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Importance of Renal Graft Reperfusion Thermoregulation in Living Donor Kidney Transplant Patients: Gasometrical and Hemodynamical Study

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ABSTRACT

INTRODUCTION: Hypothermia, defined as a decrease in core body temperature below 36°C, has a notable influence on hemodynamic variables during anesthesia, which is of great interest in perioperative medicine. Temperature regulation is crucial in anesthetic management because hypothermia can significantly impact the patient's cardiovascular functioning. Accidental (uncontrolled) hypothermia during anesthetic and surgical procedures carries considerable risks such as: Increases the incidence of surgical site infections, prolongs the effects of drugs administered during anesthesia, and disrupts normal coagulation, potentially increasing the risk of bleeding. For these reasons, body temperature regulation is a critical aspect to monitor and control during anesthesia.

MATERIAL AND METHODS: A descriptive, observational, single-center, and retrospective study was carried out in patients undergoing a related living donor kidney transplant between June 2022-2023 at the Juarez Hospital in Mexico. All data were collected from the demographic sheets, laboratories and trans anesthetic sheets of the patient's file. The data was integrated into an Excel database and statistical processing was performed in SPSS or STATSm software. The statistical analysis was tested for normality according to Kolmogorov-Smirnov with Lilliefors correction, where it was found that the population has a normal or non-normal distribution. The Mann-Whitney U test was performed to compare the difference of the means between the two groups. A correlation was made with Kendall´s Tau coefficient; All statistical analyzes were performed with a value of $p<0.05$, considering these significantly.

RESULTS: Of the 65 transplanted patients between Jun 2023 and June 2024 only 28 have appropriate inclusion criteria. Of the remaining 28, 16 were female (57.14%) and 12 were male (42.8%) with an average age of recipients of 30.2430.46 ±11.45 years with a weight of 58.23 ±10.47 kg, height 154.20 ±15.32 cm.

<u>Gasometrical and Hemodynamic Values upon Reperfusion with a Forced Air Turbine.</u> The gasometrical variables before reperfusion were: Venous pH 7.41±0.05 (p=0.046); Arterial pH 7.40±0.04 (p=0.015); Venous Oxygen Saturation 68.2±9.74% (p = 0.039). Hemodynamic variables before reperfusion were: IC 3.67±1.77 lt/min/m2 (p=0.001); Stroke Volume 79.5±39.6 ml/beat (p=0.022), Oxygen Extraction 25.1±9.95% (p=0.001) and Myocardial Efficiency

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0.28±0.06 (p=0.024); The gasometrical variables after reperfusion were: Venous pH 7.40±0.03; Arterial pH 7.380±0.04; Venous Oxygen Saturation 60.03±4.37%; The hemodynamic variables after reperfusion were: IC 2.88±0.48 liter/min/m2; Stroke Volume 65.4±16.01 ml/beat; Oxygen Extraction Rate 36.9±4.31% (p = 0.039) and Myocardial Efficiency 0.32±0.06

Gasometrical and Hemodynamic Values upon Reperfusion without Forced Air Turbine. The gasometrical variables before reperfusion were: Venous pH 7.32±0.04 (p=0.012); Arterial pH 7.30±0.04 (p=0.019); Venous Oxygen Saturation 64.7±8.27% (p = 0.026). Hemodynamic variables before reperfusion were Cardiac Index 3.28±1.66 lt/min/m2 (p=0.006); Stroke Volume 72.39±45.44 ml/beat (p=0.029); Oxygen Extraction 29.11±9.65% (p=0.001) and Myocardial Efficiency 0.268±0.08 (p=0.022). The gasometrical variables after reperfusion were: Venous pH 7.33±0.04; Arterial pH 7.320±0.05; Venous Oxygen Saturation 58.593±5.41%. The hemodynamic variables after reperfusion were: Cardiac Index 2.75±0.69 liter/min/m2, Stroke Volume 59.05±18.81 ml/beat, Oxygen Extraction Rate 38.47±6.17% and Myocardial Efficiency 0.31±0.05.

