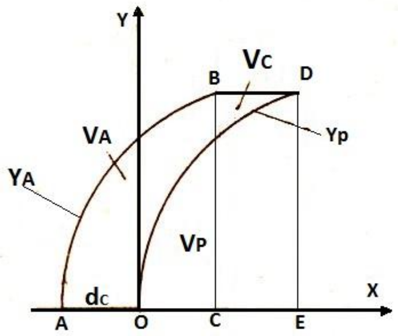

Fig. 8. Calculation diagram for the weight of the contact lens

$$V = V_a + V_c - V_p \qquad (11)$$

V_a – volume corresponding to the determined anterior face segment;

V_c – volume of the cylindrical section;

V_p – volume of the determined posterior face segment;

$$V = \int_r^d y^2 dx \qquad (12)$$

If the lens has elliptical surfaces the equation:

$$y^2 = 2px - gx^2 \qquad (13)$$

$$V = \pi\left[px^2 - \frac{1}{3}gx^3\right]_c^d \qquad (14)$$

$$g = 1 - \varepsilon^2 = \frac{b^2}{a^2} \qquad (15)$$

For the spherical surface:

$$y^2 = 2px - x^2 \qquad (16)$$

$$V = \pi\left[px^2 - \frac{1}{3}x^3\right]_c^d \qquad (17)$$

Example: $\Phi'_{S'}$ = –10 dpt,r_{10} = 9.6 mm,d_c = 0.15 mm ,r_{20}=8 mm, D=9.0 mm and ρ = 1.2 g/cm^3

For the face 1

For y_1 = 4.5 mm; x_1 = 1.12 mm

$$V = \pi\left[9{,}6 \cdot 1{,}12^2 - \frac{1}{3} \cdot 1{,}12^3\right] = 36{,}36 \text{ mm}^3$$

For the face 2

y_2 = 4.5 mm; x_2 = 1.3856 mm

$$V = \pi\left[8 \cdot 1{,}3856^2 - \frac{1}{3} \cdot 1{,}3856^3\right] = 45{,}47 \text{ mm}^3$$

For the cylindrical area

$x_2 + d_c - x_1 = 1.3856 + 0.15 - 1.12 = 0.4156$ mm

$V = \pi \cdot 4.5^2 \cdot 0.4156 = 26.4392$ mm^3

The resulted volume of the contact lens is:

$V = 36.36 + 26.44 - 45.47 = 17.33$ mm^3

$G = V \cdot \rho = 20.8$ mg.

II.3. Position of the center of mass of the contact length

For a homogenous body with a shape that allows a revolution axis, the position of the center of mass is computed with the formula:

$$x_s = \frac{\int_a^b \pi \cdot x\left(f_s^2 - f_i^2\right)dx}{\int_a^b \pi\left(f_s^2 - f_i^2\right)dx} \tag{18}$$

For the lens from figure 8 we obtain the relation:

$$x_s \cdot V = \pi\int_a^b x\left(f_x^2 - f_i^2\right) \cdot dx \tag{19}$$

Or, developing for the three distinct areas; the anterior surface, the cylindrical surface and the posterior surface:

$$x_s \cdot V = \pi\left[\int_{-dc}^{x_1-dc} xy_a^2 \cdot dx + \int_{x_1-dc}^{x_2} x \cdot \left(\frac{\Phi}{2}\right)^2 dx - \int_{o}^{x_2} xy_p^2 \cdot dx\right] \tag{20}$$

Example:

The lens with $\Phi'_{S'} = -10$ dpt, D = 9 mm, d_c = 0.15 mm, r_{aa} = 9.6 mm, r_o = 8 mm and ρ = 1.2 g/cm^3

For the anterior surface:

$$y_a^2 = 2p(x + d_c) - g(x + d_c)^2 = 2 \cdot 9{,}6(x + 0{,}15) - (x + 0{,}15)^2$$

For the spherical surface g = 1:

$$\mathrm{I}_{\text{ant}} = \int_{-dc}^{x_1-dc} xy_a^2 \cdot dx = \int_{-dc}^{x_1-dc} xy_a^2 \times \left[2 \cdot 9{,}6(x + d_c) - (x + d_c)^2\right] \cdot dx$$

$$\mathrm{I}_{\text{a}} = \left[(19{,}2 - 2d_c)\frac{1}{3}x^3 + \left(19{,}2d_c - d_c^2\right)\frac{1}{2}x^2 - \frac{1}{4}x^4\right]_{-dc}^{x-dc}$$

The abscissa x_1 corresponding to y = 4.5 is deduced from the equation of the first face.

