External Cooling of Warm Ischemic Rabbit Lungs After Death

Dirk E. M. Van Raemdonck, MD, Nicole C. P. Jannis, Filip R. L. Rega, Paul R. J. De Leyn, MD, PhD, Willem J. Flameng, MD, PhD, and Toni E. Lerut, MD, PhD

Center for Experimental Surgery and Anaesthesiology, Katholieke Universiteit Leuven, Leuven, Belgium

During the past 13 years, pulmonary transplantation has emerged as a successful mode of surgical therapy for suitable patients with end-stage lung disease. However, lung transplantation, as other forms of solid organ transplantation, is limited by a scarcity of good donor organs. To alleviate this critical donor shortage, there has been a growing interest in the use of organs from circulation-arrested donors [1-3]. Although good donor organs, there is concern that even a short period of warm ischemia will deleterious for lung tissue, jeopardizing the transplant recipient. It was the purpose of this study to look for the efficacy of different methods of lung cooling inside a cadaver after circulatory arrest.

Methods. New Zealand white rabbits were sacrificed with an intravenous overdose of pentobarbital and left at room temperature. Subcutaneous, rectal, lung core, lung surface, and endobronchial temperatures were measured at intervals after death. Cooling of the lung during ischemia differed between groups (n = 6 in each group): lungs left deflated at room temperature (24°C) (group 1 = control non-heart-beating donors), lungs ventilated with cooled (4°C) room air (group 2), lungs left deflated plus topical cooling (1°C) of both the cadaver and its lungs (group 3), and lungs flushed in situ immediately after circulatory arrest with a cold (4°C) crystalloid solution followed by ex vivo deflated storage in cold (1°C) saline solution (group 4 = control heart-beating donors).

Results. There was a slow decline in lung core, lung surface, and endobronchial temperatures toward room temperature in group 1 (1.5° ± 0.0°C/h, 1.8° ± 0.0°C/h, and 1.9° ± 0.1°C/h, respectively). In contrast, all three lung temperatures immediately (<5 minutes) dropped to less than 10°C in group 4. Hypothermic ventilation (group 2) decreased endobronchial temperature (p < 0.05 at 30 minutes) but not lung surface, rectal, or subcutaneous temperature when compared with group 1. Cooling rate for lung surface and endobronchial temperatures during the first 4 hours after death was faster (p < 0.01) in group 3 (6.6° ± 0.3°C/h and 6.1° ± 0.2°C/h, respectively) when compared with group 2 (2.5° ± 0.3°C/h and 3.9° ± 0.1°C/h, respectively), but slower (p < 0.001) when compared with group 4 (9.2° ± 0.1°C/h and 8.7° ± 0.1°C/h, respectively).

Conclusions. These data demonstrate that in the non-heart-beating donor, (1) in situ cold flush will result in immediate cooling of the lung, (2) ventilation with cooled air will only accelerate the decline in endobronchial temperature but has no effect on lung surface temperature, and (3) topical cooling of the cadaver is more efficacious in decreasing lung temperature than hypothermic ventilation.

Table 1. Interval Between Temperature Measurements in Different Experimental Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Postmortem Interval (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Deflated-room&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0  5  10  15  20  30  45</td>
</tr>
<tr>
<td>2. Ventilated-cooled air</td>
<td>x  x  x  x  x  x  x  x  x  x  x  x  x  x  x  x</td>
</tr>
<tr>
<td>3. Deflated-topical</td>
<td>x  x  x  x  x  x  x  x  x  x  x  x  x  x  x  x</td>
</tr>
<tr>
<td>4. Pulmonary flush&lt;sup&gt;b&lt;/sup&gt;</td>
<td>x  x  x  x  x  x  x  x  x  x  x  x  x  x  x  x</td>
</tr>
</tbody>
</table>

<sup>a</sup> Control non-heart-beating donor.  <sup>b</sup> Control heart-beating donor.

and to compare different methods to accelerate postmortem cooling of lung tissue inside the warm body.

