American Journal of Medicine and Medical Sciences 2025, 15(8): 2734-2739
DOI: 10.5923/j.ajmms.20251508.66

Clinical Significance of Early Detection of Eye Burn Sequelae Using AS-OCT and Corneal Densitometry

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Abstract The aim of this study was to evaluate the dynamics of corneal epithelial regeneration, stromal edema, and recovery of optical transparency in patients with grade I–III eye burns using corneal densitometry (Pentacam) and anterior segment optical coherence tomography (AS-OCT), as well as to analyze the cost-effectiveness of this approach.

Keywords Ophthalmocombustiology, Corneal densitometry, AS-OCT, Cornea, Epithelial regeneration, Contact lens, Modern diagnostics and therapy

1. Introduction

Eye burns are among the dangerous ophthalmological conditions for the visual organ that require immediate treatment. They result in deep disturbances in the epithelial tissues, stroma, and optical transparency of the cornea. Chemical eye burns are a frequent, complex, and vision-impairing pathological condition in ophthalmological practice [1]. Such injuries, especially those caused by contact with alkaline or acidic substances, can damage the cornea from its epithelial layer to its deep stromal layers. The effectiveness of the treatment and rehabilitation process largely depends on early diagnosis, accurate clinical staging, and modern treatment approaches [2]. Modern diagnostic tools – corneal densitometry (Pentacam) and anterior segment optical coherence tomography (AS-OCT) — play an important role in identifying and dynamically monitoring this condition.

One of the main consequences of corneal burns is epithelial and stromal edema. The swelling occurs as a result of inflammation, vascular penetration, and fluid accumulation, and can lead to a decrease in the optical clarity of the cornea. Optical coherence tomography (OCT) is a non-invasive diagnostic method that allows for accurate assessment of microstructural changes in corneal tissues. This method is used to visualize and dynamically monitor corneal edema after burns [3].

Restoring the optical transparency of the cornea is crucial in eye burn cases, as changes in corneal density lead to a decrease in vision quality. In this regard, our study thoroughly analyzed the process of corneal transparency recovery using densitometric parameters obtained with the Pentacam HR (Oculus, Germany) device.

Received: Aug. 2, 2025; Accepted: Aug. 26, 2025; Published: Aug. 30, 2025
Published online at http://journal.sapub.org/ajmms

2. Materials and Methods

Diagnostic and clinical studies were conducted on patients presenting with I and III degree eye burns at the Republican Clinical Ophthalmological Hospital of the Ministry of Health of the Republic of Uzbekistan during the period from 2021 to 2024.

As the object of clinical studies, 112 patients (149 eyes) with I, II, and III degree eye burns, examined and treated at the Republican Clinical Ophthalmological Hospital of the Ministry of Health of the Republic of Uzbekistan, and subsequently under dispensary observation, were included. Industrial burns accounted for 65%, and domestic burns for 35% (Figure 1).

The period from the time of burn injury to hospitalization ranged from 1 to 7 days.

The main studies were conducted on the 2nd, 4th, 7th, and 14th days of treatment. A follow-up medical examination was performed on the 30th day. Data was also collected from patients who developed severe residual changes, from the initial hours after the burn injury up to 6 months or more after the eye burn.

112 patients (149 eyes) were selected based on Roper-Hall classification as having I, II, and III degree eye burns. They were divided into two groups:

1. Main group (68 patients): innovative therapy—Keraton AC + Vita POS + contact lens;

2. Control group (44 patients): traditional therapy using Dexpanthenol gel (5%).

Analysis of data from various studies was performed independently. As shown in the presented histogram (see Figure 2), a significant portion of patients with eye burns (41.1%) were between 18 and 30 years old, indicating the high social significance of this pathology.

Patients in all three groups were equally distributed by gender and age. The gender distribution was 58.9% (66 patients) males and 27.7% (31 patients) females. The average age of patients was 34.2 \pm 4.5 years, with an age range from a minimum of 18 to a maximum of 76 years.