CONCLUSIONS: Understanding the behavior of blood gas and hemodynamic variables upon reperfusion in transplant patients is essential for adequate kidney graft survival. In these patients, the use of a hot forced air turbine improves the conditions under which said reperfusion is performed, impacting not only at the blood gas level (venous pH, arterial pH and venous oxygen saturation) but also at the hemodynamic level (cardiac index, stroke volume, myocardial efficiency The limitations of the study are heterogeneity of the etiologies of CKD, sample size, and volume status prior to the procedure. To date the published works are consistent with the literature.

KEYWORDS: Reperfusion, Kidney Transplant, Blood Gas, pH, Venous Oxygen Saturation, Cardiac Index, Oxygen Extraction, Tissue Perfusion, Myocardial Efficiency, Kidney Graft.

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I. INTRODUCTION

Hypothermia in the field of anesthesia is a phenomenon that has gained special importance in modern clinical practices due to its potential beneficial and harmful effects on patients. This state of decreased core body temperature, intentional or accidental, has been associated with varied outcomes in different surgical procedures and has become a focus of interest and study for anesthesiologists and other health professionals.

Hypothermia, defined as a decrease in core body temperature below 36°C, has a notable influence on hemodynamic variables during anesthesia, which is of great interest in perioperative medicine. Temperature regulation is crucial in anesthetic management because hypothermia can significantly impact the patient's cardiovascular functioning.

From a beneficial perspective, induced hypothermia has been used in specific situations as a therapeutic tool. Research has shown that controlled brain cooling may represent the most potent neuroprotectant in laboratory studies, reducing neurological damage in cases of cardiac arrest and neonatal hypoxic-ischemic encephalopathy. Hypothermia has also been shown to be relevant in mitigating neurological disorders, from brain trauma and stroke to degenerative diseases. However, accidental hypothermia during anesthetic and surgical procedures carries considerable risks. For example, it can increase the incidence of surgical site infections, prolong the effects of drugs administered during anesthesia, and disrupt normal coagulation, potentially increasing the bleeding risk. For these reasons, the body temperature regulation is a critical aspect to monitor and control during anesthesia[1].

In the operating room, the anesthesiologist plays a critical role in preventing unintentional hypothermia. Implementation of surgical safety checklists, such as those recommended by the World Health Organization, includes measures to confirm proper function of anesthetic equipment. During anesthesia, thermal homeostasis is compromised by several factors, including the anesthetic drugs effects on the body's thermoregulatory mechanisms and the cold operating room environment patient's exposure. These conditions may lead to inadvertent hypothermia, which in turn may impair hemodynamic function and exacerbate the risks associated with the surgical procedure and postoperative recovery. Hypothermia affects hemodynamic variables by decreasing heart rate and increasing peripheral vascular resistance, resulting in decreased cardiac index. This may be problematic in patients with pre-existing heart disease, as the heart may not be able to adequately compensate for the demands of constant blood pressure and blood flow. Additionally, hypothermia can alter the viscoelastic blood properties, which increases viscosity and puts more work heart[2].

At a cellular level, hypothermia can also influence hemorheology, affecting blood's ability to flow and form clots. Coagulation mechanisms are highly susceptible temperature variations; therefore, hypothermia can lead to platelet dysfunction.

II. MATERIAL AND METHODS

This is a retrospective, descriptive and analytic study. It was conducted in records in Abdominal Transplant Unit in Hospital Juarez de México from June 2023-2024. The sampling was non probabilistic by convenience. Inclusion criteria included kidney orthotopic adult patients with or without thermoregulation with hot air turbine. Those with decompensated kidney disease due to bleeding o hemodynamic instability were excluded. The aim was to compare the gasometrical and hemodynamical variables before and after reperfusion in the group with thermoregulation with hot aire turbine and without.

Demographic data were obtained, and gasometrical and hemodynamical variables including the following: venous pH, arterial pH, Oxygen Venous Saturation (ScVO2), Arterial Lactate, Cardiac Output (CO), Cardiac Index (CI), Stroke Volume (SV), Systemic Vascular Resistance (SVR), Oxygen Extraction Rate (OER), Cardiac Power (CP), Myocardial Efficency (EH) were recorded before (1 minuto) and after reperfusion (3 minutes). Cardiac Output, Cardiac Index, Stroke Volume and Systemic Vascular Resistance were obtained by monitorization with Edwards Hemosphere.