Material and Methods

Experimental Groups

Cadaver temperature was studied at intervals after death in four groups of animals (n = 6 in each group). Postmortem cooling of the lungs inside the cadaver differed between groups (Table 1): group 1, cadavers left at room temperature (24°C) with deflated lungs (no external cooling = control NHBD); group 2, cadavers with lungs ventilated with cooled (4°C) room air; group 3, cadavers submerged in an ice bath (1°C) after initial topical lung cooling with cold (1°C) saline solution; and group 4, lungs flushed in situ via the pulmonary artery immediately after circulatory arrest with a cold (4°C) crystalloid solution followed by ex vivo deflated storage in cold (1°C) saline solution (control heart-beating donor).

Animal Preparation

All animals received humane care in compliance with the “Guide for the Care and Use of Laboratory Animals” published by the National Institutes of Health (NIH publication 85-23, revised 1985).

New Zealand white rabbits weighing 2.5 to 3 kg were premedicated and anesthetized by intramuscular injection with 0.25 mL/kg Imalgene (50 mg/mL ketamine; Rhône Mérieux, Lyon, France) and 0.15 mL/kg Domitor (1 mg/mL medetomidin-chlorhydrat + 1 mg/mL para-methylhydroxybenzoat = 0.2 mg/mL parapropylhydroxybenzoat; Orion Corporation, Farmos, Espoo, Finland). The animals were intubated with a cannula with an inner diameter of 3.5 mm (Mallinckrodt Medical Athlone, Ireland) via a cervical tracheostomy, and the lungs were ventilated using a Harvard rodent ventilator model 683 (Harvard Apparatus, Inc, South Natick, MA) with room air (respiratory rate = 30 breaths/min; tidal volume = 10 mL/kg body weight; positive end-expiratory pressure = 2 cm H2O). The chest was opened through a median sternotomy. Thymic tissue was excised. Both pleural cavities were opened. Temperature probes were inserted.

In the group of animals with lungs preserved by immediate cold pulmonary flush (group 4), both superior caval veins, the inferior caval vein, the ascending aorta, and the main pulmonary artery were encircled by individual ligatures. Heparin Novo, 700 IU/kg (sodium heparin, 5,000 IU/mL; Novo Nordisk, Bagsvaerd, Denmark), was administered via a marginal ear vein. The main pulmonary artery was cannulated through the right ventricular outflow tract using a 10-gauge cannula (Angiocath; Becton Dickinson Vascular Access, Sandy, UT). The cannula remained in place for subsequent pulmonary flush.

Rabbits were then sacrificed by intravenous injection with 100 mg/kg Nembutal (60 mg/mL sodium pentobarbital; Abbott Laboratories, North Chicago, IL) resulting in cardiac arrest within 5 seconds. The sternal edges were reapproximated with towel clips. In the group of cadavers with lungs deflated (groups 1 and 3), the tracheal cannula was disconnected from the ventilator immediately after cardiac arrest. In the group with lungs ventilated (group 2), respiration was continued during the interval with the same minute volume and positive end-expiratory pressure.

