Development of a Novel Mechanism for Early Stage Keratoconus Identification System (ESKIS)

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Abstract

In keratoconus (KC) disease, the collagen network structure in the eye is disrupted and shows relaxation in a certain area. This area, which has relaxation with the effect of intraocular pressure, is bombarded outwards, thus changes in the refractive power, visual quality and surface structure of the cornea. In this study, an experimental system was established to map the elasticity of the entire surface of the cornea, and software was prepared to receive and process the data. The developed system can apply force at desired points on the entire surface with its electromechanical structure and can measure the shape change. The results showed that; In the event that the experimental setup developed within the scope of the study is developed and used especially in safe use, it is possible to detect keratoconus disease at the initial stage with all surface scanning performed on the eye.

Keywords*:* Keratoconus, Eye, Mechatronic, Design.

I. INTRODUCTION

Keratoconus (KC), a non-inflammatory corneal disease that has a tendency to progress; It is a discomfort in the cornea that physically creates regional enlargement and deformity. As a result of this deformity, the cornea bends forward and takes a conical shape (see Figure 1). To express this situation, it takes its name from the combination of the words kerato (cornea) and conus (cone). As a result of this formal change and distortion in the cornea, the light that comes to the eye falls without focusing properly on the retina, resulting in decreased vision and deterioration (see Figure 2).

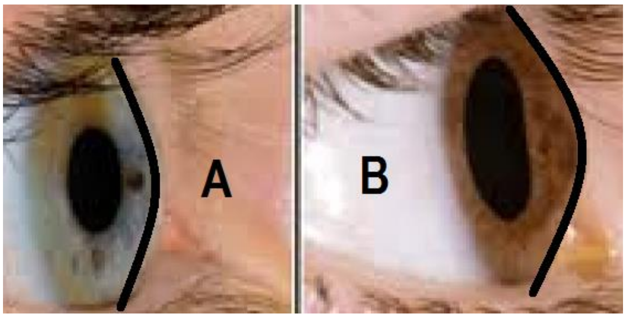

Figure 1: Healthy eye and eye with keratoconus A: healthy eye, B: eye with keratoconus.

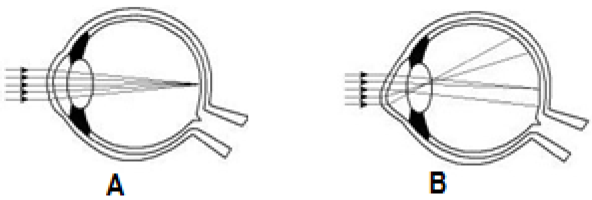

Figure 2: Light refraction in cCornea A: Healthy Eye, B: Eye with Keratoconus [1].

The reason for the occurrence of the disease is that the enzymes in the cornea show a change other than expected. As a result, the corneal tissue is weakened. Also, eye rubbing, incompatibility with contact lenses, chronic eye irritation and exposure to ultraviolet light from the sun, genetic predisposition, etc. causes are also effective parameters in the development of this disease. The incidence of KC disease was determined as 1/2000 and the distribution ratio of KC between men and women is equal [2,3]. Clinical findings have been very well defined after the disease has become evident due to the high incidence. In mild cases of keratoconus, the progress of the disease cannot be prevented with contact lenses and glasses, but current visual impairments can be overcome. As a treatment method; soft lenses are used initially. If not enough; Adequate vision can be achieved with hard, gas-permeable contact lenses. In some cases, both lenses are used together (See Figure 3) [4].

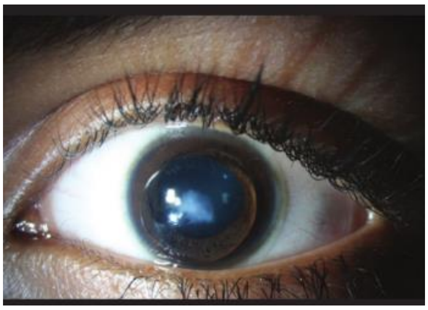

Figure 3: Contact lens for keratoconus [4].

However, in this option, the fact that the contact lens cannot be positioned on the cornea, which does not have a regular shape, creates problems in practical and clinical use. It is not possible to place the lens in the eye in patients with advanced keratoconus. In advanced cases; Invasive approach may be required in patients with contact lens intolerance and with problems such as lens placement on the eye. In the advanced cases, the most preferred treatment method up to the last decade is corneal transplantation, and other than this method, the method of wearing the ring in the cornea is one of the widespread surgical treatment methods. Corneal transplantation is not required if treatment is provided. With the application of cross-linking method in the age range (between 10-20 years old), which is the rapid progress stage of the disease, vitamin B2 is added to the cornea of the patient and the internal strength of the cornea tissue is increased by establishing cross bridges between the ultraviolet A light and the collagen molecules in the cornea (**See Figure 4**). If treatment is started at the appropriate time, the progression of keratoconus disease is stopped at success rates over 90 percent [5-8].