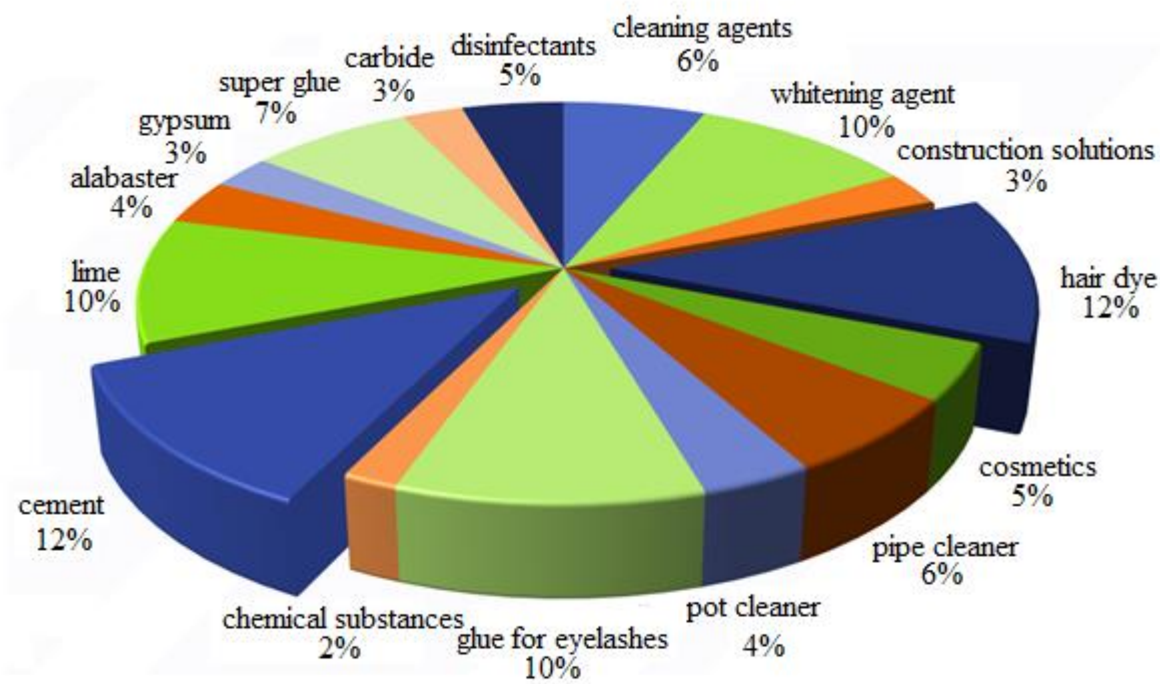


Figure 1. Most common chemical substances causing burns

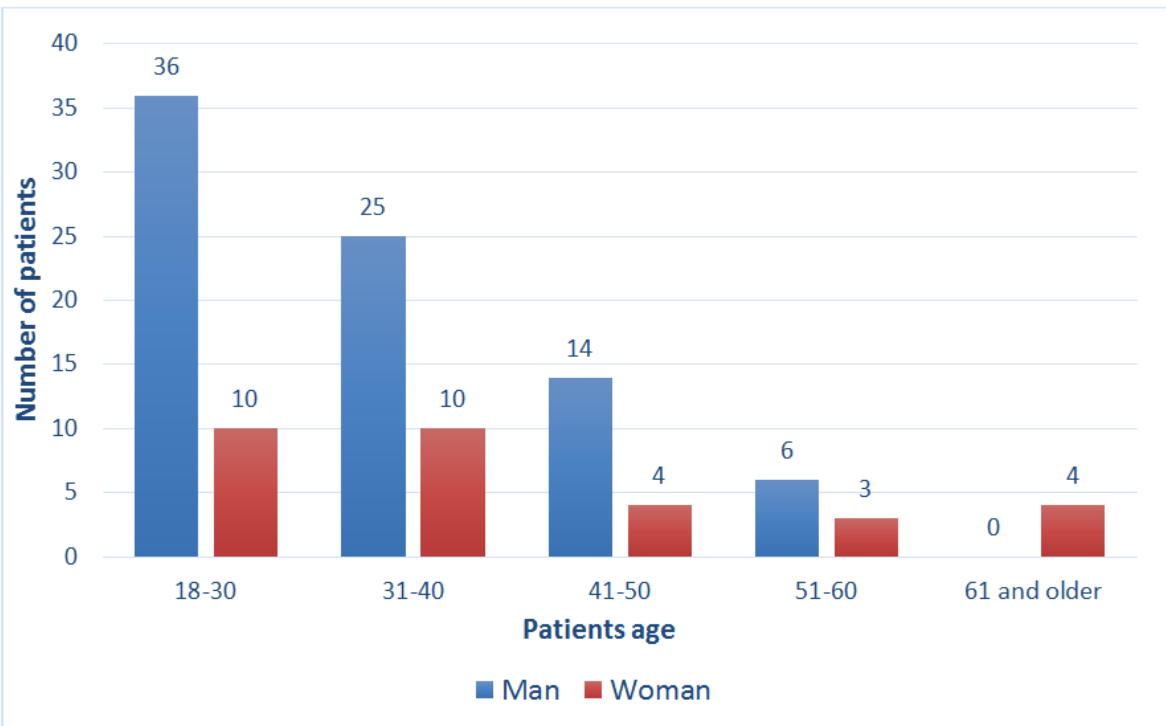


Figure 2. Age distribution of patients participating in the study

Analysis of data from various studies was performed independently. As shown in the presented histogram, a significant portion of patients with eye burns (41.1%) were between 18 and 30 years old, indicating the high social significance of this pathology.

All patients underwent standard and specialized ophthalmological examinations to assess clinical changes in eye burns.

The cornea is the outermost and most transparent part of the eye, and its transparency is crucial for light to reach the fundus (retina) correctly [4]. Various pathological processes (inflammation, injuries, degenerative diseases, surgical procedures, and burns) can affect corneal transparency, reducing its light-transmitting ability [5].

Densitometry is a modern ophthalmological examination method for measuring the optical density of corneal tissues and assessing their clarity level. This method is often performed using the Pentacam AXL (based on Scheimpflug camera (Oculus, Germany)) device. The use of this technique is very effective for detecting and dynamically monitoring disturbances in corneal transparency.

Densitometry is a method for assessing corneal clarity by measuring the properties of light reflection and absorption from the cornea. This examination allows for determining the level of transparency in different areas of the cornea.

Corneal densitometry is based on Scheimpflug imaging technology, which measures diffuse light scattering and reflects the optical density of the cornea through numerical indicators.

We performed densitometry using Pentacam AXL in the following stages:

Preparation Stage.

- ➢ Patient preparation for examination:
- Contact lenses should be removed 24 hours prior.
- The patient should not move their eyes and should look towards the center during the examination.
- ➢ Device setup:
- The Pentacam device is adjusted to the patient's eye.