Procedure.

By standardized anaesthetic procedure at the Hospital Juarez de México, general anaesthesia was administered to all patients with intravenous Fentanyl at a dose of 2mcg/kg, Propofol at 2mg/kg and Rocuronium at a dose of 0.60 mg/kg with a latency of 4 minutes and ventilation with Intermittent manual positive pressure with FIO2 100%. All patients underwent atraumatic laryngoscopy with endotracheal tubes that varied in the case of women (6.5-7.5 DI) and in the case of men (7.5-8.5 DI). They were connected to an anaesthetic circuit with mechanical ventilation in airway protective parameters in PCV-VG mode VTE 6-8 ml/kg, RR 10-17 rpm, I:E 1:2.5, PEEP 6-8 according to PEEP/ARDSnet. For anaesthetic maintenance, Desflurane of 0.8-1.2 MAC with Sedline (30-50 PSI) is used. The left or right jugular vein was cannulated with a 7FR central catheter according to the exhaustion of the patient's central venous access and a 20G arterial line was placed in the left or right radial according to the presence of arteriovenous fistula.

All patients were administered 3 boluses of 100 ml/hr each to dilute medications (antibiotic therapy, glucocorticoid, antihistamine) and are subsequently maintained at a dose of 10-15 ml/kg/hr and additional boluses of intravenous fluid. 250 ml of Hartman solution in case of hypotension (defined with SBP <90 mm Hg or MAP <60 mm Hg). Type II monitoring of heart rate, continuous blood pressure and central venous pressure (CVP) is maintained. In case of having a CVP greater than 15 mm Hg and hypotension, multiple boluses of Ephedrine 5 mg IV (boluses) are administered until the episode resolves.

There were divided by two groups: The first group has thermoregulation with hot air turbine and the second group was not thermoregulated with hot air turbine.

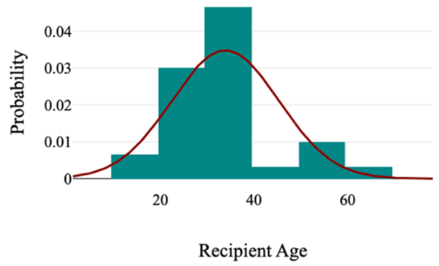
Statistical analysis

The data was integrated into an Excel database and statistical processing was performed in SPSS or STATSm software. The statistical analysis was tested for normality according to Kolmogorov-Smirnov with Lilliefors correction, where it was found that the population has a normal or non-normal distribution. The Mann-Whitney U test was performed to compare the difference of the means between the two groups. A correlation was made with Kendall´s Tau coefficient; All statistical analyzes were performed with a value of $p<0.05$, considering these significantly.

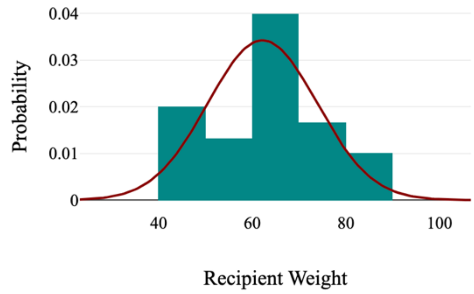
This work was performed with the approval of the institutional research and ethics committees. The present study is considered without research risk in accordance with the regulations of the general health law on health research.

III. RESULTS

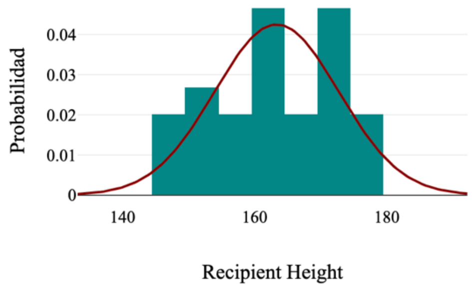
Of a total of 65 transplant patients, records were reviewed, with only 28 having appropriate inclusion criteria. Of the remaining 28, 16 were female (57.14%) and 12 were male (42.8%) with a mean age of recipients of 30.24±11.45 years (graphic 1) with a weight of 58.23±10.47 kg (graphic 2), height 154.20±15.32 (graphic 3).



