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CONTACT LENS FOR ORTHOKERATOLOGY – SOLUTION FOR ENSURING VISUAL COMFORT

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Abstract: *The cornea deformation due to the keratoconus pathology has represented a real clinical challenge for specialists in the field of ophthalmology to find the best method to eliminate, minimize or just improve as much as possible the effects of this pathology on the visual function. That is why a series of solutions have been sought over time to be able to ensure visual comfort, good and long-lasting vision for these subjects/patients, using different investigative procedures and/or different intervention methods. One of these forms of vision improvement in the case of some subjects/patients with keratoconus forms or low/medium myopia is represented by the rigid contact lens for orthokeratology. In the first and second part of this paper, the general aspects related to the construction of the contact lens for orthokeratology are presented, as well as the theoretical foundation related to the behavior of the ortho-k lens in contact with the cornea, tear film assembly. The third part of the paper presents the analysis model of this assembly and the application of the methodology for ensuring visual comfort for a sample of subjects by using the ortho-k lens in cases of low and medium myopia. The final part of the paper presents the results of these experimental studies as well as the conclusions on the efficiency of using the ortho-k lens.*
Key words: *contact lens, ortho-k, myopia, thin plate, visual comfort.*

1. INTRODUCTION

The orthokeratology procedure is a treatment method for the visual system, known as Ortho-K. From the definition and namen point of view, Ortho refers to correction, straightening, and keratological refers to the cornea, especially to its frontal surface, so the method of correcting the corneal surface.

As shown in various specialized studies, the orthokeratology method was developed, starting in 1962, by George Jessen [1] who described for the first time the "orthofocus" technique applied in the procedure to reduce the level of myopia in different subjects /patients.

At first, he used a hard PMMA lens with a flat surface, and over time, he discovered that the cornea (after removing the hard contact lens) flattened, allowing vision to improve without any other aid. In the following period, the technique, renamed "orthokeratology", was developed and refined by many specialists who searched for the best solution to improve vision in myopia or keratoconus.

If at the beginning the use of the orthokertology lens allowed to obtain obvious results only after it was worn for about 3 years, with the passage of time and the development of new methods for determining the shape of the ortho-k contact lens, the results appeared after 18 months and even less (depending on the level of the refractive error and the age of the patient).

Another important aspect of the ortho-k lens wear at the beginning was obtaining approaches to stabilize and center the otherwise unstable ortho-k contact lens, which tended to achieve poor centering due to the base surface. plan from the central area.

The process of flattening the cornea was usually controlled by the progressive modification of the base curve of the lens, in small steps and respectively by the modification of the diameter of the optical zone and the peripheral curves.

On the other hand, this method of improving visual function includes a series of other steps such as corneal refractive therapy (CRT), vision modeling treatment (VST) and the special Euclid Emerald lens. [2]

Regardless of the name, Ortho-K is the procedure of using contact lenses to reshape the eye while the subject/patient is asleep.

The subsequent effect of this slight deformation is materialized by better vision for a day (in some cases even for two days), without wearing glasses or corrective contact lenses.

So, these contact lenses, otherwise custom designed for each individual subject / patient, for orthokeratology are worn overnight, reshaping the cornea, so that the vision is clear the next day, without the need for external optical aid (Figure 1).

This process is completely reversible and aims to reduce or eliminate forms of keratoconus, refractive errors such as myopia, presbyopia and astigmatism. [4]

Also, the ortho-k lens being customized and dimensionally adapted to the parameters of the eyeball on which it sits will allow its wear to be comfortable, without aggressions on the corneal surface and with beneficial effects on the quality of vision.

The essential differences between the ortho-k contact lens and the other contact lenses consist of two important aspects, as follows.

The first difference is that the ortho-k lens is a therapeutic lens (used only at night), and regular contact lenses are only corrective lenses to help improve vision (used during the day).