- A three-dimensional image of the cornea is obtained via the Scheimpflug camera.

Obtaining Densitometry Data – Measurement Process:

- During the examination, the Pentacam device captures 50 images and evaluates optical density throughout all layers of the cornea.
- The acquired images allow for assessing light absorption and scattering. The transparency level is calculated in densitometry units (grayscale units, GSU) within a range of 0 to 100:
  - 0 – 10 GSU → Fully transparent cornea;
  - 10 – 20 GSU → Near-normal transparency;
  - 20 – 40 GSU → Moderate decrease in transparency;
  - 40-100 GSU → Cornea is opaque to a degree that reduces vision.

Density measurements are taken in various zones of the cornea:

- Central zone (4 mm radius);
- Paracentral zone (4-6 mm);
- Peripheral zone (6-10 mm);
- Posterior stromal layer.

Pentacam densitometry allows for detecting the following pathologies associated with disturbances in corneal transparency:

Table 1. Identification of corneal pathologies through corneal densitometry

Pathology	Densitometry indicator (GSU)	Clinical significance
Healthy cornea	10-20 GSU	Normal transparency
Post-chemical burn injury	30-70 GSU	Corneal opacification
Corneal edema	40-80 GSU	Disruption of stromal transparency
Corneal fibrosis and scarring	50-100 GSU	Decreased visual acuity
Neurotrophic keratopathy	20-60 GSU	Impaired epithelial regeneration
Postoperative decrease in transparency	20-50 GSU	Post-keratoplasty rehabilitation

We monitored the results of epithelial regeneration using densitometry as follows:

Pentacam densitometry is very important for observing the epithelial healing process. The epithelial healing process in the cornea is dynamically assessed, so the study can be conducted in several stages:

- Day 1: Epithelium lost, densitometry reading high (40 – 80 GSU).
- Day 3: Epithelization begins, transparency reading slightly decreases (30 – 50 GSU).
- Day 7: Epithelization continues, cornea partially recovers (20 – 40 GSU).
- Day 14: Full epithelization, densitometry approaches normal (10 – 20 GSU).