Graph 1. **Histogram with mean and median ages of the donor and recipient respectively with normal distribution. Kolmogorov-Smirnov with Lilliefors Correction (*p=0.04*)**



Graph 2. **Histogram with mean and median weight of the recipient with no normal distribution. Kolmogorov-Smirnov with Lilliefors Correction (*p=0.077)***



***Graph 3.* Histogram with mean and median height of the recipient with no normal distribution. Kolmogorov-Smirnov with Lilliefors Correction (*p=0.072*)**

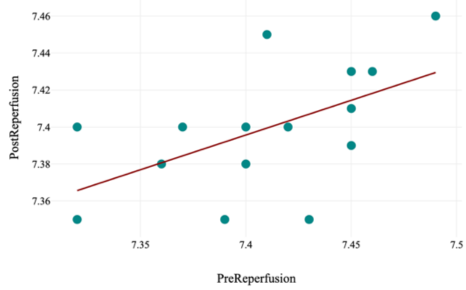
<u>Gasometrical and Hemodynamic Values upon Reperfusion with Forced Air Turbine.</u>

The gasometrical variables before reperfusion were: Venous pH 7.41±0.05 (p=0.046); Arterial pH 7.40±0.04 (p=0.015); Venous Oxygen Saturation 68.2±9.74% (p = 0.039); Arterial Lactate 1.17±0.46 (p=0.052); Hemodynamic variables before reperfusion were: Cardiac Output 5.87±3.15 lt/min (p=0.063); Cardiac Index 3.67±1.77 lt/min/m2 (p=0.001); Stroke Volume 79.5±39.6 ml/beat (p = 0.022); Systemic Vascular Resistance 884.9±389.5 dyne/cm5; (p = 0.067), Oxygen Extraction 25.1±9.95% (p = 0.001), Cardiac Power 1.18±0.54 (p=0.061) and Myocardial Efficiency 0.28±0.06 (p=0.024) (*table 1*).

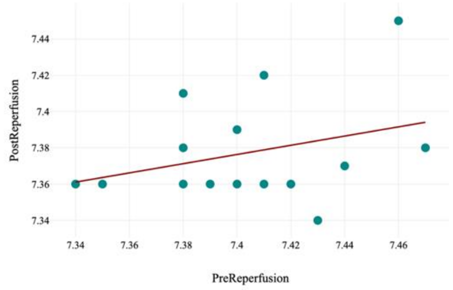
Table 1. Gasometrical and hemodynamical variables before and after reperfusion with hot forced air turbine.

Gasometrical and Hemodynamic Values upon Reperfusion with Forced Air Turbine.	**PreReperfusión**	**PostReperfusión**	**Correlation (Kendall´s Tau)**
Venous pH	7.41±0.05	7.40±0.03	*p=0.046 (graph 4)*
Arterial pH	7.40±0.04	7.38±0.04	*p=0.024 (graph 5)*
Oxygen Venous Saturation % (SCVO2)	68.2±9.74	60.03±4.37	*p=0.039*
Arterial Lactate	1.17±0.46	0.81±0.39	*p=0.052*
Cardiac Output Lt/min (CO)	5.87±3.15	4.57±0.95	*p=0.063*
Cardiac Index Lt/min/m^2 (CI)	3.67±1.77	2.88±0.48	*p=0.001(graph 6)*
Stroke Volume ml/beat (SV)	79.5±39.6	65.4±16.01	*p=0.022*
Systemic Vascular Resistance dynas/cm3 (SVR)	884.9±389.5	1323.8±340.8	*p=0.067*
Oygen Extraction Rate % (OER)	25.1±9.95	36.9±4.31	*p=0.001(graph 7)*
Cardiac Power (PC)	1.18±0.54	0.90±0.20	*p=0.061*
Myocardial Efficiency (EH)	0.28±0.06	0.32±0.06	*p=0.024 (graph 8)*

