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# University of Wisconsin vs normal saline solutions for preservation of blood vessels of brain dead donors: A histopathological study

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## Abstract

**Objective**: To compare the cellular changes of harvested arteries which were preserved in normal saline (NS) and the standard and routinely used University of Wisconsin (UW) solution.

**Methods**: This experimental study was conducted on 20 brain dead patients. The femoral and iliac arteries were bilaterally removed and were placed in NS and UW solutions. The vascular change indices including endothelial detachment (ED), medial detachment (MD), and internal elastic membrane disruption (IEMD) were surveyed for each preserver in the first, 5th, 10th, and 21st day.

**Results**: The mean age of the included patients was 32.28 ± 8.88 years, and there were 13 (65.0%) men and 7 (35.0%) women among the patients. The NS and UW preservation solutions were comparable regarding the indices of vascular changes at first, 5th, and 10th day of the study. Only in 21st day of the study, there was a significant difference between 2 group regarding MD changes ($P$ = .049).

**Conclusion**: The results of this in vitro study demonstrated that NS can be used as a worthy preserver for harvested vessels for up to 21 days, especially in resource-limited transplantation centers.

KEYWORDS
blood vessels, brain dead, organ preservation solutions, saline solution, University of Wisconsin solution

## 1 | INTRODUCTION

Liver transplantation is known as a lifesaving procedure for patients with end-stage liver disease with a success rate of 80% that depends on surgical techniques, proper donor selection, pre-operation organ preservation, and the new immunosuppressive agent that has markedly reduced the rejection rate.[1-3] Despite the remarkable progression in liver transplantation, surgeons still face serious complications such as organ rejection, early or late organ failures, and vessel-related complications such as thrombosis, narrowing, or aneurysm.[4-6]

Harvesting the iliac and femoral arteries and veins from the donor and using them as a substitute vessel in the case of vessel-induced complication is a routine technique that is performed by many surgeons.[7] Preservation is the foundation of successful organ transplantation.[8] Before the innovation of preserving solutions, liver and vessels could be preserved for 4-6 hours, but nowadays vessels can be kept by new keeping methods and be used a few days when

are needed.[9] With the introduction of new preserving solutions, surgeons are now able and have enough time to check the organs and their propriety and well-being state during harvesting operation.[10] Actually, there are some physiologic changes in vessels after the brain dead. Initially, the sympathetic tone is increased which is followed by a period of decreased sympatric tone resulting in massive reduction in systemic vascular resistance.[11] Initially, the endothelial dysfunction occurs and inflammatory cytokines are secreted from the endothelial cells resulting in ultimate endothelial detachment. Finally, thrombosis of the vessels occurs.[12,13] However, knowledge of vascular changes in brain dead patients is very primitive and data accordingly are scarce.

Nowadays, there are several preserving solutions including University of Wisconsin (UW) solution, histidine-tryptophan-ketoglutarate (HTK) solution, and Celsior solution. Among these solutions, UW is the most common cold static solution for organ preservation. HTK has been introduced an alternative to UW which is cheaper with low viscosity and low-potassium content and does not require a filter. Another solution is Celsior which combines the key compounds of both UW and HTK solutions. Recently, normal saline (NS) is used as preserving solution in resource-limited centers especially in third-world countries. However, little information is available on the comparison of Celsior, HTK, UW, and NS solutions.[14-16] This study was performed in our center to estimate the efficacy and integrity of preserved vessels which were preserved in different preserver solutions and checking their viability in sequential days. The evaluated solutions were NS 0.9% and UW solutions.

## 2 | MATERIALS AND METHODS

### 2.1 | Study population

This experimental study was conducted on 20 brain dead patients donating their livers for transplantation at Nemazee hospital. A tertiary solid organ transplantation center in southern Iran affiliated with Shiraz University of Medical Sciences. Study inclusion criteria were as follows: age >18 and <65 years, without arterial or venous insufficiency. Patients with history of malignancy, active infections, and previous vascular disease were excluded from this study. The study protocol was approved by the institutional review board (IRB) and the Medical Ethics Committee of Shiraz University of Medical Sciences. All the patients' representatives or guardians provided their informed written consents before obtaining the vascular samples from the cadavers.