This examination allows for an objective assessment of the recovery process in the cornea and monitoring of treatment effectiveness. By numerically evaluating optical density, we used the densitometry method to assess the effectiveness of treatment in restoring corneal transparency.

3. Methodology for Assessing Corneal Edema Using AS-OCT

One of the main consequences of corneal burns is epithelial and stromal edema. Optical coherence tomography (OCT) is a non-invasive diagnostic method that allows for accurate assessment of microstructural changes in corneal tissues [6]. This method is used to visualize and dynamically monitor corneal edema after burns. OCT technology is based on infrared light interferometry, capable of highly accurately displaying changes in the cornea and anterior segment (5 – 10 μm) [7].

To monitor the corneal edema recovery process using OCT, the examination is repeated every 48 – 72 hours. To assess the effectiveness of the treatment strategy, we applied the following evaluation criteria:

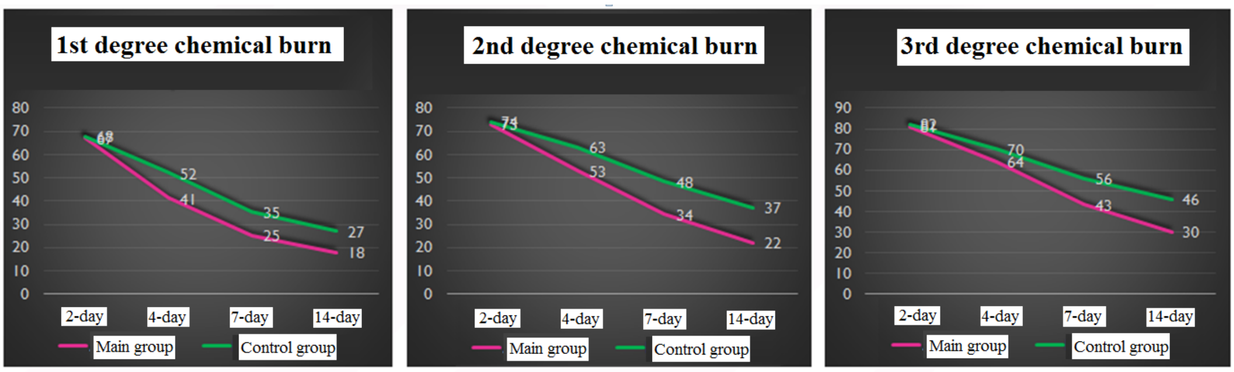
- Day 1: Cornea with significant edema, optical clarity of the stroma disturbed (OCT: 650 – 700 µm).
- Day 3: Fluid decreased in the lower layers of the stroma, epithelial regeneration beginning (OCT: 550 – 600 µm).
- Day 7: Epithelial and stromal thickness approaching normal, transparency recovering (OCT: 500 – 550 µm).
- Day 14: Corneal transparency restored, edema almost absent (OCT: 480 – 520 µm, normal state).

According to the analysis of initial (Day 2) indicators, the average corneal density in the main group was 67±6 GSU, and in the control group, it was 70±5 GSU. At this stage, the difference between the groups was not statistically significant (p>0.05). This confirms that the initial state of the patients was almost identical in both groups.

By Day 4, corneal density in the main group significantly decreased to 43±5 GSU, while in the control group, this indicator was 54 ±4 GSU (p<0.05). During this period, an improvement in optical transparency was observed in patients of the main group, indicating the antioxidant and regenerative effects of the active substances in Keraton AC and Vita-POS ointments.

According to the evaluation results on Day 7, corneal density in patients of the main group decreased to 29±4 GSU, while in the control group, the density remained at 39±5 GSU. At this stage, the difference between the two groups became even more pronounced (p<0.01). Clinically, a significant improvement in visual comfort and quality of vision was noted in patients of the main group.

