Evaluation of New Prototype for Corneal Transportation in Eye Banking

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ABSTRACT

Purpose: To assess thermal control of a new prototype for transporting donor corneas and compare it to the traditional method.

Methods: The prototype, comprised of a Peltier effect cell, was compared to a polypropylene thermal box containing a vegetable cellulose-based refrigerant thermogel, preservative, and water wrapped in polyethylene rigid packaging. The required temperature for corneal transport (2°-8°C) was measured. Both methods were monitored four times for thermal stability based on temperature measurements every 30 minutes for 36 hours. The measurements were recorded and compared using a data logger.

Results: The mean latency period for reaching 8°C was 21.0 ± 1.4 minutes for the polypropylene thermal box and 19.0 ± 1.0 minutes for the prototype. The prototype had an average thermal stability of 2.6 ± 0.5ºC without a gradual temperature increase. In two of the four measurements, the assessed values were within the range of 2ºC to 8ºC. In the polypropylene box, the upper limit was exceeded after an average of 14.8 ± 4.0 hours (range, 10-19 hours) and the temperature increased was gradual and irreversible.

Conclusion: The prototype maintained the thermal stability within a recommended temperature range for 36 hours, which was superior to the results obtained with the polypropylene thermal box. The prototype may be more suitable for corneal transportation over long distances and internationally.

Keywords: corneal transplant, Peltier effect, thermal box, transport of the cornea, shipping containers

Successful transplantation of corneal tissue relies on tissue donation that is properly performed and controlled. The logistics consider several aspects: the family interview, tissue processing, evaluation of corneal quality, storage of donated corneas, and transport.[1-3] Among them, donor corneal transportation is currently of the greatest concern. The surgical techniques used to harvest and transplant, control corneal material, and storage are well established and performed safely, according to the standards and health regulations established by the Brazilian National Health Surveillance Agency (ANVISA).[3]

The concern regarding tissue transportation revolves around the fact that this is one of the only unscreened processes that the medical team does not control and that may impact the quality of the donor corneas.

According to ANVISA, tissue must be transported packaging suitable to maintain and preserve tissue quality as much as possible. The agency also stipulates that the ideal temperature range should be between 2°C and 8°C.[3,4]

To comply with these regulations, Brazilian eye banks usually use thermal boxes constructed of the polymers polypropylene and polyurethane to transport corneas. Containers with the reusable refrigerant Gelo-X (Termogel Inc., São Paulo, Brazil) are inside the thermal box. Monitoring the internal temperature usually is performed through an external thermometer attached to the lid (Fig. 1).

The current study evaluated a new prototype for transporting eye bank corneas based on the Peltier thermoelectric effect to determine if the proposed system maintains a more constant temperature interval over time and compared it to the traditional method of transportation.

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FIGURE 1. *Standard thermal box used in Sorocaba Eye Bank for corneal transportation. A: external view. B: internal view.*

METHODS

The insulated box used for corneal transportation by the Sorocaba Eye Bank, which is considered the gold standard (Fig. 1) and similar to those used in other eye banks in Brazil, was compared to the prototype.

Four containers with the Gelo-X coolant wrapped in rigid polyethylene packaging were placed in the box. A holder for transport and accommodation of one 20-ml vial of the Optisol GS preservative medium (Bausch & Lomb Inc., Rochester, NY) without a cornea, and a data logger also were included. The box then was sealed (Fig. 1A, B).

One study author (VRS) built the prototype at the COGNI Company of São José dos Campos, São Paulo, Brazil. The prototype, comprised of two simple expanded polystyrene boxes with a power source attached to the bottom, is based on the Peltier effect cell (Fig. 2A, B, C).

The Peltier cell, installed in the simple expanded polystyrene boxes cover, is a semiconductor junction that when subjected to electric current, undergoes temperature differences at both ends, i.e., while one end heats, the other cools.[5,6] The hot end is directed to the external environment; the cold end is directed to the internal environment of the prototype box. Therefore, for energy dissipation, air circulators were coupled on both internal and external radiators to aid in forced convection and a continuous cooling cycle was created.

The prototype has an embedded system that controls operation of the Peltier cell by a dedicated temperature algorithm that controls the range. When the prototype is turned on, the Peltier cell starts to cool its internal component. A 20-ml vial of the Optisol GS preservative medium was placed in the prototype.