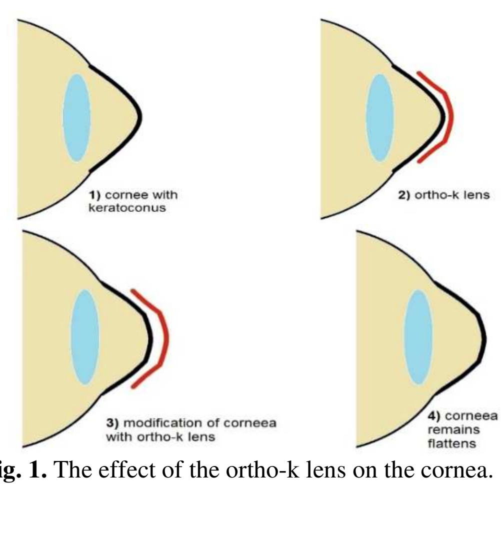


Fig. 1. The effect of the ortho-k lens on the cornea. [3]

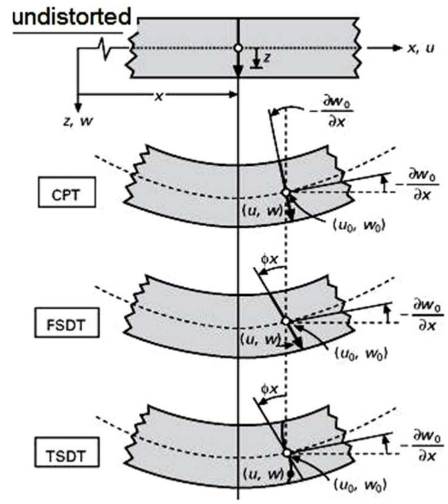


Fig. 2. Deformation of a typical transverse normal line in different beam theories [5].

The second difference is represented by the fact that the ortho-k contact lens is rigid and designed / calculated to "deform" the cornea corresponding to good vision, and the other contact lenses are soft and are perfectly adapted to the shape of the cornea's surface. An essential advantage of the ortho-k contact lens is that the subject/patient can enjoy (during the day) an activity without restrictions, can move and perform a series of actions without having to wear glasses or lenses of corrective contact, can perform different physical activities or live in areas with extreme weather conditions (dry, wet, hot, cold).

2. THEORETICAL FOUNDATION OF THE ASSEMBLY MADE BETWEEN THE CONTACT LENS AND THE EYEBALL

2.1 Theory of thin plates

Aspects related to the stratified structure of the cornea and its interaction with the rest of the components of the human eye, but also with the contact lens assembly, are studied using the theory of thin plates. Starting from the classical theory of thin plates (CPT), a theory that was developed, with the addition of first-order shear deformation theory (FSDT), reaching the theory of third-order shear deformation (TSDT).

$$u(x,y,z,t) = -z\frac{\partial w_0}{\partial x} \tag{1}$$

$$v(x,y,z,t) = -z\frac{\partial w_0}{\partial y} \quad (2)$$

$$w(x,y,z,t) = w_0(x,y,t) \quad (3)$$

The first and simplest theory, which is based on the following displacement field (Kirchhoff 1850) is represented by the set of equations of the displacement components along the coordinates *x, y* and *z*, respectively, of a point in the mean plane (i.e., z = 0) [5]. Where *u, v* and *w* are the components of the displacement along the *x, y* and *z* coordinates, respectively, of a point in the mean plane (i.e., z = 0).

The displacement field given by equations (1), (2), (3) is described using the Kirchhoff hypothesis which states that straight lines normal to the x-y plane before deformation remain straight and normal to the mid-surface after deformation (Figure 2).

The Kirchhoff hypothesis is equivalent to neglecting both transverse shear and transverse normal effects, i.e., the deformation is entirely due to in-plane bending and stretching respectively [5]. Subsequently, the plate theory was developed, which is based on the effect of transverse deformation formulated by Reissner (1944, 1945), Hencky (1947) and Mindlin (1951) [5].