### 2.2 | Sample collection

According to the study criteria, twenty dead brain donors who had already been selected for transplantation were operated. Their femoral and iliac arteries were bilaterally removed, washed with normal saline, and sliced into 8 equal 5 mm pieces each. Four pieces were put in NS and another 4 in UW solution. We used the commercially available UW solution (Belzer UW® Cold Storage Solution, Duraent Biologicals Ltd, Telangana, India). All were kept in 4° Celsius temperature in sterile situation. One sample in each group was sent for pathology study and recorded and predicated as the fresh sample of the first day. The other 3 samples of each group were sent to pathology laboratory in the fifth, tenth, and twenty-first day of harvesting day. All 10th-day samples were also cultured and checked for microbial growth.

### 2.3 | Histopathology and microscopic studies

All samples were fixed in paraffin and cut into 5-μm-thick sections and were dyed by hematoxylin and eosin (H&E) and CD-31. All the histopathology examinations were performed by a pathologist who was expert in vascular and solid organ transplantation histopathology with 15 years of experience. The pathologist was blind toward the study groups.

### 2.4 | Medium-size arteries morphology

These arteries are known as distributive arteries and contain smaller tensile layer than larger arteries, and the tunica media layer (middle layer) shows increased thickness and smooth muscle cells. Normal medium-size arteries compose of 3 layers:

1. Intima layer (tunica intima) includes endothelial and few amounts of smooth muscle cells. Its outer layer is limited to an internal elastic membrane. The endothelial cell basal membrane is directly attached to middle elastic membrane. Intima layer thickness increases with age.
2. Tunica media or middle layer is preponderantly composed of smooth muscle cells and little amount of fibroblast cells. This layer majorly contributes to arterial spasm and contractions. It plays an important role in setting of blood pressure.
3. Tunica adventitia or outer layer: Collagen fibers are predominant in this layer. Existing external elastic layer in this part is not as visible as internal layer.

Several factors were considered to evaluate the histological changes including detachment of internal endothelial layer (ED), internal elastic membrane disruption (IEMD), and medial layer detachment (MD). Evaluation of tissue inflammation and necrosis was established based on foregoing changes and classified to 4 grades including no change, less than 10% changes, between 10% and 50% changes, and more than 50% changes.

### 2.5 | Statistical analysis

All statistical analyses were performed with the Statistical Package for Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA). Arithmetic mean or the average number of scores of each group was assumed as the judgment base, and chi-square test was used for data comparison and evaluation of microscopic changes in different vessel layers. A $P$-value of <.05 was considered statistically significant.

## 3 | RESULTS

### 3.1 | Baseline characteristics

**TABLE 1** The baseline characteristics of 20 brain dead patients donating their livers for transplantation who were included in this study

| Variable | Value |
|---|---|
| Age (years) | 32.28 ± 8.88 |
| Gender | |
| Men (%) | 13 (65.0%) |
| Women (%) | 7 (35.0%) |
| Cause of brain dead | |
| Motor-vehicle accident (%) | 16 (80.0%) |
| Fall (%) | 3 (15.0%) |
| Hypoxic brain damage (%) | 1 (5.0%) |
| Comorbidities | |
| Hypertension (%) | 4 (20.0%) |
| Smoking (%) | 3 (15.0%) |
| Ischemic heart disease (%) | 2 (10.0%) |

The mean age of the included patients was 32.28 ± 8.88 years, and there were 13 (65.0%) men and 7 (35.0%) women among the patients. Motor-vehicle accident (80.0%) was the most common cause of brain dead, followed by fall (15%) and hypoxic brain damage (5%). Baseline characteristics of the patients are summarized in Table 1.

