• Clinical Research •

Clinical application of a shape-preserving rapid corneal donor dehydrater

Yu Sun[1,2], *Xiao-Lin Qi*[2,3], *Xiao Lin*[4], *Xiao-Yu Zhang*[2], *Li Gao*[2], *Hua Gao*[2,3]

[1]Shandong First Medical University & Shandong Academy of Medical Sciences, Jinan 250117, Shandong Province, China
[2]Eye Hospital of Shandong First Medical University (Shandong Eye Hospital), Jinan 250021, Shandong Province, China
[3]State Key Laboratory Cultivation Base, Shandong Provincial Key Laboratory of Ophthalmology, Shandong Eye Institute, Shandong First Medical University & Shandong Academy of Medical Sciences, School of Ophthalmology, Shandong First Medical University, Jinan 250021, Shandong Province, China
[4]Eye Hospital Affiliated to Shandong University of Chinese Medicine, Jinan 250004, Shandong Province, China
Correspondence to: Hua Gao. Shandong Eye Hospital, 372 Jingsi Road, Jinan 250021, Shandong Province, China. hgao@sdfmu.edu.cn
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Abstract

● **AIM:** To describe the design and clinical application of a corneal donor dehydrator which can quickly dehydrate corneas and keep its original shape.

● **METHODS:** The corneal donor material is placed on stainless steel beads with different diameters in the dehydrating box to make the cornea the same shape as the steel ball. Then, the cornea is placed inside the dehydrater for rapid dehydrating using the internal cleaning and ventilation system. Totally 83 eyes underwent deep anterior lamellar keratoplasty (DALK) using corneal donor tissue preserved with corneal dehydrater, and 60 patients (60 eyes) received DALK by the same surgeon using corneal donor tissue preserved with glycerol were included in the control group. The best corrected visual acuity (BCVA), the thickness and transparency of the corneal buttons were recorded.

● **RESULTS:** After the completion of dehydrating, all the donor corneas maintained a normal shape without any shrinkage or distortion, and the average intraoperative rehydration time was 43.3±12.1s during operation. The mean BCVA of the dehydrater group was 0.30±0.18 at 1wk and 0.32±0.16 at 1mo, which were statistically better than that of the control group (P<0.001). The score of corneal buttons transparency were lower than that of the control group with statistical difference (P<0.001). The thickness of corneal buttons at 1wk and at 1mo in the dehydrater group was significantly better than that of the control group respectively (P<0.001). One week after operation, no corneal button turbidity or edema was observed in both groups.

● **CONCLUSION:** The dehydrater can quickly dehydrate the corneal material in a clean and airtight environment and maintain the original shape of the corneal donor during the dehydrating process. This dehydrater is recommended for long-term high-quality preservation in areas where corneal materials cannot be used within a reasonable time period.

● **KEYWORDS:** keratoplasty; corneal donor; dehydration; organ culture storage; eye bank

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INTRODUCTION

Corneal blindness has been reported as the second only to cataract in the leading causes of blindness, 10 million of the patients having bilateral corneal blindness[1-4]. Keratoplasty is the main method for the treatment of corneal blindness[3-7]. At present, corneal materials from donors are in short supply worldwide with the exception of a few countries, such as the United States and European countries. An estimated 12.7 million patients are placed on a long waiting list and the number is still growing[8-9]. Due to the paucity of trained keratoplasty surgeons and the shortage of cornea donors in some areas, cornea donations obtained cannot be used in reasonable time and efficiently[10].

Donor corneas cannot be preserved in Optisol corneal storage medium for more than two weeks[11-12]. To properly preserve donor corneas and avoid waste, dehydration treatment is often required for lamellar keratoplasty. At present, the main preservation methods of inactive corneal materials include glycerol preservation and dehydration preservation[13]. The most common disadvantage of glycerol preservation is that the glycerol molecules cannot be completely removed from the corneal donor after rehydration, thereby generating high water content and poor transparency of the corneal button[14].

In addition, postoperative complications, such as interlamellar effusion and double anterior chamber, easily occur. The traditional dehydrating preservation uses anhydrous calcium chloride, which exhibits strong water absorption and releases a considerably amount of heat in the process, which damages and deforms the cornea, thus limiting its clinical application. This paper introduces a new type of corneal dehydrater that can be used to quickly dehydrate and still maintain the shape of the cornea. Using this system, the cornea dries fast without wrinkling and deforming. This system solves the problem of high-quality preservation of corneal donor tissue and is a new method worthy of clinical application.

SUBJECTS AND METHODS

Ethical Approval This study was adhered to the tenets of the Declaration of Helsinki and approved by the Institutional Review Board of Shandong Eye Hospital, Jinan, China. ID:201904. All patients signed an informed consent approved by the Institutional Review Board.