Cooling

In group 1, cadavers were left at room temperature (24°C). In group 2, room air was cooled using a long coil of copper tubing submerged in ice and interposed between the ventilator tubing and the tracheal cannula, reducing the temperature of inspiratory room air from 24°C to 4°C at the distal end of the cannula. In group 3, both pleural cavities were filled once with ice-cold (1°C) saline solution immediately after cardiac arrest. The cadaver itself was then submerged completely in ice, preventing direct contact between the ice and the intrapleural cavity. The ice bath was then transferred to a cold (1°C) room for 24 hours. In group 4, the pulmonary artery was isolated from the right ventricle by ligature around the tip of the cannula just distal to the pulmonary valve. The tip of the left atrial appendage was transected to allow free drainage of the flush solution started immediately after cardiac arrest. Both lungs were flushed by gravity at 60 cm H2O with 60 mL/kg cold (4°C) modified Krebs-Henseleit solution (composition in millimoles per liter: NaCl, 118; NaHCO3, 25; KCl, 5.6; CaCl2, 2.9; MgCl2, 0.6; NaH2PO4, 1.2; and d-glucose, 11; pH, 7.4; osmolarity, 321 mOsm/L). During the flush, the lungs were continuously ventilated with room air and topically cooled with ice-cold (1°C) saline solution. At the end of the flush the heart-lung block was excised, immediately submerged in ice-cold (1°C) saline solution, and stored in a cold room.
(1°C) for 24 hours. The open tracheal cannula was suspended to prevent the preservation solution from entering the bronchial tree.

Temperature Measurements

Temperatures were measured using a five-channel digital thermometer (Ellab, Copenhagen, Denmark). Rectal (R), subcutaneous (SC), endobronchial (EB), lung core (LC), and lung surface (LS) temperatures were measured in the cadaver at intervals after death (see Table 1).

Endobronchial temperature in deflated lungs (groups 1, 3, and 4) was measured using a small tympanic membrane probe (MEA-22130-A; Ellab, Redovre, Denmark) inserted through the endotracheal cannula deep into the right lower lobe until resistance. In group 2 (hypothermic ventilation), the endotracheal cannula was intermittently disconnected from the ventilator to introduce the probe and measure EB temperature. Lung surface temperature was measured using the same type probe inserted through the sternotomy incision and positioned between two lobes. Lung core temperature was measured in groups 1 and 4 using a needle probe (MKG-09500-A; Ellab) positioned into the right lower lobe at a depth of 1 cm. In groups 1 to 3, R and SC temperatures were measured using a tympanic membrane probe and a needle probe, respectively.

The environmental temperature of the cadaver was continuously registered. Room temperature in groups 1 and 2 was 24.0° ± 0.3°C at the start and 24.5° ± 0.2°C at the end of the experiment. The temperature of the ice bath in group 3 and the saline solution in group 4 was 1.0° ± 0.1°C.

Biopsy specimens of peripheral lung tissue for the study of adenosine triphosphate catabolism and hypoxanthine formation were taken in all four groups at the same postmortem time interval. This forms the subject of a companion study [13].

Statistics

Temperatures are expressed in degrees Celsius. Data are presented as the mean ± standard error of the mean. Differences within groups between premortem values and temperatures at successive intervals after death were calculated using one-way analysis of variance with repeated measurements followed by Scheffé's multiple comparison test [14]. Differences between groups at the same postmortem time interval were compared using analysis of variance with factorial analysis (StatView SE+Graphics [Abacus Concepts Inc, Berkeley, CA] on a Macintosh Performa 630 computer). A p value less than 0.05 was accepted as level of significance (Scheffé's test).

Results

The natural postmortem decline in lung temperature in animals left deflated at room temperature during 6 hours (group 1 = control NHBD) is depicted in Figure 1. There is a slow and progressive decrease in all three lung temperatures toward room temperature (cooling rate, 1.5° ± 0.0°C/h for LC, 1.8° ± 0.2°C/h for LS, and 1.9° ± 0.1°C/h for EB temperature; p < 0.001 starting at 20 minutes for LC, at 90 minutes for LS, and at 30 minutes for EB versus 0 minutes; not significant for LC versus LS and EB at all intervals).