This theory was called the first-order shear deformation theory (FSDT) and it is based on the displacement field given by the following relations (4-6):

$$u(x,y,z,t) = z\varphi_x(x,y,t) \quad (4)$$

$$v(x,y,z,t) = z\varphi_y(x,y,t) \quad (5)$$

$$w(x,y,z,t) = w_0(x,y,t) \quad (6)$$

where φ_x and φ_y are the rotations about the axes Ox and Oy.

The FSDT theory relaxes the normality restriction in the CPT theory by including in the kinematic assumptions a gross transverse shear strain, (i.e., the transverse shear strain is assumed to be constant with respect to the thickness z coordinate).

This constant shear strain, and therefore constant shear stress, does not fully respect the static boundary conditions relative to the free surfaces of the plate.

So that the FSDT theory requires, as the authors show, the "factorization" of transverse shear forces using correction factors that depend not only on the material and geometric parameters of the plate, but also on the loading conditions and on the imposed boundary conditions, too.

2.2. The tension states developed in thin curved plates that act to deform the corneal surface

At another level of studies on the theory of plates, the higher-order theory regarding shear deformation can be approached, namely the theory that eliminates the correction factors in the shearing process.

This theory of third-order shear deformation, as it is expressed in specialized works [5,6], is based on the following displacement field:

$$u(x,y,z,t) = z\varphi_x(x,y,t) - \frac{4z^3}{3h^2}\left(\varphi_x + \frac{\partial w_0}{\partial x}\right) \quad (7)$$

$$v(x,y,z,t) = z\varphi_y(x,y,t) - \frac{4z^3}{3h^2}\left(\varphi_y + \frac{\partial w_0}{\partial y}\right) \quad (8)$$

$$w(x,y,z,t) = w_0(x,y,t) \quad (9)$$

Using such an approach, shear correction operations will not be necessary in the case of using the TSDT theory. But in each plate element, five degrees of freedom must be defined: three translations and two rotations (Figure 3) and a series of other characteristics of curved plates, too [8]:

- They must be thin, i.e., the thickness of the plate must be small in relation to the dimensions established for the plate element.
- Force F can act in any direction between the direction perpendicular to the surface and the one that was in the surface.
- Moment loads M should act around an axis that is at the periphery of the element.

According to what was presented, for the study of the behavior of the ortho-k contact lens assembly and the cornea, the theory of thin plates charged with forces acting in a perpendicular direction both on the outer surface and on the one in contact with the cornea can be adopted and applied.

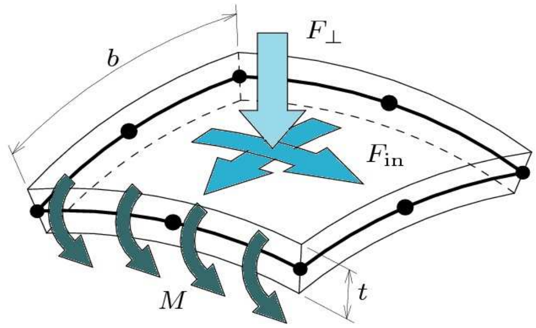


Fig. 3. Curved thin plate element assimilated to the shape of the cornea [7].

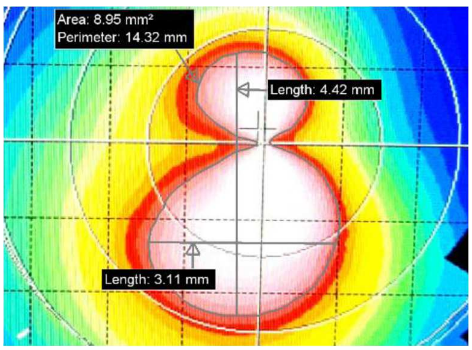


Fig. 4. Measurement of the keratoconus surface on the corneal topographic image of the left eye, subject 1A.