To collect the temperature measurements, we used a data logger code 2c\temp(Marathon Products Inc., San Leandro, CA), an electronic device that registers the assessed data over time in relation to the temperature, when it was placed in the box. After the system was sealed, it was connected to an energy grid.

Cooling was monitored until a temperature from 2°C to 8°C was reached in the box, pre-programmed by the embedded system. The environment in which the insulated box and prototype were kept for measurements was subjected to a constant temperature of 20ºC.

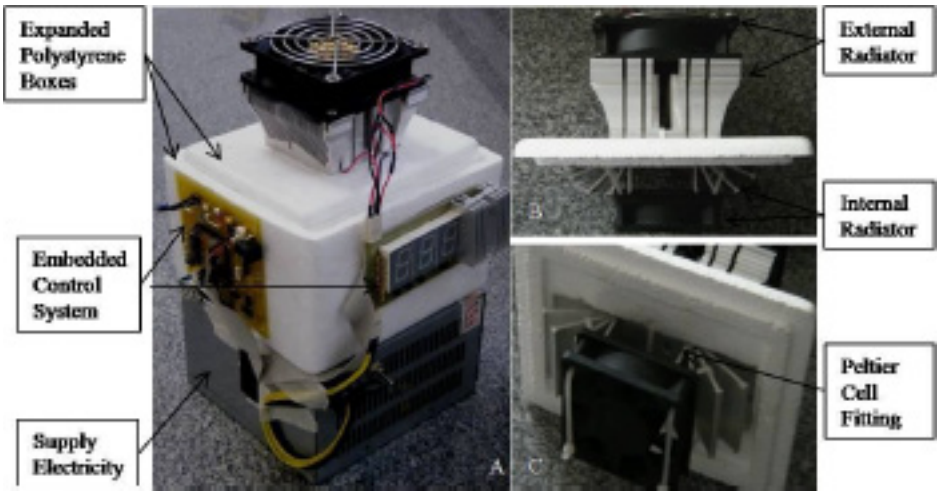

FIGURE 2. *Prototype box for corneal transport. A: external view; B: prototype cover; C: Peltier cell fitting.*

After the beginning of the cooling process, the latency time was evaluated (in minutes) to obtain the required temperature for corneal storage (2°C-8°C).

Both methods were monitored four times for thermal stability by temperature measurements every 30 minutes for 36 hours.

The measurements were recorded individually through the data logger and compared between the two methods. The recorded data were read and converted into graphs with software Marathon Data Analysis Software (MDAS-PRO, Marathon Products Inc.).

To supply electricity to the prototype, the original rechargeable and portable batteries were replaced by an electrical source converted to facilitate the tests.

RESULTS

The time lag for obtaining a temperature of 8°C was 21.0 minutes for the thermal polypropylene box and 19.0 minutes for the prototype.

The results of the four different thermal stability monitoring measurements of the two systems throughout the 36-hour period, ignoring the latency periods of the two methods, are shown in Figs. 3 and 4, respectively. The prototype had an average thermal stability of 2.6 ± 0.5°C and did not show a gradual temperature increase over 36 hours (Fig. 3).

In the polypropylene box, the upper limit of 8°C was exceeded after an average of 14.8 ± 4.0 hours (range, 10-19 hours); the temperature increase was gradual and irreversible (Fig. 4).

A comparison of the average thermal stability between the two methods is shown in Fig. 5.