### 3.2 | Tissue changes at the first day

Endothelial detachment with different percentages of change varying from <10% to >50% was observed in 15 of 20 samples in NS group, and it was seen in 14 of 20 samples in UW group ($P$ = .985). Internal elastic membrane disruption (IEMD) was seen in none of them in NS group, while it was detected in 2 sample with <10% and 10%-50% changes in UW group ($P$ = .349). Medial detachment (MD) was only seen in 4 samples preserved in NS, but it was observed in 3 samples preserved in UW ($P$ = .638). In addition, 1 sample progressed with inflammation in NS group, while there was no inflammation or necrosis among the samples in UW group ($P$ = .988). Therefore, no significant difference was observed between 2 NS and UW groups with respect to ED, IEMD, MD, inflammation, or necrosis at the first day (Table 2).

**TABLE 2** The vascular changes of the femoral and iliac arteries of the 20 brain dead patients donating their livers in 2 different preservation solutions during the first day

| | Wisconsin solution (n = 20) | Normal saline solution (n = 20) | *P*-value |
|---|---|---|---|
| Endothelial detachment | | | |
| No change (%) | 6 (30.0%) | 5 (25.0%) | .985 |
| <10% Change (%) | 8 (40.0%) | 9 (45.0%) | |
| 10%-50% Change (%) | 3 (15.0%) | 3 (15.0%) | |
| >50% Change (%) | 3 (15.0%) | 3 (15.0%) | |
| Internal elastic membrane disruption | | | |
| No change (%) | 18 (90.0%) | 20 (100.0%) | .349 |
| <10% Change (%) | 1 (5.0%) | 0 (0.0%) | |
| 10%-50% Change (%) | 1 (5.0%) | 0 (0.0%) | |
| >50% Change (%) | 0 (0.0%) | 0 (0.0%) | |
| Medial layer detachment | | | |
| No change (%) | 17 (85.0%) | 16 (80.0%) | .638 |
| <10% Change (%) | 2 (10.0%) | 1 (5.0%) | |
| 10%-50% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| >50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| Inflammation | | | |
| No Change (%) | 20 (100.0%) | 19 (95.0%) | .988 |
| <10% Change (%) | 0 (0.0%) | 0 (0.0%) | |
| 10%-50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| >50% Change (%) | 0 (0.0%) | 0 (0.0%) | |
| Necrosis | | | |
| No change (%) | 20 (100.0%) | 19 (95.0%) | .988 |
| <10% Change (%) | 0 (0.0%) | 0 (0.0%) | |
| 10%-50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| >50% Change (%) | 0 (0.0%) | 0 (0.0%) | |

**TABLE 3** The vascular changes of the femoral and iliac arteries of the 20 brain dead patients donating their livers in 2 different preservation solutions at 5th day

| | Wisconsin solution (n = 20) | Normal saline solution (n = 20) | *P*-value |
|---|---|---|---|
| Endothelial detachment | | | |
| No Change (%) | 5 (25.0%) | 4 (20.0%) | .536 |
| <10% Change (%) | 9 (45.0%) | 9 (45.0%) | |
| 10%-50% Change (%) | 3 (15.0%) | 3 (15.0%) | |
| >50% Change (%) | 3 (15.0%) | 4 (20.0%) | |
| Internal elastic membrane disruption | | | |
| No change (%) | 17 (85.0%) | 16 (80.0%) | .106 |
| <10% Change (%) | 1 (5.0%) | 1 (5.0%) | |
| 10%-50% Change (%) | 1 (5.0%) | 1 (5.0%) | |
| >50% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| Medial layer detachment | | | |
| No change (%) | 16 (80.0%) | 13 (65.0%) | .318 |
| <10% Change (%) | 2 (10.0%) | 5 (25.0%) | |
| 10%-50% Change (%) | 1 (5.0%) | 3 (15.0%) | |
| >50% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| Inflammation | | | |
| No change (%) | 19 (95.0%) | 16 (80.0%) | .421 |
| <10% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| 10%-50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| >50% Change (%) | 0 (0.0%) | 1 (0.0%) | |
| Necrosis | | | |
| No change (%) | 19 (95.0%) | 19 (95.0%) | .896 |
| <10% Change (%) | 1 (5.0%) | 0 (0.0%) | |
| 10%-50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| >50% Change (%) | 0 (0.0%) | 0 (0.0%) | |

### 3.3 | Tissue changes of the 5th and 10th days

According to statistical analysis, there were no significant differences between 2 preservation solutions regarding ED, IEMD, MD, inflammation, or necrosis at 5th and 10th days. The histopathological changes of the femoral and iliac arteries of the patients in 2 preservation solutions at 5th and 10th days were detailed in Tables 3 and 4.