Details of Corneal Dehydrater The corneal dehydrater that can be assembled quickly is made of high transparent plastic material. The box body is a vertical rectangular structure. The external size is 530×390×320 mm^3, and the specification is 45 liters. The system is composed of ultraviolet lamp tube, powerful silent circulating fan, color-changing silica gel, dustproof filter net, dehydrating box, and 304 steel balls (Figures 1 and 2).

The rated voltage of the power supply is 220 V, and the rated frequency is 50 Hz. There are two ultraviolet lamp tubes that are 4 W and 6 W, separately. The lamps are used to sterilize the inner space of the dehydrater and keep the air sterile. Rapid dehydrating of donor corneas is primarily achieved using color-changing silica gel and a strong silent circulating fan. A rechargeable hygroscopic card monitors air humidity and ensures the use of dehydrated air in the dehydrater. The specification of the strong silent circulating fan is 100 mm, the input power is 25 W, and the rated speed is 2800 r/min. The fan is used to circulate the air inside the dehydrater forcibly and then transmit the dry air to the dehydrating box through the circulating pipe (110 PVC pipe, after reducing diameter to 50). In addition, to ensure that the circulating air is free of impurities, the fan side of the circulation fan and the circulation pipe are equipped with a 3-mm thick dustproof screen.

The dehydrating box is a semienclosed space that is 170×110×9 mm^3 in size. The dehydrating box is provided with 8 positioning holes to hold stainless steel beads of different diameters (10-20 mm in diameter). During dehydrating, the corneal donor is placed on 304 steel balls of the same diameter as the cornea to maintain the normal shape of the cornea and solve the problem of corneal tissue shrinkage and deformation during dehydrating.

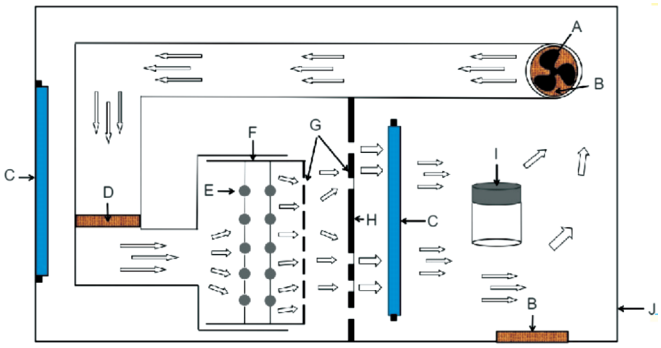

Figure 1 The schematic diagram of the dehydrater A: Circulating fan; B: Dustproof filter screen; C: Ultraviolet lamp tube; D: Dustproof filter screen; E: Positioning hole; F: Dehydrating box; G: Air vents; H: Fixed platform surface; I: Regenerative humidifier; J: Sealed working box.

Figure 2 The internal structure of dehydrater.

The process of rapid shaping and dehydrating of the corneal donor: The indoor temperature and humidity were adjusted to 22℃-23℃ and 48%-50%, respectively. First, the inner wall of the dehydrater was wiped with 75% alcohol, and then the ultraviolet lamp is turned on for 30min for disinfection. An agar plate was placed in the dehydrater for air detection. After the system was validated, the corneal donor was dehydrated. The corneal donor was removed using surgical forceps, and the endothelium was placed downward on 304 stainless steel beads that were the same diameter as the cornea. The cornea was leveled using surgical forceps. The strong silent circulation fan was turned on for dehydrating, and the dehydrating time is approximately 103±11min. After the completion of dehydrating, the cornea was transferred to a storage container and stored in a refrigerator at 4℃ after vacuum pumping (Figure 3).

Patients A consecutive series of 83 eyes (83 patients) underwent deep anterior lamellar keratoplasty (DALK) using corneal donor tissue preserved with corneal dehydrater (dehydrater group) for fungal keratitis at the Shandong Eye Hospital from January 1, 2019 to October 1, 2020. To compare the postoperative outcomes, 60 patients (60 eyes) who received DALK using corneal donor tissue preserved with glycerol

for fungal keratitis by the same surgeon were included in the control group (glycerol group).

All patients met the following inclusion criteria for surgery[15-16]: 1) clinically diagnosed as fungal keratitis confirmed by the presence of fungus in potassium hydroxide preparations, confocal microscopic images, or positive culture results; 2) antifungal medication as reported in our previous studies was given for at least 2wk but was ineffective; 3) slit-lamp examination and RTVue optical coherence tomography (Optovue; Fremont, CA, USA) scans displaying stromal layer pathological changes with fusion and diffuse opacity reaching more than 3/5 of the depth of the stroma but without reaching Descemet's membrane (DM)[17]; 4) a complete follow-up of at least 6mo.