$(x_1 + d_c)^2 - 19. (x_1 + d_c) + 4.52 = 0$

Results: $x_1 + d_c = 1.12$, $x_1 = 1.12 - 0.15 = 0.9$ mm

$$\mathrm{I}_{\text{a}} = \left[6{,}3\, x_1^3 + 1{,}42875\, x_1^2 - 0{,}25 x_1^4\right]_{-0{,}15}^{0{,}97} = 6{,}8620\, mm^4$$

For the spherical segment corresponding to the posterior surface of the lens with the equation:

$$y_p^2 = 16x - x^2$$

considering y = 4.5 mm, results x^2 = 1.3856

$$\mathrm{I}_p = \left[\frac{16}{3}x^3 - \frac{1}{4}x^4\right]_0^{1{,}3856} = 13{,}2662 mm^4$$

For the cylindrical area $y_c = \dfrac{D}{2} = 4{,}5mm$

$$\mathrm{I}_c = \int_{x_1-dc}^{x_2} y^2 \cdot dx = \left[\frac{1}{2}x^2 \cdot 4{,}5^2\right]_{0{,}97}^{1{,}3856} = 9{,}9122 mm^4$$

The abscissa of the center of mass of the lens x_s is deduced from the formula:

$$x_s \cdot V = \pi\left[\mathrm{I}_a + \mathrm{I}_c - \mathrm{I}_p\right] = \pi \cdot 3{,}508$$

$$x_s = \frac{\pi \cdot 3{,}508}{17{,}33} = 0{,}6359 \text{ mm}$$

II.4. The shape of the contour of the customized contact lens

The customized contact lens can have a circular or non-circular contour shape. This paper proposed for the customized lens a non-circular shape that can be oval or approximately trapezoidal. The shape resulted from the increase of the requirement for direct oxygenation of the cornea. The area of the oval shape, respectively the approximately trapezoidal shape, is smaller compared to the classic circular shape. The requirement for cornea oxygenation when wearing contact lenses and especially rigid lenses imposes the reduction of the coverage area contact lens - cornea. The oval shaped contact lens (figure 9.a) and the one with approximately trapezoidal shape (figure 9.b) determines a coverage coefficient that can be expressed by coefficient p.

Fig. 9.a Customized contact lens with oval shape

Fig. 9.b Customized contact lens with approximately trapezoidal shape

To assess the corneal oxygenation increase coefficient is required the involvement of a coverage coefficient of the human eye cornea by the contact lens. For the calculation of the coverage coefficient of the oval shaped contact lens is proposed the diagram from figure 10. The ratio of the areas determines the coverage coefficient of the human eye cornea

$$p = \frac{A_e}{A_c} = \frac{a}{b}100 \tag{21}$$

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Example: a= 6 mm, b=10 mm, results a coverage percentage of 60%. If 100% represents the coverage determined by a circular lens, this results in an increase in the direct oxygenation by 40%. The values of a, b can be selected to obtain an improvement of the uncovered cornea percentage. The same method can be used to calculate the coefficient p for the approximately trapezoidal shape.

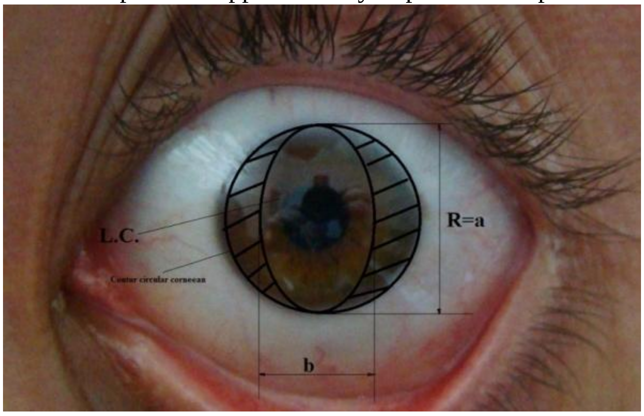

Fig. 10 Position of the contact lens with oval shape on the cornea

The contact lens was manufactured using a modern "fast-cast" type system. The "fast-cast" term refers to the fact that the manufacturing is conducted very quickly, in approximately 60 minutes. It is practically a gravitational casting in optical glass shapes followed by a polymerization with ultraviolet radiation at room temperature.

III. CONCLUSION

The most important geometric elements for the design of the customized contact lenses are: Posterior surface, diameter of the posterior optical area, anterior surface, thickness at the center, shape of the edge and the contour. The shape of the posterior surface influences the interaction with the cornea and affects, together with the weight and the geometrical center, the centering and movement of the lens when blinking. The elliptical posterior surface ensures a very good centering and a slow movement of the customized contact lens.

As for any other type of contact lens, in the case of the non-circular shaped lens we must contend with the problem of the stability of the lens on the surface of the cornea. The stability of the lens is ensured by the shape of the posterior surface and eventually a ballast prism in the lower part of the lens. The numerical eccentricity of the ellipsis of the posterior surface is another stability factor for the customized lens. The stability of the lens is also ensured by the surface tension resulted from the contact of the posterior surface of the contact lens with the tear layer that exists on the anterior surface of the cornea. A force balance must exist between the weight of the lens and the surface tension of the tear layer.

The combination of anterior-posterior surfaces can be: Spherical - spherical, spherical - toric, toric - toric, spherical - elliptic, toric - elliptic. In the case of astigmatism, if the compensation is made with contact lenses with toric surfaces, this ensured the maximum optical acuity and also a very good stability of the customized lens. The center of mass for the contact lenses with negative diopter powers is toward the cornea which gives an additional stability for the customized lens. This same aspect does not arise for the contact lenses with positive diopter power. From the perspective of the center of weight the lenses for myopic persons are the most recommended. The contact lenses show a lower deforming of the images for astigmatic persons than glasses. The eye entry pupil with the contact lens is higher than for myopic glasses and reversed for hypermetropic. The field of vision is higher with the contact lens compared with the prescription glasses, and is not modified by the contact lens. The wearing of contact lenses reduces the growth of ametropia in the progressive myopia.

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