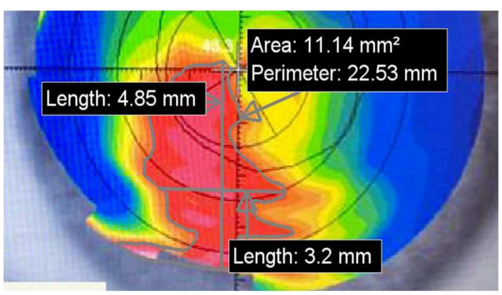


Fig. 5. Measurement of the keratoconus surface on the corneal topographic image of the left eye, subject 6A.

In addition, the effects of the flow of the tear film located at the interface between the hard lens and the cornea can induce superficial contact tensions that also participate in the changes in the curvature of the cornea.

All these aspects contribute to the deformation effect of the cornea through the ortho-k lens, thus forming an assembly of thin plates.

3. DIMENSIONAL DETERMINATIONS OF ORTHOKERATOLOGY MAPS

To be able to determine the profile of the ortho-k lens, it is necessary to obtain the topographical map of the cornea as precisely as possible and with as much data as possible regarding the refractive state of the entire eyeball. In this sense, the iProfiler Plus device provides all the necessary data for high-resolution wavefront measurement, respectively corneal topography [9-11].

On the other hand, it is necessary that the videokeratoscopy procedure obtained with the iProfiler Plus system be completed with dimensional measurements for the design of the contact lens, but also for the dimensional monitoring of corneal changes in terms of myopia control and respectively the monitoring of corneal changes because of wear the lenses.

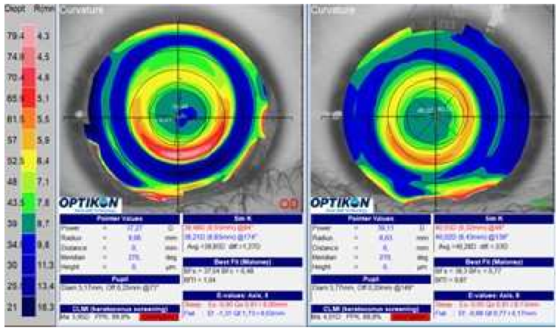
Thus, after identifying the deformation characteristics of the corneal surface, the ICMeasure software application is used to measure the various dimensions (areas of corneal deformation expansion, perimeters, lengths, atypical shapes).

In Figure 4 the case of subject no. 1A is exemplified, and in Figure 5 of subject no. 6A from the sample (A) of 6 subjects in which the dimensions of this dysfunction recorded by corneal topography were analyzed.

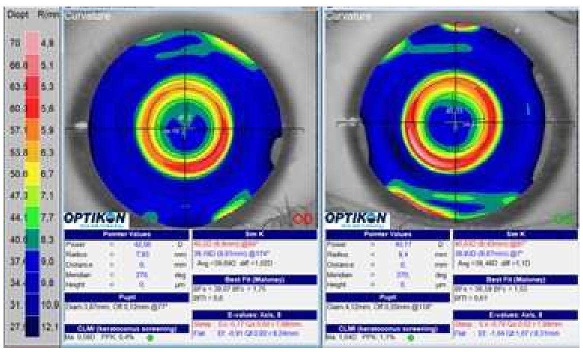
Furthermore, it was possible to identify and dimensionally evaluate different forms of keratoconus, dimensions necessary to establish the shape and construction of the ortho-k lens that will be customized to each individual patient. Also, to ensure visual comfort, especially in the case of correction of myopia-type refractive errors with this type of ortho-k lenses, the effect of poor hygiene and inflammatory pathologies that can reduce visual acuity is also monitored (Figure 6a-6c).

As a result, it can be observed in the case of a subject from the second analysis sample (B) (of 5 subjects) how the visual acuity changes over the course of a year and also how the cornea is affected by an allergic conjunctivitis (Figure 6b) during the period of wearing the lens ortho-k.