Outcome Measures All patients were observed daily during the first week after surgery, weekly during the next 2mo, and monthly thereafter. The best corrected visual acuity (BCVA) and the thickness of the corneal buttons were evaluated at 1wk, 1, and 6mo after surgery. The transparency of corneal buttons were evaluated at 1d, 1wk, and 1mo.

The standard of postoperative corneal button transparency: 0: The corneal buttons is transparent; 1: Small superficial non-interstitial opacity, and the pupillary margin and iris vessels are visible through the corneal buttons; 2: Small, deep interstitial opacity with visible pupillary margin and iris vessels; 3: Moderate interstitial opacity, visible only at pupillary margin; 4: Large interstitial opacity with only part of the pupillary margin visible; 5: Very large interstitial opacity with no anterior chamber visible.

Statistical analyses were performed using SPSS 21.0 (SPSS, Chicago, Illinois, USA). The demographics between the two groups were compared with independent samples *t*-test and Chi-square analysis. The BCVA, transparency of corneal buttons, thickness of the corneal buttons and the time of epithelium completely healed were compared between the two groups using independent samples *t*-test. A *P* value of <0.05 was considered statistically significant.

RESULTS

Patient Information The dehydrater group was followed for an average of 8.5±2.0mo, whereas the control group was followed for an average of 8.3±1.7mo. The age, sex, and preoperative BCVA of the two groups of patients were comparable, and intergroup comparisons showed no significant differences.

The age, sex, and mean preoperative BCVA of the two groups of patients were comparable, and intergroup comparisons showed no significant differences (*P*>0.05; Table 1).

For the dehydrated corneal materials, the average dehydrating time was 103±11.2min. After the completion of dehydrating, all the donor corneas maintained a normal shape without any shrinkage or distortion, and the average intraoperative rehydration time was 43.3±12.1s during operation.

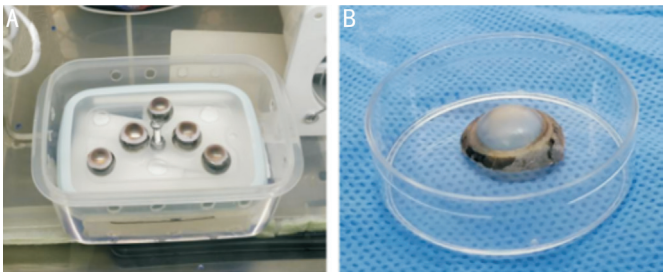

Figure 3 The process of dehydration A: The corneal materials are placed on 304 steel balls; B: The corneal material has been dehydrated.

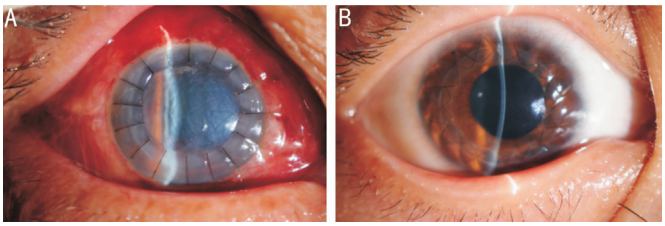

Figure 4 Comparison of postoperative effect A: There was interlaminar effusion after glycerol preservation; B: There was transparent corneal buttons by using the dehydrated corneal material.

Table 1 Preoperative comparisons of dehydrater group and glycerol group

Parameters	Dehydrater group	Glycerol group	*P*
Mean age, y	68.9±9.6	69.7±8.3	0.698[a]
Sex, female	43	27	0.498[b]
BCVA	0.07±0.08	0.08±0.06	0.853[a]

BCVA: Best corrected visual acuity; [a]Independent sample *t*-test; [b]Chi-square test.

All of the 143 corneal materials were used in DALK surgery[18], and all surgeries were performed by a single surgeon (Gao H).

Visual Acuity and Corneal Buttons The mean BCVA was 0.30±0.18 at 1wk and 0.32±0.16 at 1mo in the dehydrater group; these values were significantly better than those in the glycerol group, which were 0.14±0.09 and 0.23±0.09, respectively (*P*<0.001). However, no statistically significant difference was obtained at 6mo between the two groups in BCVA (Table 2).

The score of transparency of corneal buttons in dehydrater group was lower than that of the control group at 1d (1.3±0.8 *vs* 2.8±0.7) and 1wk (0.4±0.5 *vs* 2.0±0.4), which means postoperative corneal button transparency rate was higher in the dehydrater group, with statistical difference (*P*<0.001, Table 2). The epithelium completely healed at 3.3±0.6d after surgery (negative for fluorescein sodium staining; Figure 4).