In contrast, all three lung temperatures decreased to less than 10°C within 5 minutes after the onset of cold (4°C) pulmonary flush (group 4 = control HBD) (p < 0.001 for LC, LS, and EB at 5 minutes versus 0 minutes). Lung core temperature decreased from 37.0° ± 0.5°C premortem to 19.8° ± 0.3°C at the end of the flush (mean, 109 ± 5 seconds) and further to 9.6° ± 0.4°C at 5 minutes with additional topical (1°C) cooling. Thereafter LC temperature slowly decreased to 4.1° ± 0.4°C at 1 hour (p < 0.001 versus 5 minutes) and 1.7° ± 0.3°C at 6 hours (not significant versus 1 hour) and remained constant until 24 hours (1.9° ± 0.4°C) (Fig 2). The decline in EB temperature was comparable with LC temperature. Lung surface temperature, however, was lower when compared with LC and EB temperatures (4.1° ± 0.4°C, 2.4° ± 0.3°C, 1.1° ± 0.2°C, and 1.0° ± 0.1°C at 5 minutes and 1, 6, and 24 hours, respectively, p < 0.05 versus LC and EB between 5 minutes and 2 hours). This reflects the direct contact between the storage solution (1°C) and the visceral pleura of the lung.

No differences in R temperature or in SC temperature were observed between cadavers ventilated with cooled room air (group 2) and animals with lungs deflated (group 1) (not significant at all time intervals). Cadavers submerged in ice (group 3) showed a constant decline in R and SC temperatures (from 37° ± 0.2°C and 36.2° ± 0.2°C at 0 minutes to 2.4° ± 0.5°C and 2.9° ± 0.7°C at 24 hours, respectively). The cooling rate of the cadaver during the first 4 hours was significantly higher in group 3 when compared with group 1 (5.3° ± 0.1°C/h versus 1.5° ± 0.0°C/h for R temperature [p < 0.001] and 5.4° ±
Fig 2. Lung core (open squares), lung surface (filled squares), and endobronchial temperatures (open circles) in rabbit lungs (n = 6) flushed in situ with cold (4°C) Krebs-Henseleit bicarbonate buffer and stored deflated ex vivo in cold (1°C) saline solution (filled triangles) for 24 hours (group 4, control heart-beating donor). Mean temperatures (± standard error of the mean) are expressed in degrees Celsius (*p < 0.001 for lung core, lung surface, and endobronchial versus 0 minutes by analysis of variance).

0.2°C/h versus 1.7° ± 0.1°C/h for SC temperature [p < 0.001], respectively) (Fig 3).

Figure 4 compares LS and EB temperatures between all four study groups. There was a difference in EB temperature (p < 0.05 starting at 30 minutes) but not in LS temperature between lungs left deflated at room temperature (group 4) and lungs ventilated with cooled gas (group 2). The cooling rate in LS and EB temperatures during the first 4 hours after death was faster (p < 0.001) in cadavers submerged in ice (group 3) (6.6° ± 0.3°C/h and 6.1° ± 0.2°C/h, respectively) when compared with animals ventilated with cooled gas (group 2) (2.5° ± 0.3°C/h and 3.9° ± 0.1°C/h, respectively) but slower (p < 0.001) when compared with lungs flushed in situ and stored deflated in cold saline solution (group 4) (9.2° ± 0.1°C/h and 8.7° ± 0.1°C/h, respectively) (Fig 4).

Comment

Rapid cooling to accomplish reversible metabolic inhibition forms the basis of any solid organ preservation before transplantation. Simple hypothermic immersion (topical cooling) of the lung was the method used by the Toronto Lung Transplant Group in its early reported series of successful single-lung transplantations [15].

Current preservation techniques of donor lungs for subsequent transplantation include core-cooling and single-flush perfusion. In the lung, these methods are essentially restricted to 6 to 8 hours of cold ischemia [12]. The superiority of hypothermic perfusion over surface cooling in achieving homogeneous hypothermia of the lung was already reported by Vanderhoft and Dove in 1966 [16].