### 3.4 | Tissue changes of the 21st day

In UW group, ED change less than 10% existed in 12 (60.0%), 10%-50% in 4 (20.0%), and more than 50% in 4 (20.0%), while the changes were observed in 12 (60.0%) less than 10%, in 3 (15.0%) between 10% and 50%, and in 5 (25%) more than 50% in NS group ($P = .803$). IEMD changes were recorded in 3 (15%) less than 10%, 2 (10%) between 10% and 50%, and 1 sample (5%) more than 50% in UW group, while in NS group these were 2 (10%), 3 (15%), and 3 (15%), respectively ($P = .667$). The number of samples with no change in MD was 10 (50%) in UW group comparing to 7 (35%) in NS group, and there was a significant difference between 2 groups regarding MD changes at 21st day ($P = .049$). Similar to previous days, there were not any significant differences between 2 groups regarding inflammation and necrosis changes ($P = .289$ and $P = .998$, respectively). Table 4 summarized the vascular changes of the patients in 2 preservation solutions at 21st day.

### 3.5 | Microbiological surveys and cultures

All samples in 2 groups were cultured in conventional media. Three positive cultures were observed in each group. Staph saprophyticus, Candida, and Staph saprophyticus were seen in the 3 samples of UW groups, and Klebsiella, Candida, and Staph epidermidis were seen in the 3 samples of NS group.

## 4 | DISCUSSION

The quality of transplanted vessels is multifactorial and depends on the donor characteristics, the technical quality of vessels extraction, and the ischemia-reperfusion injury. Moreover, vessel walls are extremely vulnerable and are sensitive to traction or mechanical compression. Therefore, the role of preservation solution in vessels transplantation outcomes is essential.[17-19] A so far unresolved

**TABLE 4** The vascular changes of the femoral and iliac arteries of the 20 brain dead patients donating their livers in 2 different preservation solutions at 10th day

| | Wisconsin solution (n = 20) | Normal saline solution (n = 20) | *P*-value |
|---|---|---|---|
| Endothelial detachment | | | |
| No change (%) | 1 (5.0%) | 0 (0.0%) | .783 |
| <10% Change (%) | 11 (55.0%) | 12 (60.0%) | |
| 10%-50% Change (%) | 4 (20.0%) | 4 (20.0%) | |
| >50% Change (%) | 4 (20.0%) | 4 (20.0%) | |
| Internal elastic membrane disruption | | | |
| No change (%) | 15 (75.0%) | 14 (70.0%) | .503 |
| <10% Change (%) | 2 (10.0%) | 2 (10.0%) | |
| 10%-50% Change (%) | 2 (10.0%) | 2 (10.0%) | |
| >50% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| Medial layer detachment | | | |
| No change (%) | 12 (60.0%) | 9 (45.0%) | .082 |
| <10% Change (%) | 3 (15.0%) | 5 (25.0%) | |
| 10%-50% Change (%) | 3 (15.0%) | 3 (15.0%) | |
| >50% Change (%) | 2 (10.0%) | 3 (15.0%) | |
| Inflammation | | | |
| No change (%) | 17 (85.0%) | 15 (75.0%) | .121 |
| <10% Change (%) | 2 (10.0%) | 2 (10.0%) | |
| 10%-50% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| >50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| Necrosis | | | |
| No change (%) | 19 (95.0%) | 19 (95.0%) | .896 |
| <10% Change (%) | 1 (5.0%) | 0 (0.0%) | |
| 10%-50% Change (%) | 0 (0.0%) | 1 (5.0%) | |
| >50% Change (%) | 0 (0.0%) | 0 (0.0%) | |

complication of allogeneic vessels transplant is proper preservation. In the present study, we were looking for 2 main objectives: (i) Inspection of vessel parameters on different days to find the best and the most cost-effective solution for preserving vessels; (ii) Indicating the maximum length during which the harvested vessels can be kept in preserving solutions with minimum cell destruction and staying in good quality.