After the surgery, the thickness of corneal buttons was 588±18 μm at 1wk and 544±41 μm at 1mo in the dehydrater group; these values were significantly better than those in the glycerol group, which were 654±30 and 585±49 μm, respectively (*P*<0.001). But no statistically significant difference was

Table 2 Postoperative comparisons of dehydrater group and glycerol group

Parameters	Dehydrater group	Glycerol group	*P*
BCVA			
1wk	0.30±0.18	0.14±0.09	<0.001
1mo	0.32±0.16	0.23±0.09	<0.001
6mo	0.31±0.18	0.30±0.17	0.724
Transparency of corneal buttons			
1d	1.3±0.8	2.8±0.7	<0.001
1wk	0.4±0.5	2.0±0.4	<0.001
Thickness of corneal buttons (μm)			
1wk	588±18	654±30	<0.001
1mo	544±41	585±49	<0.001
6mo	510±33	523±38	0.134

obtained at 6mo between the two groups (P>0.05). These values indicate that the corneal buttons were stable and reached the normal level after 6mo (Table 2).

Postoperative Complications The surgery was smooth and lacked implant bed microperforations, posterior elastic layer ruptures and other complications.

DISCUSSION

Keratoplasty is the main method used to restore vision in patients with corneal blindness[3,19-20]. At present, many developing countries, including China, lack corneal donors due to traditional, cultural, and religious reasons[21-22]. In addition to the shortage of corneal donors, there are some practical problems in clinic, such as patients waiting for donors and donors waiting for corneas[23-25]. The utilization rate of donor corneas cannot reach the ideal level, and some freshly corneal donors may not be immediately used in patients. This phenomenon aggravates the shortage of donors[9]. If a freshly corneal donor is discarded towards the end of the preservation period, donor resources will be wasted. If the cornea is dehydrated, it can be used for lamellar keratoplasty in the future. Therefore, a high-quality, long-term dehydrating and preservation method is helpful to make full use of the limited corneal donor resources.

Some problems are associated with traditional glycerol preservation and anhydrous calcium chloride dehydrating preservation, such as incomplete dehydration and donor shape changes after dehydration. These limitations prevent the clinical application of these methods. Compared with the traditional dehydrating and preservation methods, the dehydrater described in this study has two advantages: fast dehydrating and maintaining the original shape of the cornea. The rapid dehydrating of corneal donors is mainly dependent on the hydroscopicity of discolored silica gel and a strong silent circulation fan. Discoloration silica gel is a fine porous silica gel with high active adsorption capacity that is combined with cobalt chloride on the internal pore surface of silica gel using specific technological steps. The gel has a strong adsorption effect on water vapor in the medium and is nontoxic and harmless, odorless, and highly safe for clinical application. We placed the discolored silica gel at the bottom of the dehydrating box to directly absorb the volatile water from the donor corneas. In addition, the strong silent circulation fan continuously circulates the air in the dehydrating box, thus ensuring that the corneal donor dries quickly within 2h, avoiding donor pollution, autolysis and other problems caused by long-term separation.

To solve the problem of shrinkage and deformation of corneas during dehydrating, the second innovation we proposed involves dehydrating donor corneas on 304 stainless steel beads that are the same diameter. Positioning holes are located in the dehydrating box that hold stainless steel beads of different diameters. When dehydrating, the donor cornea is laid flat on the stainless-steel bead with the endothelium facing downward. Given that the cornea and the bead have the same diameters, the cornea completely fits the circumference of the steel ball, thus maintaining the normal shape of the donor cornea.

Based on the results, the dehydrater can efficiently dehydrate the corneal material and maintain the original shape. Cases of shrinkage and deformation were not observed. A significant improvement in the BCVA was noted with an average increase of more than two lines. In terms of the transparency of corneal buttons, the corneal buttons exhibited mild edema on the first day after DALK. The edema generally disappeared one week after operation. The epithelium healed quickly after the operation. In terms of the thickness of corneal buttons, the central thickness of corneal buttons was 588±18 μm 1wk after operation and 544±41 μm 1mo after operation. These results indicate that the corneal buttons were stable and reached the normal level.

In summary, the cornea dehydrater with rapid dehydrating and shaping quickly dehydrates the corneal donor, and significantly reduces early complications, such as interlamellar effusion and double anterior chamber after operation. It can also maintain the original shape of the cornea during the process of dehydrating. This dehydrater solves the problem of long term and high-quality preservation of corneal materials, and this new method is worthy of clinical application.

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Authors' contributions: Sun Y, Qi XL and Gao H was responsible for its design. Sun Y wrote the first draft of the manuscript. Lin X and Zhang XY participated in its design of manuscript. Zhang XY and Gao L helped revise of manuscript.

Sun Y and Lin X was involved in data collection and statistical analysis. All authors have read and approved the final manuscript.

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Conflicts of Interest: Sun Y, None; **Qi XL,** None; **Lin X,** None; **Zhang XY,** None; **Gao L,** None; **Gao H,** None.

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