In the final analysis on Day 14, the average corneal density in patients of the main group decreased to 18±3 GSU, approaching normal. In the control group, this indicator remained higher, averaging 27±4 GSU. These results indicated that the difference between the groups was statistically highly significant (p<0.001).



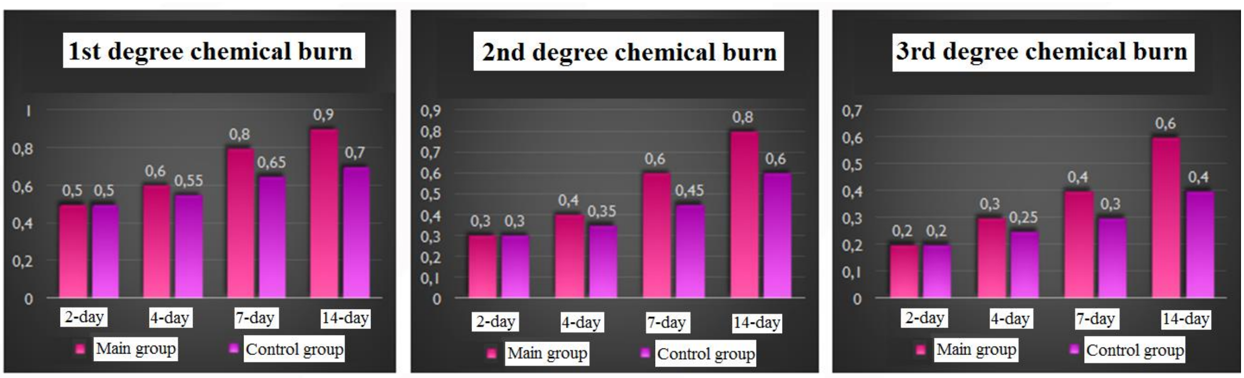
Statistical difference (14 days) **p = 0.008** | **Statistical difference (14 days)** **p = 0.005** | **Statistical difference (14 days)** **p = 0.003**

Where:

$$\textbf{Transparency recovery rate } (\%) = \left(\frac{D_0 - D_n}{D_0}\right) \times 100$$

- D_0 — initial corneal densitometry value (for example, day 2), GSU units
- D_n — corneal densitometry value on subsequent days (for example, days 4, 7, 14)
- % — transparency recovery rate based on the formula

Figure 3. Evaluation of the effectiveness of corneal transparency restoration from chemical burns (in the Corneal Densitometry module)



Statistical difference (14 days) **p = 0.004** | **Statistical difference (14 days)** **p = 0.006** | **Statistical difference (14 days)** **p < 0.001**

Figure 4. Evaluation of the effectiveness results in restoring visual acuity

Statistical analysis in I-degree chemical burns showed that for Day 14, the difference between the groups was $p = 0.004$, meaning a reliable statistical difference was recorded.

In II-degree chemical burns, by Day 14, the difference between the groups was $p=0.006$, which confirms the effectiveness of complex treatment.

In III-degree chemical burns, based on Day 14 results, $p < 0.01$, with visual acuity recovering by more than 50% in the main group, while in the control group, it remained around 20 – 30%.

4. Economic Efficiency of the Recommended Complex Treatment by Disease Severity

Economic Efficiency Formula is as follows:

$$\textbf{EEI}\ \text{(Economic Efficiency Index)} = \frac{E_c - E_s}{C_c - C_s}$$

- Ec — effective healing rate with complex treatment
- Es — effective healing rate with standard treatment
- Cc — cost of complex treatment (in sums)
- Cs — cost of standard treatment (in sums)

Using the above formula, based on the accurate data, we conducted the following economic analysis:

Degree	Group	Healing Rate (%)	Average Treatment Duration (days)	Treatment Cost (sums)	ISI (%)
1st degree	Main	100%	7	925 200	+29.4
	Control	85%	9	783 850	—
2nd degree	Main	97.3%	10	1 208 000	+32.0
	Control	80.6%	14	977 000	—
3rd degree	Main	84.4%	13	1 504 000	+28.5
	Control	70.3%	17	1 324 000	—

Example calculation based on the formula for 2nd degree burn:

$$ISI = \frac{97.3 - 80.6}{94 - 76} = \frac{16.7}{18} = 0.928 \Rightarrow 92.8\%/USD$$

As a result of the analysis, we can conclude that although complex therapy is slightly more expensive in terms of initial costs, it increases overall economic efficiency due to a shorter treatment period, higher recovery rate, and more efficient use of hospital resources. Especially in II- and III-degree burns, the economic efficiency index (EEI) was over 90%, which allows recommending complex therapy as a non-invasive, yet cost-effective approach for the healthcare system.