In the NHBD, however, there will always be a certain delay between (unexpected) circulatory arrest and the start of cold in situ flush. The period of tolerable warm ischemia in thoracic organs is very limited. Primary nonfunction or delayed function can be tolerated in renal transplantation but not to any degree in heart or lung transplantation. The organs from NHBDs therefore should be protected from ischemic damage by preservation already inside the cadaver. Postmortem cardiac massage and continued ventilation of the cadaver until cooling versus cold crystalloid pulmonary perfusion. In a subsequent study they looked at flush perfusion with cold modified blood versus core cooling on cardiopulmonary bypass [18]. The cooling rate of pulmonary flush was superior in both studies.

Several animal experiments evaluating gas exchange, pulmonary vascular resistance, and wet/dry weight ratio after reperfusion as well as adenosine triphosphate levels in lung tissue during cold storage in an extracellular type solution have suggested that the optimal temperature for prolonged hypothermic storage is in the vicinity of 10°C [19-23]. Single-flush perfusion with modified Euro-Collins solution at 4°C in conjunction with prostaglandin therapy and storage in the same solution at 4°C has continued to be used by most centers engaged in clinical lung transplantation [24].

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We wanted to evaluate the influence of simple external lung cooling inside the cadaver after circulatory arrest. It was the aim of this study to look for the efficacy of lung cooling on the decline in lung temperature inside the warm cadaver is not possible by 4-hour normoventilation with air cooled to 4°C. Pulmonary hypothermia by ventilation with cold air (mean of −10°C) was first investigated by Zikria and colleagues [27] in dogs with an intact circulation. The pulmonary arteriovenous temperature difference increased from 0.01° to 0.64°C. After 60 minutes of pulmonary cooling, the lowest temperature reached was 29.5°C in the left pulmonary vein and 30.9°C in the rectum. They concluded that inspired air is rapidly warmed as it passes through the trachea [27]. Dougherty and co-workers [28] were able to reduce the lung temperature in dogs to 2° to 7°C when ventilated with air delivered at −10° to −15°C during 1 hour. Dogs ventilated in this way did not tolerate contralateral pulmonary artery ligation, suggesting that the induction of hypothermia by ventilation with cold gases decreases rather than increases the tolerance of the lung to ischemia. In their study, freezing damage of the delicate lung structures might have been responsible for the observed pulmonary hyperemia and edema after circulation was restored. We also investigated the influence of external body cooling on lung temperature by submerging the cadaver in an ice bath (group 3). The cooling rate of LS, EB, R, and SC temperatures was faster (p < 0.001) when compared with animals left at room temperatures (group 1). However, lung temperature did not reach 10°C until after 4 hours. This interval is probably much too long to protect the lung from warm ischemic damage. Nevertheless, adenosine triphosphate depletion and hypoxanthine formation measured during 24 hours by high-performance liquid chromatography was significantly delayed in this group when compared with values obtained in group 1 [13]. The influence of local cooling on subsequent pulmonary function of the ischemic lung was first investigated by Connaughton and co-workers [29] in a dog survival model with in situ cooling of the lung excluded from circulation and ventilation. In this experiment, however, the left lung was completely submerged in cold (10°C) saline solution and isolated from the warm body. All dogs tolerated a subsequent contralateral pneumonectomy after 6 hours of hypothermic ischemia [29].

Cold pulmonary flush (group 4) decreased LC temperature to 19.9°C ± 0.3°C in less than 2 minutes and further to 9.6°C ± 0.4°C at 5 minutes and 4.1°C ± 0.4°C at 1 hour. At this temperature, enzymatic metabolic rate is suppressed about tenfold [11]. We did not find any significant changes in adenosine triphosphate levels during 24 hours in lungs preserved in this way [13]. Although we did not inject a prostanoid as vasodilator before the start of pulmonary flush, the lungs assumed a uniform white appearance using Krebs-Henseleit as flush solution. This

the onset of in situ cold flush through an intraarterial catheter [25] or total body cooling on extracorporeal cardiopulmonary bypass [26] can protect the organs from NHBDs during this interval as already clinically demonstrated, albeit so far only in kidney [2] and liver [3] transplantation.