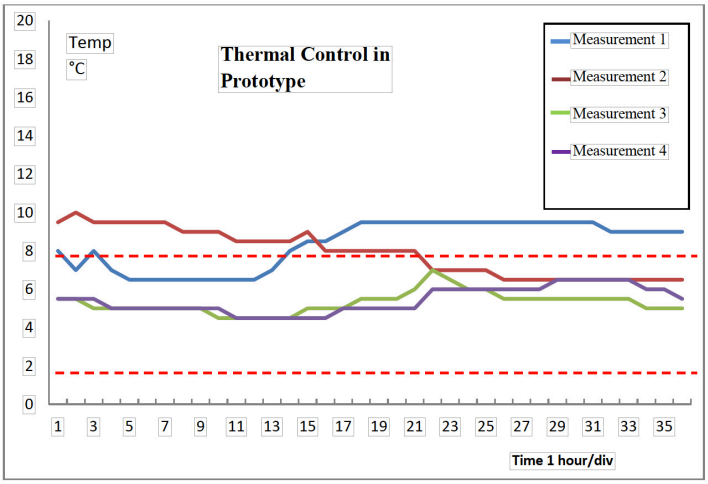

***FIGURE 3**. Thermal control in prototype.*

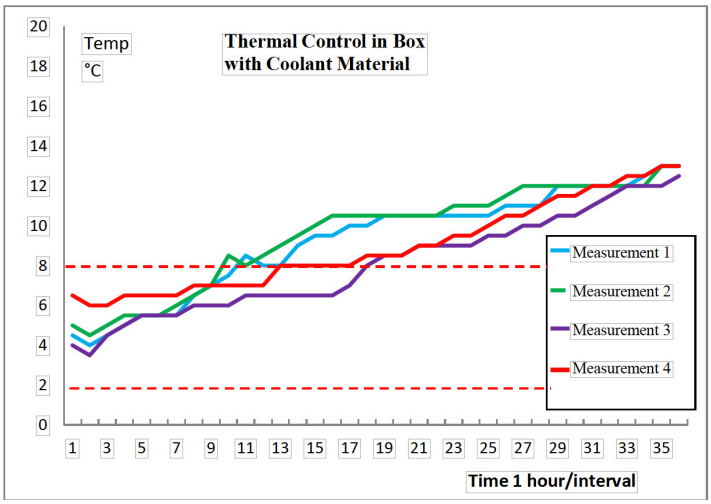

***FIGURE 4**. Thermal control in box with coolant material.*

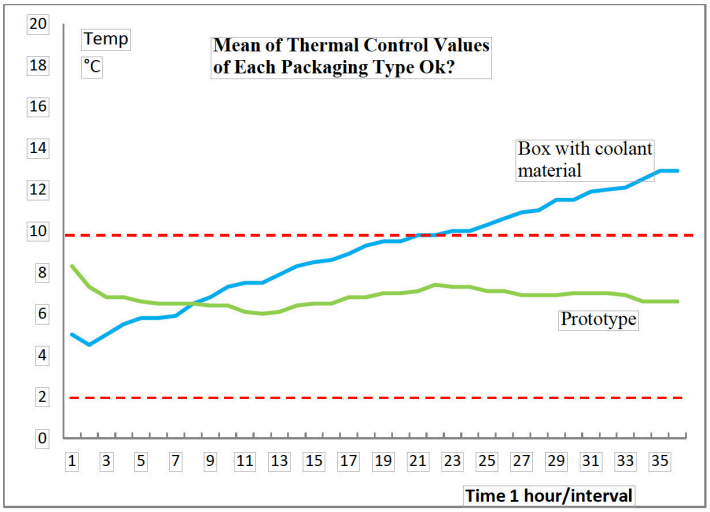

***FIGURE 5**. Comparison between the mean temperature values in the two types of packaging (prototype and coolant material) over time.*

DISCUSSION

Transportation of donor corneas is a critical step in tissue donation; therefore, it is important that it be performed adequately by meeting the ANVISA standards.[3] In the daily operation of eye banks, transportation of corneas is an essential part of the supply chain.[7]

The status of corneal tissue during transportation has not been studied extensively, even though variations in status are critical because they represent the final phase of preservation. Even today, with so much technology and concern for improvements in surgical techniques, shipping containers and ice packaging techniques are not well standardized. In addition, their ability to accurately maintain a temperature of 4ºC for extended periods also has been not well documented.[8,9]

Maintenance of optimal storage conditions for donor corneas is crucial to the success of penetrating keratoplasty.[9] Between 4ºC and 8ºC, the degeneration of corneal endothelial cells is slowed, indicating the importance of maintaining this temperature range inside the corneal transport container.[9] Temperature control is essential to maintain corneal endothelial viability; therefore, it is one of the most important factors in designing storage containers.[9]

Temperature maintenance inside the transport container (between 2°C -8°C) becomes a liability when corneal tissue must be transported over longer distances. There is an ongoing concern in relation to the temperature stability of donor tissue during transport.[10]