Based on several previous studies, it is known that UW is the standard and choice-preserving solution for harvested organs.[16,17,20] UW solution was firstly introduced by Belzer et al[9] and became the standard medium for preserving the organs and harvested tissues. Hydroxystarch, lactobionate, and raffinose in this solution prevent cellular edema and phosphate—a buffering ion—and glutathione eliminate oxygen-free radicals. Adenosine restarts energy producing circuit after reperfusion. Like Collin's solution, UW solution contains a high concentration of potassium that prevents potassium ion pouring out. Glucose in the solution keeps cells metabolically active, and the only concern about UW solution is the high concentration of potassium that can potentially increase cellular calcium concentration that results in increased vascular resistance and subsequent endothelial damage.

Our study showed that there is no statistical difference in vascular index between NS and UW groups until 21st day, and just changes in medial layer detachment of samples preserved in NS significantly increased in comparing with UW group at 21st day. To the best of our knowledge, previous studies focused on clinical and functional results of vessels which were preserved in different solutions, and there is not any study to considered histopathology aspect of the preserved vessels. For example, Abrahamse and colleagues compared preservation-induced changes in smooth muscle cell and endothelial cell function between different preservation solutions.[21] Excised carotid arteries were stored at 4°C in 0.9% (w/v) NaCl, UW, histidine-tryptophan-ketoglutarate (HTK), Celsior, or a modified HTK solution for up to 14 days. Preservation-induced changes in smooth muscle cell and endothelial cell function were determined using an organ bath for isometric tension recording. Finally, they concluded that UW is superior to 0.9% (w/v) NaCl, HTK, and Celsior solutions for prolonged preservation (7 days) of carotid arteries. In another study, Bas et al[14] compared the cellular vitality and functional efficiency of vein preserved in UW solution vs HTK solution. Twenty-seven human vein segments (vena saphena magna) were stored after explant in University of Wisconsin solution or

**TABLE 5** The vascular changes of the femoral and iliac arteries of the 20 brain dead patients donating their livers in 2 different preservation solutions at 21st day

| | Wisconsin solution (n = 20) | Normal saline solution (n = 20) | *P*-value |
|---|---|---|---|
| Endothelial detachment | | | |
| No change (%) | 0 (0.0%) | 0 (0.0%) | .803 |
| <10% Change (%) | 12 (60.0%) | 12 (60.0%) | |
| 10%-50% Change (%) | 4 (20.0%) | 3 (15.0%) | |
| >50% Change (%) | 4 (20.0%) | 5 (25.0%) | |
| Internal elastic membrane disruption | | | |
| No change (%) | 14 (70.0%) | 12 (60.0%) | .667 |
| <10% Change (%) | 3 (15.0%) | 2 (10.0%) | |
| 10%-50% Change (%) | 2 (10.0%) | 3 (15.0%) | |
| >50% Change (%) | 1 (5.0%) | 3 (15.0%) | |
| Medial layer detachment | | | |
| No change (%) | 10 (50.0%) | 7 (35.0%) | **.049** |
| <10% Change (%) | 5 (25.0%) | 3 (15.0%) | |
| 10%-50% Change (%) | 3 (15.0%) | 5 (25.0%) | |
| >50% Change (%) | 2 (10.0%) | 5 (25.0%) | |
| Inflammation | | | |
| No change (%) | 14 (85.0%) | 13 (75.0%) | .289 |
| <10% Change (%) | 3 (15.0%) | 3 (15.0%) | |
| 10%-50% Change (%) | 2 (10.0%) | 2 (10.0%) | |
| >50% Change (%) | 1 (5.0%) | 2 (10.0%) | |
| Necrosis | | | |
| No change (%) | 18 (95.0%) | 18 (95.0%) | .998 |
| <10% Change (%) | 1 (5.0%) | 1 (5.0%) | |
| 10%-50% Change (%) | 1 (5.0%) | 1 (5.0%) | |
| >50% Change (%) | 0 (0.0%) | 0 (0.0%) | |

Bold values: statistically significant difference between the subcategories.

histidine-tryptophan-ketoglutarate solution at 4°C. After 3, 24, 48, 72, and 96 hours, vein functionality was tested. Their results indicated that human saphenous vein transplants had better endothelium and smooth muscle function at 48 hours when preserved in UW solution comparing HTK solution.