Figure 4: Crosslinking treatment for keratoconus.

In another method of treatment of keratoconus, intracorneal rings method (ICR), ICR is placed around the cornea, flattening is provided in the central cornea. It is a technique used in myopia and keratoconus and has advantages such as being recyclable, removable and replaceable, not touching the cornea central. However, it is expensive, surgical technique is difficult and it takes time to learn, it limits its usage area. This method is a safe and effective treatment option in keratoconus patients. In appropriate keratoconus patients, implantation of intrastromal ring segments can not only improve refraction and vision, but also delay or prevent corneal transplantation (See Figure 5) [9].

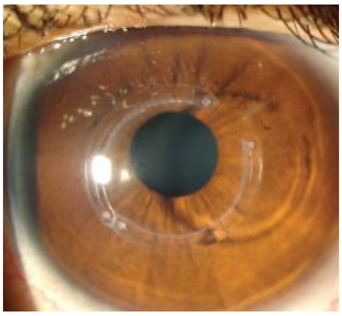

Figure 5: Intracorneal ring.

Treatment studies are carried out with different methods (see Figure 6).

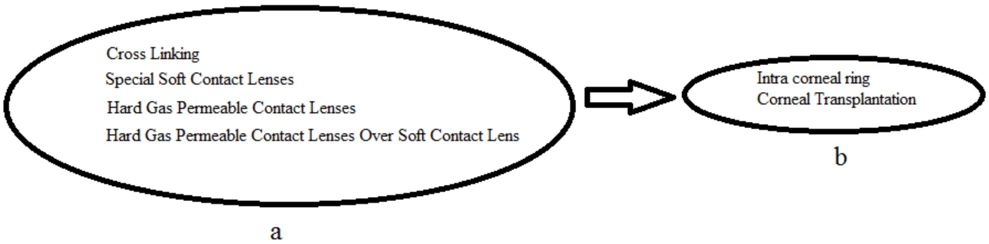

Figure 6: Keratoconus treatment methods a: Early and middle stage, b: Advanced stage.

However, regardless of the method of treatment, the expected realization rate of the result obtained from the treatment is quite low if it is not detected at an early stage. Early forms of the disease can be detected by examining the anterior corneal topography and determining the changes in the early stage. Computerized video keratoscopy is an aid in early detection of keratoconus disease, follow-up of disease progression and contact lens application (See Figure 7) [10].

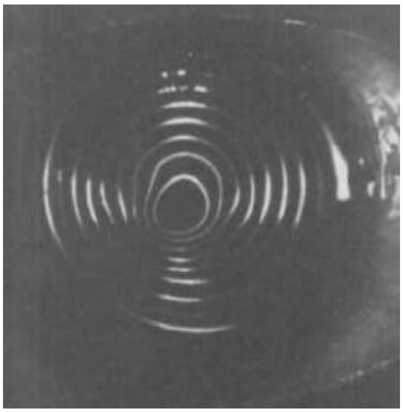

Figure 7: Photograph created by using computerized videokeratoscopy [10].

Current status and treatment methods show that; The most important thing in the treatment of keratoconus is the detection of the disease at an early stage. In this study, an experimental setup has been created in order to physically determine the enzymatic deterioration in the cornea that is the cause of KC disease. As it is known, in KC, differentiation occurs on the cornea as a result of enzymatic degradation in the cornea, and the region whose resistance decreases is bombarded outwards with the effect of intraocular pressure. The loss of resistance caused by enzymatic deterioration is the main factor in the formation and progression of KC, and if this region is detected with the help of an electromechanical system, the keratoconus can be detected at the initial stage, when the region where the loss occurs. And, the treatment process can be carried out much earlier. The electromechanical system developed to adhere to this study target was examined experimentally, the results showed that the deterioration zone was detectable at an early stage. It has been determined that the experimental system can provide significant gains in early stage detection of KC, especially if it is equipped with fully reliable protection mechanisms at the stage of human experiments and the sensitivity of the system elements is further increased.

II. EXPERIMENTAL SYSTEM

The early stage keratoconus identification system (ESKIS) developed within the scope of the study is given in Figure 8.