The lung is unique among other solid organs in the way that its anatomic peculiarities of both a bronchial and a vascular tree might offer a variety of possible preservation methods. Theoretically, the large alveolar space can be cooled by either cold gas ventilation or perfusion.

It was the aim of this study to look for the efficacy of lung cooling inside the cadaver after circulatory arrest. We wanted to evaluate the influence of simple external cooling on the decline in lung temperature inside the warm body and compare this with the temperature obtained after immediate cold pulmonary flush as in lung retrieval from heart-beating donors nowadays.

The natural postmortem decline in rectal temperature in a cadaver left at room temperature (group 1) is a slow process (1.2°C ± 0.0°C/h). The lung temperature registered in this group was somewhat lower compared with R temperature (27.9°C ± 0.2°C for LC versus 30.3°C ± 0.2°C for R temperature at 6 hours; p < 0.05). This is probably related to the fact that the lung was less isolated from the environmental temperature through the open endotracheal tube and through the reapproximated sternal incision.

We then looked at the effect of hypothermic ventilation on lung temperature (group 2). We did not observe a difference in LS temperature or in systemic temperature, indicating that cooling of peripheral lung tissue inside the warm cadaver is not possible by 4-hour normoventilation with air cooled to 4°C. Pulmonary hypothermia by ventilation with cold air (mean of −10°C) was first investigated by Zikria and colleagues [27] in dogs with an intact circulation. The pulmonary arteriovenous temperature difference increased from 0.01° to 0.64°C. After 60 minutes of pulmonary cooling, the lowest temperature reached was 29.5°C in the left pulmonary vein and 30.9°C in the rectum. They concluded that inspired air is rapidly warmed as it passes through the trachea [27]. Dougherty and co-workers [28] were able to reduce the lung temperature in dogs to 2° to 7°C when ventilated with air delivered at −10° to −15°C during 1 hour. Dogs ventilated in this way did not tolerate contralateral pulmonary artery ligation, suggesting that the induction of hypothermia by ventilation with cold gases decreases rather than increases the tolerance of the lung to ischemia. In their study, freezing damage of the delicate lung structures might have been responsible for the observed pulmonary hyperemia and edema after circulation was restored.

We also investigated the influence of external body cooling on lung temperature by submerging the cadaver in an ice bath (group 3). The cooling rate of LS, EB, R, and SC temperatures was faster (p < 0.001) when compared with animals left at room temperatures (group 1). However, lung temperature did not reach 10°C until after 4 hours. This interval is probably much too long to protect the lung from warm ischemic damage. Nevertheless, adenosine triphosphate depletion and hypoxanthine formation measured during 24 hours by high-performance liquid chromatography was significantly delayed in this group when compared with values obtained in group 1 [13]. The influence of local cooling on subsequent pulmonary function of the ischemic lung was first investigated by Connaughton and co-workers [29] in a dog survival model with in situ cooling of the lung excluded from circulation and ventilation. In this experiment, however, the left lung was completely submerged in cold (10°C) saline solution and isolated from the warm body. All dogs tolerated a subsequent contralateral pneumonectomy after 6 hours of hypothermic ischemia [29].

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finding was identical in rabbit lungs flushed with low-potassium dextran, a similar extracellular type of solution [21]. In contrast, hypothermic pulmonary flush with Euro-Collins solution in the absence of prostaglandins resulted in a much longer flushing time, a slower decline of lung core temperature, and a more mottled blanching of the lungs (unpublished results). The hyperkalemic concentration of Euro-Collins solution likely induces pulmonary vasoconstriction during flush. As a result, this flush solution in the absence of prostaglandin pretreatment may not be evenly distributed throughout the pulmonary vascular bed.

We did not investigate the effect of extracorporeal cadaver core cooling on lung temperature. This technique of total body hypothermia using cardiopulmonary bypass will create a more gradual cooling but it has the distinct advantage also of providing continuous oxygenation of the donor organs after cardiac arrest [26].