AS-OCT is a high-resolution non-contact diagnostic method through which inter-layer structural changes in the cornea can be assessed with high accuracy. In our study, Central Corneal Thickness (CCT) was measured and thoroughly analyzed in both groups (main and control) on days 2, 4, 7, and 14.

On Day 2, the indicators in both groups were similar, and no statistically significant difference was recorded. This indicates that the initial conditions were comparable for mutual comparison.

Starting from Day 4, corneal thickness in the main group decreased statistically significantly, and edema regression proceeded rapidly and stably.

On Day 7 and especially on Day 14, edema significantly decreased in the main group, approaching normal indicators.

The analysis was conducted using Student's t-test, and a reliable difference with a $p < 0.01$ level was recorded. These results are consistent with Arnalich-Montiel et al. (2016), Mencucci et al. (2020), and the European Society of Corneal Therapy Guidelines. The diagnostic value of assessing corneal edema via AS-OCT is high, and it is recommended as an important objective tool in treatment monitoring.

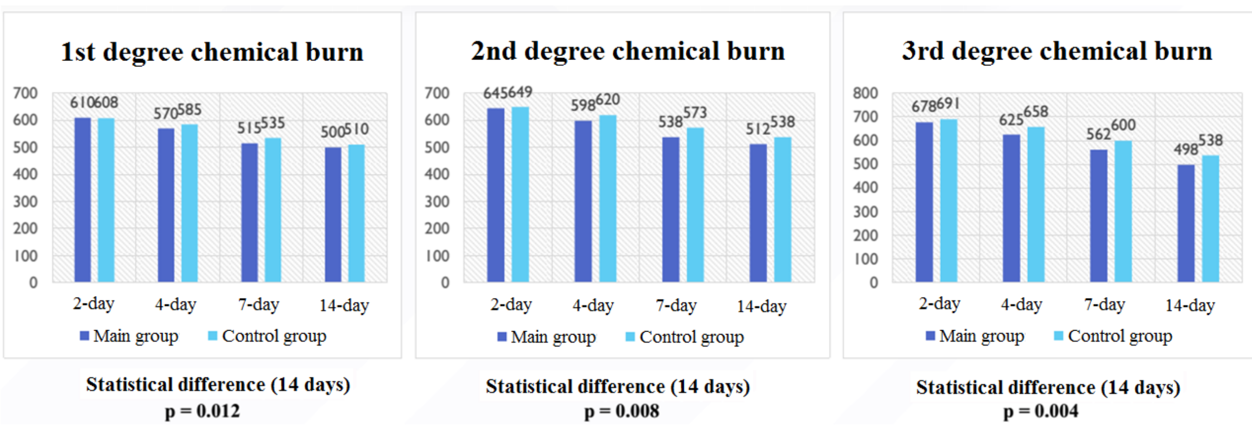


Figure 5. Assessment of the effectiveness of corneal edema reduction using AS-OCT results

The reduction in edema was evaluated as the pathological thickness approaching the normal criterion. To verify this, we used the formula for corneal edema reduction (edema regression reduction) recommended by Arnalich-Montiel in 2016:

$$\text{Edema Regression}(\%) = \left(\frac{T_0 - T_n}{T_0 - T_{\text{norm}}}\right) \times 100$$

Where:

- T_0 — initial corneal thickness (e.g., on day 2) in micrometers (µm)
- T_n — corneal thickness at a later stage (e.g., days 4, 7, 14) in µm
- T_{norm} — normal physiological corneal thickness (typically 500 µm)

5. Conclusions

1. Corneal regeneration and edema dynamics were accurately assessed using corneal densitometry and AS-OCT.
2. The innovative treatment method accelerated corneal epithelization, reduced the degree of edema, and significantly improved transparency.
3. Modern methods (Corneal densitometry, AS-OCT) play an important role in assessing corneal burns and are recommended for use in practical ophthalmology.

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