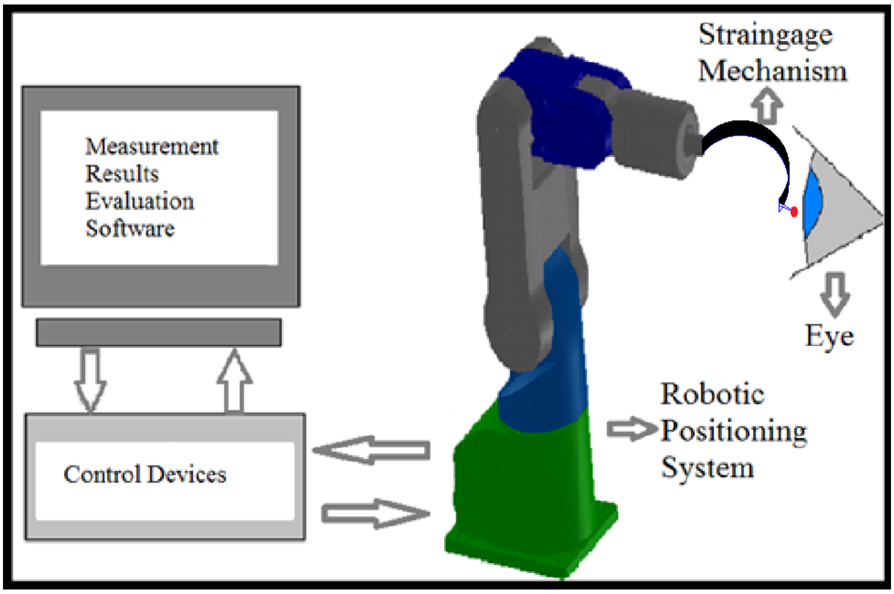

Figure 8: The early stage keratoconus identification system (ESKIS)

System elements of the ESKIS are;

1. Corneal Elasticity Measurement System (with straingage mechanism)
2. Robot
3. Control Devices
4. Measurement Results Evaluation Software

Mathematical Modelling of the Robot

One of the industrial micro robot types, repetition accuracy is ± 0.02 mm. Mitsubishi-RV2AJ series robot with 5 degrees of freedom was used as an experimental application motion platform in this study (**See Figure 9**). Robot limb lengths are given in Table 1. Robot axes working ranges are given in Table 2. Robot communication with the computer was made through the serial port.

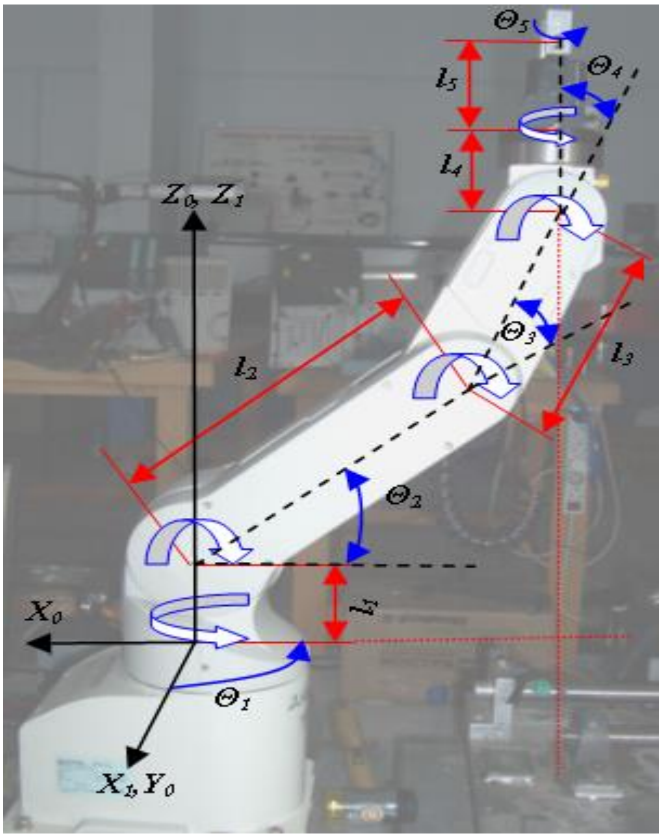

Figure 9: Link representation of Mitsubishi RV-2AJ robot

Table 1. Link dimensions of Mitsubishi RV-2AJ robot.

Link	**Dimension (mm)**
Shoulder Shift	**0**
Upperarm	**250**
Forearm	**160**
Elbow Shift	**0**
Wrist Length	**72**

Table 2. Operation Ranges of Mitsubishi RV-2AJ robot.