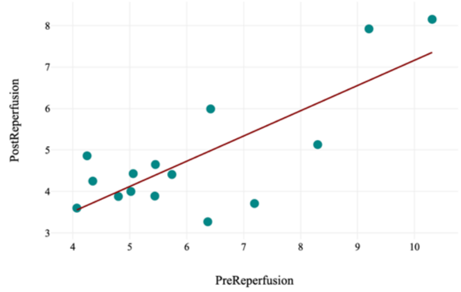
The gasometrical variables after reperfusion were: Venous pH 7.40±0.03; Arterial pH 7.38±0.04; Venous Oxygen Saturation 60.03±4.37%; Arterial Lactate 0.81±0.39; Hemodynamic variables after reperfusion were: Cardiac Output 4.57±0.95 lt/min; Cardiac Index 2.88±0.48 lt/min/m^2; Stroke Volume 65.4±16.01 ml/beat; Systemic Vascular Resistance 1323.8±340.8 dynas/cm5 Oxygen Extraction Rate 36.9±4.31% (p = 0.039); Cardiac Power 0.90±0.20 and Myocardial Efficiency 0.32±0.06 (*table 1*).



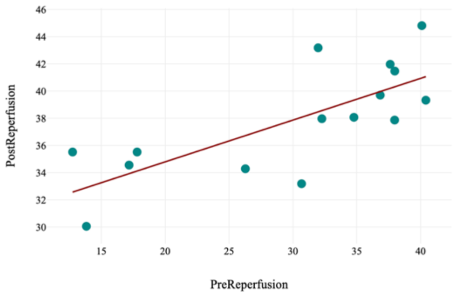
***Graph 4.* Scatter Diagram of Venous pH Data Pre and Post Reperfusion Data with Forced Air Turbine (r=0.98, p=0.046)**



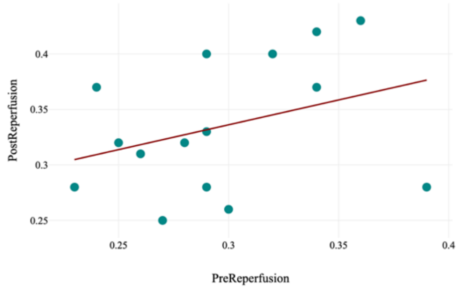
***Graph 5.* Scatter Diagram of Arterial pH Data Pre and Post Reperfusion Data with Forced Air Turbine (r=0.82, p=0.024)**



***Graph 6.* Scatter Diagram of Cardiac Index Data Pre and Post Reperfusion Data with Forced Air Turbine (r=0.77, p=0.001)**



***Graph 7*. Scatter Diagram of Oxygen Extraction Rate Data Pre and Post Reperfusion Data with a Forced Air Turbine (r=0.75, p=0.001)**



***Graph 8*. Scatter Diagram of Myocardial Efficiency Data Pre and Post Reperfusion Data with a Forced Air Turbine (r=0.82, p=0.024)**

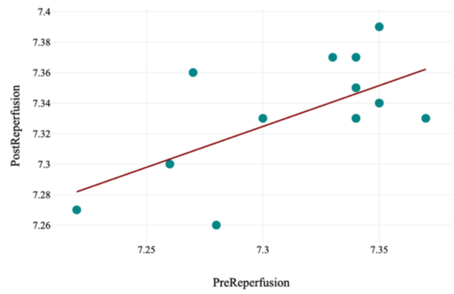
Gasometrical and Hemodynamic Values upon Reperfusion without Forced Air Turbine.

The gasometrical variables before reperfusion were: Venous pH 7.32±0.04 (p=0.012); Arterial pH 7.30±0.04 (p=0.019); Venous Oxygen Saturation 64.7±8.27% (p = 0.026); Arterial Lactate 0.94±0.63 (p = 0.058); Hemodynamic variables before reperfusion were: Cardiac Output 5.43±3.23 lt/min (p=0.0509); Cardiac Index 3.28±1.66 lt/min/m2 (p = 0.006); Stroke Volume 72.39±45.44 ml/beat (p=0.029); Systemic Vascular Resistance 818.4±417.66 dynas/cm5 (p = 0.063); Oxygen Extraction Rate 29.11±9.65% (p = 0.001); Cardiac Power 0.97±0.584 (p=0.069) and Myocardial Efficiency 0.268±0.08 (p=0.022) (*table 2*).