During this study, the 10th-day culturing and microbiologic study, we had 3 positive results among the samples of each group despite the sterile methods during harvesting and preservation procedures. These results are comparable with previous rates for cross-infection during the solid and tissue transplantations.[22,23] These remind us that we have to recheck our sterility strategies during our surgical, cold storage operations, and preservation equipment and environments in our center.

There are several physiologic and pathologic changes after the brain dead. These changes have been less studied because of the nature of the condition. The changes after brain dead affect almost all the organs including the cardiovascular, pulmonary, endocrine, hepatic, and renal systems.[11] Brain dead results in activation of endothelial cells, platelets, and leukocytes. There is upregulation of proinflammatory mediators in peripheral organs, making them more susceptible to post-transplantation host inflammatory and immunologic responses. Elevated levels of proinflammatory cytokines have been demonstrated in the serum [24] and hearts [25] of brain stem dead donors. The mRNA expression of cytokines, chemokines, and adhesion molecules increases after brain stem death because of a variety of interrelated events, including central injury, hypotension, and circulating factors.[26]

We note some limitation to our study. First, we did not calculate a sample size before the study and included those patients who were eligible and had consent for the study. However, the postanalysis power calculation revealed that the study had an 85% power for detection of differences between the 2 study groups. The other limitation of the study was the in vitro nature of the study. Clinical studies investigating the outcome of transplanted vessels are warranted to shed light on the clinical aspect of the issue. However, the aim of this study was to investigate the in vitro changes of the harvested arteries in 2 different solutions. This is among the only studies available in the literature addressing the histopathology changes of harvested arteries in brain dead patients and also to compare the 2 preservation solutions. Further studies are required to complete the results of this primary report.

In conclusion, the results of this in vitro study demonstrated that NS can be used as a worthy preserver for harvested vessels for up to 21 days. The absence of significant changes between NS and UW and some less destructive changes in normal saline preserved samples asserted normal saline as a trustable preserver as the standard of choice UW solution. Accordingly, we recommend the NS as a standard preservation solution in short-term (up to 21 days) especially in resource-limited centers where UW solution would not be easily available. The results of this study should be confirmed in a clinical setting.

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## CONFLICT OF INTEREST

No conflict of interest.