Link	**Operation Ranges**
Waist rotation	-150˚ to +150˚ max. velocity 180˚/s)
Shoulder rotation	-60˚ to +120˚ (max. velocity 90˚/s)
Elbow rotation	-110˚ to +120˚ (max. velocity 135˚/s)
Wrist pitch	-90˚ to +90˚ (max. velocity 180˚/s)
Wrist roll.	-200˚ to +200˚ (max. velocity 210˚/s)

Kinematics of robot manipulator

Using the geometric data given in Figure 9, the position of the robot finisher is calculated as follows;

$$x_0 = [a_1 + l_2 \cos\theta_2 + l_3 \cos\theta_{23} + (l_4 + l_5)\cos\theta_{234}]\sin\theta_1$$
$$y_0 = [a_1 + l_2 \cos\theta_2 + l_3 \cos\theta_{23} + (l_4 + l_5)\cos\theta_{234}]\cos\theta_1$$
$$z_0 = l_1 + l_2 \sin\theta_2 + l_3 \sin\theta_{23} + (l_4 + l_5)\sin\theta_{234} \quad (1)$$

where [$\theta_{23}= \theta_2+ \theta_3$, $\theta_{234}= \theta_2+ \theta_3+ \theta_4$], θ_{23} is the angle of the waist, θ_2 is the angle of the shoulder, θ_3 is the angle of the elbow, θ_4 is the angle of the wrist pitch, and θ_5 is the angle of the wrist roll. θ_{234} is the sum of θ_2, θ_3 and θ_4. The kinematic model of the robot is shown in Figure 10.

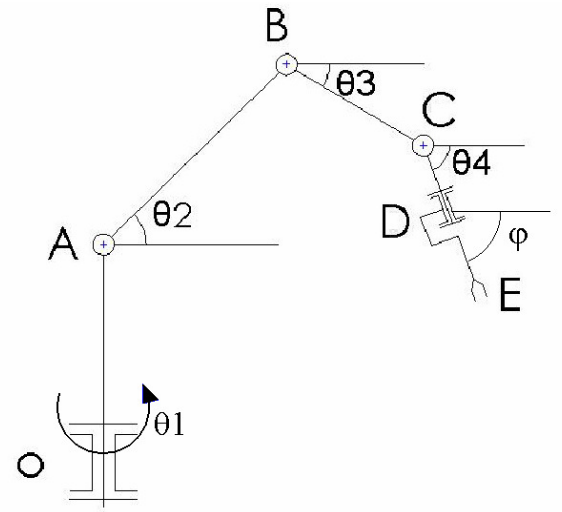

Figure 10: Kinematic model of Mitsubishi RV-2AJ

Corneal Elasticity Measurement system

The experimental system developed within the scope of ESKIS is given in Figure 11.

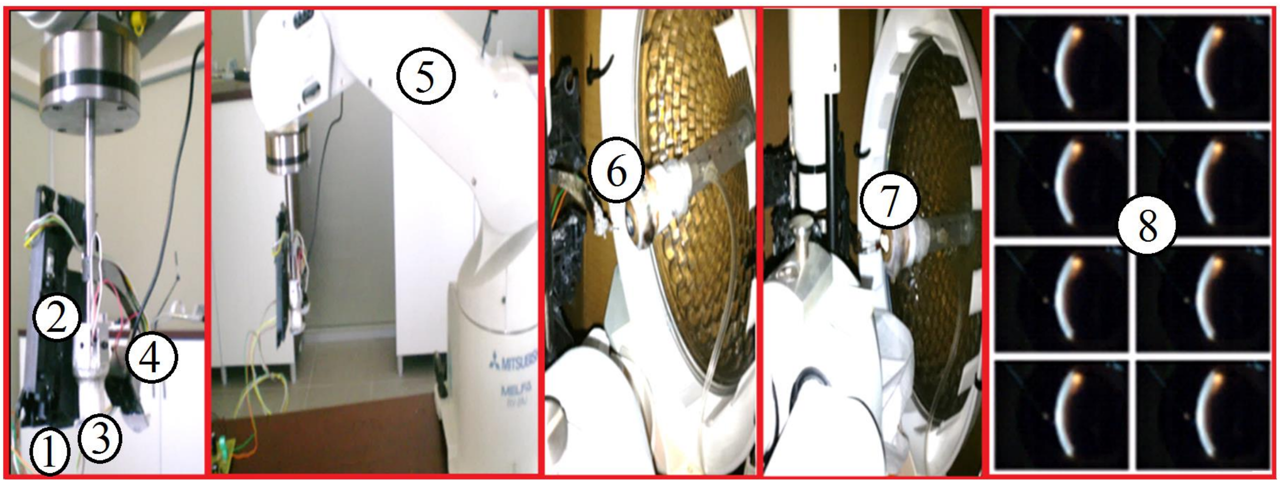

Figure 11: Mechatronic structure of corneal elasticity measurement system.