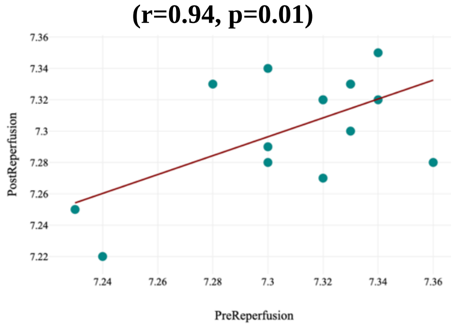
Table 2. Gasometrical and hemodynamical variables before and after reperfusion without hot forced air turbine.

Gasometrical and Hemodynamic Values upon Reperfusion without Forced Air Turbine.	Pre Reperfusión	PostReperfusión	Correlation (Kendall´s Tau)
Venous pH	7.32±0.04	7.33±0.04	*p=0.012 (graph 9)*
Arterial pH	7.30±0.04	7.32±0.05	*p=0.019 (graph 10)*
Oxygen Venous Saturation % (SCVO2)	64.7±8.27	58.59±5.41	*p=0.026*
Arterial Lactate	0.94±0.63	0.80±0.62	*p=0.058*
Cardiac Output Lt/min (CO)	5.43±3.23	4.58±1.58	*p=0.0509*
Cardiac Index Lt/min/m² (CI)	3.28±1.66	2.75±0.69	*p=0.006 (graph 11)*
Stroke Volume ml/beat (SV)	72.39±45.44	59.05±18.81	*p=0.029*
Systemic Vascular Resistance ynas/cm3 (SVR)	818.4±417.66	1205±508.19	*p=0.063*
Oygen Extraction Rate % (OER)	29.11±9.65	38.47±6.17	*p=0.001(graph 12)*
Cardiac Power (PC)	0.97±0.58	0.89±0.33	*p=0.069*
Myocardial Efficiency (EH)	0.26±0.08	0.31±0.05	*p=0.022 (graph 13)*

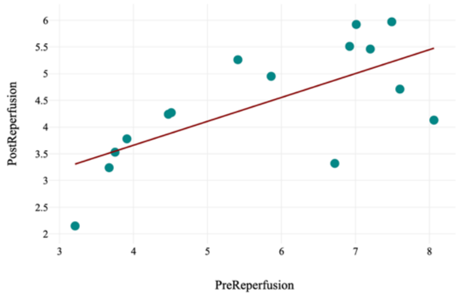
The gasometrical variables after reperfusion were: Venous pH 7.330±0.04; Arterial pH 7.320±0.05; Venous Oxygen Saturation 58.59±5.41%; Arterial Lactate 0.80±0.62; Hemodynamic variables after reperfusion were: Cardiac Output 4.58±1.58 lt/min; Cardiac Index 2.75±0.69 lt/min/m2, Stroke Volume 59.05±18.81 ml/beat; Systemic Vascular Resistance 1205±508.19 dyne/cm5, Oxygen Extraction Rate 38.47±6.17%; Cardiac Power 0.89±0.33) and Myocardial Efficiency 0.31±0.05 (*table 2*).