Transportation also relies on variables such as vehicle availability and traffic conditions, among others, which may hinder corneal transport. Increasingly, donated tissues are sent over longer distances domestically and internationally through sharing agreements with eye banks.[7]

Despite recommendations regarding preserving corneal tissue, there is no standard method for packaging corneas. The literature shows that temperature maintenance capacity depends on the container size, amount of coolant, box composition, and corneal tissue storage and disposition within the packaging, among others, making it more difficult to control and standardize packaging of the corneal tissue. Consequently, each eye bank uses its own system.[8,11]

Few studies have reported the conditions of corneal transportation or investigated the time duration during which shipping is safe and effective relative to thermal control of the packaging. For example, air transportation is dangerous for preserved corneas according to some studies.[8,10,11] Domestic and international shipments are subject to variables that may compromise the donor tissue because of extreme ambient fluctuations during shipping or custom delays.[10,11] The temperature commonly is maintained using ice and is not constant during shipping. In addition, there are no accurate registers about thermal control during the trip, which may affect the safety of the transportation.

Use of a power source connected to the embedded control system showed good efficiency for tests performed in the laboratory. The next step will be evaluation of the rechargeable batteries to meet the mobility requirement necessary for an eye bank.

The latency to the time of thermal stabilization was similar between the prototype

(19.0 ± 1.0 minutes) and the thermal box (21.0 ± 1.4 minutes), which indicated the importance of waiting this amount of time before transferring preservative medium for transport.

In the current study, the temperature inside the prototype was relatively stable for 36 hours, with few variations (average interval, 2.6 ± 0.5°C). There was a gradual increase in temperature over time (Figs. 3, 5). The control algorithm maintained the average temperature within the specified range, demonstrating its ability to provide the necessary thermal stability. This indicates that the same algorithm used in a properly prepared shipping box will facilitate transportation longer than 36 hours.

Another concern was the risk of freezing of the corneal tissue during transport in standard packaging. Corneal tissue must be properly accommodated in the packing material with an appropriate amount of coolant material to prevent freezing, which damages the endothelium.[10,11] The current study showed that the prototype maintained the required temperature and was relatively stable, which prevented freezing of the corneal tissue.

In the first two measurements of the prototype, the temperature exceeded the upper limit required (Fig. 3), and ice formed along the wall of the internal radiator. We believe this caused energy dissipation and impaired air circulation and consequently different temperatures in the spatial arrangements of the test box. In this scenario, the data logger was placed in the center of the box just beneath the fan. During subsequent measurements, the data logger was placed inside on the sidewall of the test box. After this modification, the temperature measurements were within the required limits. Therefore, some adjustments are needed to avoid ice accumulation next to the radiator to avoid interference with heat transfer.

The current study also confirmed that the thermal box commonly used to transport corneas by eye banks (gold standard) can achieve temperatures ranging from 2°C to 8°C, proper functioning for short distances that do not require long time intervals. However, it was impossible to obtain thermal control over time and to monitor and track the temperature. Fig. 4 shows that after an average of 14.8 ± 4.0 hours, the temperature increased gradually beyond the upper limit (8ºC). This increase was inevitable and irreversible. During this time, the coolant material began

to melt (lasts from 8-12 hours in coolers, according to the manufacturer's specifications). The coolant then loses its cooling capability and the temperature in the box begins to rise gradually. It is impossible to reverse this process because the box must be kept closed and sealed during transport, making it impossible to replace the refrigerant.

Conversely, the technology of the Peltier cell associated with the control algorithm can be applied to maintain thermal stability to transport other anatomic structures, i.e., biologic tissues and fluids, thereby contributing to quality. This project, which is innovative in Ophthalmology, opens new horizons related to corneal transport, allowing its expansion via the proposed alternative packaging method. It is now possible that materials can be shipped to other states and countries that need donations to meet current demand with reliable temperature control. With the gradual increase in the number of corneal transplant procedures, expansion in the logistics of this procedure means a technologic breakthrough.

In conclusion, the prototypical Peltier effect cell maintained thermal stability in a temperature range of 2°C to 8°C for 36 hours with better results than those obtained using a thermal polypropylene box.

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