System elements;

1. Strain Gage mechanism
2. Servo system for movement of strain gage mechanism (for applying the desired amount of force on the cornea)
3. Section light source
4. High definition camera
5. Robot
6. Sheep eye and fixing apparatus
7. Cornea shape measurement and image acquisition system under sectional light
8. Software for converting sectioned light corneal curve into position data.

The following results were achieved with the experimental system developed within the scope of the study;

1. Simultaneous movement and positioning on X, Y, Z axes with 3 freedoms,
2. Possibility to measure in different positions on the cornea,
3. Possibility of positioning the measurement system in a fully automatic system in line with the cornea, real-time image acquisition application,
4. Real-time measurement of the pressure force applied to the eye with Strain Gage system,
5. Possibility of obtaining the necessary images for the application of image processing and creating the cornea curve.

ESKIS working systematics with the strain gage developed in this study are given in Figure 12.

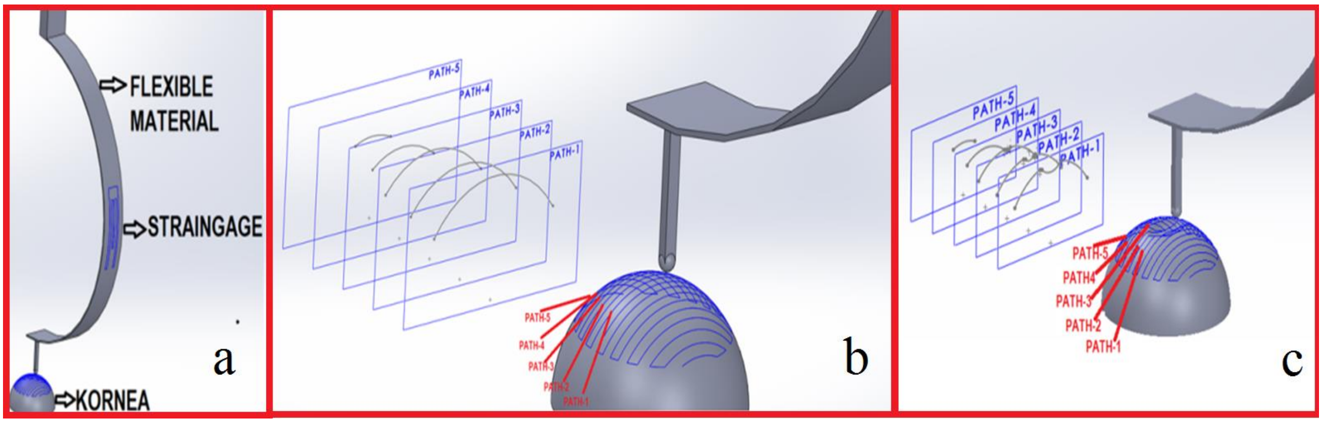

Figure 12: ESKIS measurement system a: measurement apparatus, b: Sample measurement for healty eye, c: measurement example of structural change in the eye.

Within the scope of the study, scanning curves on the cornea with small intervals are created using the mechatronic system. Despite applying the same force, different curves are obtained in keratoconus patients due to the difference in elasticity in the cornea. The different curves obtained consist of position data of the finisher (end point of the force measurement system) at the robot end. This position data enables the regions showing different elasticities to be modeled as 3D curves. As a result of the modeling of these 3D curves, the region with keratoconus can be detected before the deformation has occurred yet at the stage of biological change and when structural deterioration has begun.

III. Results

Cornea is one of the organs that the medical world has focused on most recently and is seeking solutions to their diseases. While the collagen texture of the cornea shows a certain resistance, there may be stretching or relaxation with some factors. The most affecting this resistance is its own collagen network structure and intraocular pressure. The aim of this study is; determining the elasticity of the cornea during routine checks and developing a system to map this elasticity. Thus, it is the detection of the disease at the initial stage and the provision of preventive and therapeutic health services. Early stage detection of keratoconus disease is possible provided that the experimental setup developed within the study is provided with a more sensitive and reliable mechanical structure.

IV. Acknowledgments

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