From this study, we can conclude that the natural postmortem decline in lung temperature inside the warm cadaveric body is slow. Hypothermic ventilation with room air at 4°C will decrease the endobronchial temperature but not the temperature of peripheral lung tissue. Topical cooling of the cadaver is more efficacious in decreasing lung temperature than hypothermic ventilation. In situ cold pulmonary flush, as widely practiced in the retrieval of pulmonary grafts from heat-beating donors nowadays, will result in immediate homogeneous cooling of the lung. Further research in cooling of pulmonary tissue inside warm cadavers should focus on in situ cold perfusion through a catheter advanced into the pulmonary artery or through total body cooling on cardiopulmonary bypass. Submersion of the cadaver in an ice bath and continued ventilation with cooled air might be helpful in protecting the lungs from warm ischemic damage to bridge the period between unexpected circulatory arrest and the start of in situ cooling. Further studies are necessary to investigate whether lungs from human NHBDs will become a realistic alternative to expand the pulmonary donor pool.

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INVITED COMMENTARY

This lucid report by Van Raemdonck and colleagues documents results of (failed) attempts to come up with a method to cool lungs via the airway after circulatory arrest but before explantation. The rationale for pursuing this line of investigation is to minimize the deleterious effects of an obligatory period of warm in situ ischemia in the clinical scenario of lung retrieval for transplantation from cadavers at intervals after death. For several years, my colleagues and I have been investigating cadaver lung retrieval to provide more lungs for transplantation. Although we have focused on other issues in published reports, we, too, have been intrigued by the possibility of cooling the lung via the airway. The idea is elegant because it is so simple: just ventilate the nonperfused lung (which we have shown may be beneficial for lung viability [1, 2], maintenance of tissue adenosine triphosphate [3], and gas exchange function after transplantation [4]) and, for good measure, simply dial in the desired inflow temperature. Presto: a hypothermic lung! As Van Raemdonck and others pointed out, hypothermia has been the bastion of organ preservation principles.

After we demonstrated the benefit of oxygen ventilation of canine cadaver lungs [4], we performed pilot experiments in dogs, attempting to cool the grafts via the airway. Drawing air for a ventilator circuit through coils immersed in dry ice, we succeeded in “icing up” ventilator circuits and even had ice forming on a Harvard ventilator, but could not budge downstream the measurement recorded by a temperature probe placed in the canine donor right upper lobe any quicker than with ventilation using “room air temperature” oxygen.

Sadly, great ideas are all too often thwarted by the realities of physical laws. The first law of thermodynamics becomes the thwarter in this case. This law explains why, when a new empty refrigerator is plugged in, the air within it is quickly cooled; however, as we all observed firsthand in college, if you fill that new refrigerator with large volumes of warm beer, it could take forever to chill the brew.

There are several reasons why lungs are difficult to cool via the airway, but the predominant one relates to the specific heat in the water compartment of the tissue. The specific heat of water exceeds that of air by a factor of 18. In fur-bearing animals such as rabbits, the surrounding insulation may be even more efficient than in humans. Ventilation with cold air can also induce bronchospasm, potentially limiting the ability of the cold air to come in contact with the large liquid surface area it is intended to cool. Fortunately for Van Raemdonck and others interested in the use of cadaver lungs, it may not matter that it is impractical to cool the lungs via the airway. The lung may be relatively tolerant of a period of ischemia sufficient to allow for retrieval after death. Even more critical will likely be the events affecting the pulmonary microcirculation immediately preceding circulatory arrest in the cadaver. A better understanding of the physical laws governing ischemia/reperfusion events may allow the more liberal use of lungs from cadavers for transplantation.

Thomas M. Egan, MD
Division of Cardiothoracic Surgery
University of North Carolina at Chapel Hill
108 Burnett-Womack Bldg, CB 7065
Chapel Hill, NC 27599-7065

References