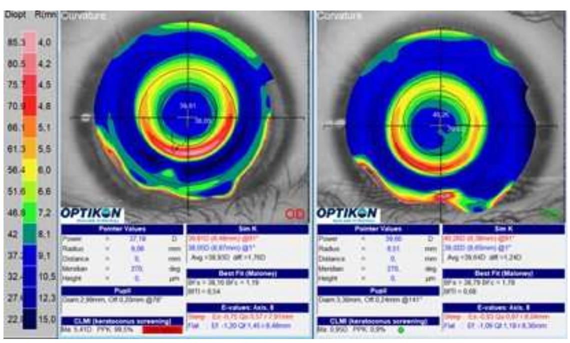
Therefore, the analysis of the effects of wearing the ortho-k lens for the correction of myopia or keratoconus to determine the visual comfort must be developed based on monitoring the visual function for long periods (1-2 years) and based on specific tests.



a) *First year, first month: VA OD 0.9, OS 0.9, Very loaded lenses*



b) *First year, six months: VA OD 0.9, OS 0.7 La OD 26.23 mm, OS 26.24 mm; Allergic conjunctivitis*



c) *First year, twelve months: VA OD 1.0, OS 0.9; La OD 26.25, OS 26.25; Loaded lenses*

Fig. 6. Evaluation of subject 2B with the help of iProfiler Plus to highlight the ortho-k lens correction of medium myopia with astigmatism with the following values: (OD –6.00DS/-1.25DC/180^0, OS –6.25DS/-0.50DC/5^0).

4. CONCLUSIONS

As shown in other studies regarding the determination of the methodology for improving the visual function [12-16], but also from the dimensional determinations of the orthokeratology maps, there are two important aspects that must be considered, namely the patients' motivation and the social role function of them.

The motivation for using ortho-k contact lenses is different from patient to patient in the case of the same pathology (personalization) but also different between those with keratoconus and those with myopia. Although these things seem totally different in a first analysis, the improvement of visual acuity may represent the most important quality obtained after applying the treatment in both situations.

In conclusion, it should be considered that although the same type of ortho-k contact lens procedure is applied, different groups of patients may be motivated by different factors and may experience different types of discomfort and relief depending on the type of disease.

In this sense, specialists must consider a series of factors such as: the type of pathology, the level of corrected vision, but also the subjective effects of the general quality of vision, the level of satisfaction, as well as the psychosocial perception among different patients. In addition, future studies will be developed in the university-industry collaboration context to adapt manufacturers market strategies to customers' needs [17, 18].

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Lentila de contact pentru ortokeratologie – soluție pentru asigurarea confortului vizual

Rezumat: Deformarea corneei datorată patologiei de keratoconus a reprezentat pentru specialiștii din domeniul oftalmologiei o adevarată provocare clinică pentru a găsi cea mai bună metodă de a elimina, minimiza sau doar de a ameliora într-o măsură cât mai mare efectele acestei patologii asupra funcției vizuale. De aceea, s-au căutat de-alungul timpului o serie de soluții pentru a putea asigura confortul vizual, o vedere bună și de durată pentru acești subiecți/pacienți, utilizând diferite proceduri de investigație sau/și diferite metode de intervenție. Una dintre aceste forme de îmbunătățire a vederii în cazul unor subiecți/pacienți ce prezintă forme de keratoconus sau miopie mică/medie o reprezintă lentila de contact rigida pentru ortokeratologie. În prima și a doua parte a acestei lucrări sunt prezentate aspectele generale legate de construcția lentilei de contact pentru ortokeratologie, cât și fundamentarea teoretică, legate de comportamentul lentilei de contact aflată în contact cu ansamblul cornee-film lacrimal. În partea a treia a lucrării este prezentat modelul de analiză a acestui ansamblu și aplicarea metodologiei de asigurare a confortului vizual pentru un eșantion de subiecți prin utilizarea lentilei ortho-k în cazuri de miopie mică și medie. În partea finală a lucrării sunt prezentate rezultatele acestor cercetări experimentale cât și concluziile asupra eficienței utilizării lentilei ortho-k.

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