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## REFERENCES

1. Adam R, Hoti E. Liver transplantation: the current situation. *Semin Liver Dis*. 2009;29:3-18.
2. Dienstag JL, Cosimi AB. Liver transplantation–a vision realized. *N Engl J Med*. 2012;367:1483-1485.
3. Fayek SA, Quintini C, Chavin KD, Marsh CL. The current state of liver transplantation in the United States: perspective from American Society of Transplant Surgeons (ASTS) Scientific Studies Committee and endorsed by ASTS council. *Am J Transplant*. 2016;16:3093-3104.
4. Duffy JP, Hong JC, Farmer DG, et al. Vascular complications of orthotopic liver transplantation: experience in more than 4,200 patients. *J Am Coll Surg*. 2009;208:896-903. discussion -5.
5. Nikeghbalian S, Aliakbarian M, Kazemi K, et al. Clinical experience in organ transplant from the Shiraz Transplant Center: 2011. *Exp Clin Transplant* 2012;10:307-309.
6. Zarrinpar A, Busuttil RW. Liver transplantation: past, present and future. *Nat Rev Gastroenterol Hepatol*. 2013;10:434-440.
7. Sellers MT, Haustein SV, McGuire BM, et al. Use of preserved vascular homografts in liver transplantation: hepatic artery aneurysms and other complications. *Am J Transplant*. 2002;2:471-475.
8. Ratigan ED, McKay DB. Exploring principles of hibernation for organ preservation. *Transplant Rev (Orlando)*. 2016;30:13-19.
9. Belzer FO. Clinical organ preservation with UW solution. *Transplantation*. 1989;47:1097-1098.
10. Garcia-Gil FA, Serrano MT, Fuentes-Broto L, et al. Celsior versus University of Wisconsin preserving solutions for liver transplantation: postreperfusion syndrome and outcome of a 5-year prospective randomized controlled study. *World J Surg*. 2011;35:1598-1607.
11. Smith M. Physiologic changes during brain stem death–lessons for management of the organ donor. *J Heart Lung Transplant*. 2004;23(9 Suppl):S217-S222.
12. Alexopoulou AN, Lees DM, Bodrug N, et al. Focal Adhesion Kinase (FAK) tyrosine 397E mutation restores the vascular leakage defect in endothelium-specific FAK-kinase dead mice. *J Pathol*. 2017;242:358-370.
13. Tamosuitis T, Pranskunas A, Balciuniene N, Pilvinis V, Boerma EC. Conjunctival microcirculatory blood flow is altered but not abolished in brain dead patients: a prospective observational study. *BMC Neurol*. 2016;16:95.
14. Bas M, Luther B, Knopf A, Suvorava T, Kojda G. Preservation of endothelial and smooth muscle function of human saphenous vein transplants. *Exp Clin Transplant*. 2016;14:86-92.
15. Latchana N, Peck JR, Whitson B, Black SM. Preservation solutions for cardiac and pulmonary donor grafts: a review of the current literature. *J Thorac Dis*. 2014;6:1143-1149.
16. Parsons RF, Guarrera JV. Preservation solutions for static cold storage of abdominal allografts: which is best? *Curr Opin Organ Transplant*. 2014;19:100-107.
17. Cavallari A, Cillo U, Nardo B, et al. A multicenter pilot prospective study comparing Celsior and University of Wisconsin preserving solutions for use in liver transplantation. *Liver Transpl*. 2003;9:814-821.
18. Garcia-Gil FA, Arenas J, Guemes A, et al. Preservation of the liver graft with Celsior solution. *Transplant Proc*. 2006;38:2385-2388.
19. Karam G, Compagnon P, Hourmant M, et al. A single solution for multiple organ procurement and preservation. *Transpl Int*. 2005;18:657-663.
20. Jeng LB, Lin PJ, Yao PC, Chen MF, Chang CH. The endothelium-dependent response of human hepatic artery after preservation with the UW solution. *J Surg Res*. 1996;61:477-481.
21. Abrahamse ST, Dinant S, Pfaffendorf M, van Gulik TM. In vitro function of porcine carotid arteries preserved in UW, HTK and Celsior solutions. *Fundam Clin Pharmacol*. 2002;16:503-511.
22. Giani T, Conte V, Mandala S, et al. Cross-infection of solid organ transplant recipients by a multidrug-resistant *Klebsiella pneumoniae* isolate producing the OXA-48 carbapenemase, likely derived from a multiorgan donor. *J Clin Microbiol*. 2014;52:2702-2705.
23. Greenwald MA, Kuehnert MJ, Fishman JA. Infectious disease transmission during organ and tissue transplantation. *Emerg Infect Dis*. 2012;18:e1.
24. Amado JA, Lopez-Espadas F, Vazquez-Barquero A, et al. Blood levels of cytokines in brain-dead patients: relationship with circulating hormones and acute-phase reactants. *Metabolism*. 1995;44:812-816.
25. Plenz G, Eschert H, Erren M, et al. The interleukin-6/interleukin-6-receptor system is activated in donor hearts. *J Am Coll Cardiol*. 2002;39:1508-1512.
26. Takada M, Nadeau KC, Hancock WW, et al. Effects of explosive brain death on cytokine activation of peripheral organs in the rat. *Transplantation*. 1998;65:1533-1542.

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