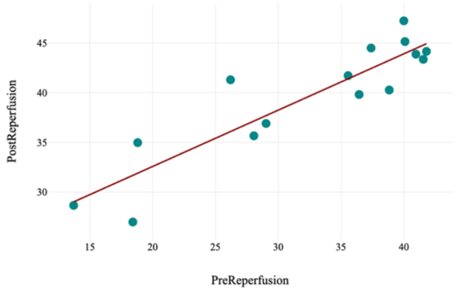
***Graph 9*. Scatter Diagram of Venous pH Data Pre and Post Reperfusion Data without Forced Air Turbine (r=0.94, p=0.01)**



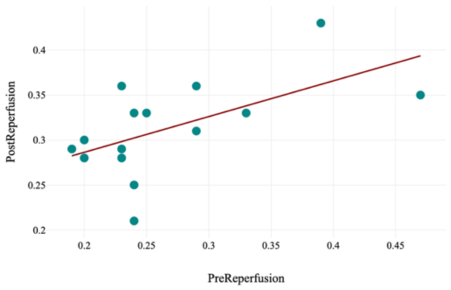
***Graph 10*. Scatter Diagram of Arterial pH Data Pre and Post Reperfusion Data without Forced Air Turbine (r=0.8, p=0.019)**



***Graph 11*. Scatter Diagram of Cardiac Index Data Pre and Post Reperfusion Data without Forced Air Turbine (r=0.86, p=0.006)**



***Graph 12*. Scatter Diagram of Oxygen Extraction Rate Data Pre and Post Reperfusion Data without Forced Air Turbine (r=0.91, p<0.001)**



***Graph 13*. Scatter Diagram of Myocardial Efficiency Data Pre and Post Reperfusion Data without Forced Air Turbine (r=0.88, p=0.022)**

IV. DISCUSION

Reperfusion during a kidney transplant is a critical moment in the surgical process, where the transplanted kidney is again exposed to blood flow after a period of ischemia. During this process, significant changes occur in various physiological parameters, including venous pH. In particular, the 3m Hugger compression device use during surgery has raised interest in its impact on acid-base homeostasis during reperfusion in these patients.

The air compression device is a type of forced air turbine used to maintain body temperature during surgery, minimizing patient heat loss. Currently, scientific evidence has shown that the hot forced air affects laminar blood flow application and therefore influences the kinetics of kidney reperfusion. These changes in the kinetics of the liquids and in the hemorheological properties influence the changes in the Venous pH, Arterial pH as well as in the Venous Oxygen Saturation, being statistically significant in our study.

Venous pH during reperfusion shows a tendency towards alkalinity (acid-base balance) compared to the group that was not under the hot air turbine effects. The arterial pH preserves this trend with a positive effect during kidney perfusion, avoiding the transient metabolic acidosis that may occur in kidney transplant patients upon graft reperfusion. It is worth mentioning that during ischemia the increase in oxygen extraction leads to the accumulation of metabolites such as lactic acid, which contributes to changes in the acid-base balance; However, by restoring the flow in reperfusion and with the proper functioning of the graft, it allows the adequate elimination of acid products and thus both venous normalization and arterial pH.

Likewise, Venous Oxygen Saturation, being a parameter that reflects the amount of oxygen extracted by the body's tissues, is a reliable indicator of tissue perfusion as a balance between supply and demand of oxygen. During the graft ischemia period (hot, cold and warm ischemia) it maintains a thermal balance without affecting oxygen extraction through the tissues. With kidney reperfusion, this increase in tissue extraction causes better graft oxygenation and therefore an improvement in SVO2, unlike what happens with the control group.

Reperfusion also produces an effect in which venous return decreases and therefore stroke volume and cardiac index. This volume decrease is due to the fact that the graft extracts both oxygenation and volume upon reperfusion, which in turn produces an acute reduction in atrial and ventricular preload with a better homeometric adaptation evidenced by the behavior of myocardial efficiency in patients who had forced hot air treatment compared to those without it.

V. CONCLUSIONS

In patients undergoing living donor kidney transplantation, understanding the blood gas and hemodynamic changes upon reperfusion are crucial to ensure the short and long-term success of the kidney graft.

Forced hot air turbine therapy improves venous pH, arterial pH, and Venous Oxygen Saturation upon reperfusion compared to transplant patients who were not applied any therapy to maintain body temperature.

Cardiac index and stroke volume are positively affected by adequate temperature maintenance with the forced hot air turbine, allowing a homeometric adaptation to the decrease in venous return that occurs upon reperfusion in kidney transplant patients.

Limitations of our study included a small sample, heterogeneity of the etiologies of patients undergoing renal transplantation, differences between patient populations in terms of sex, age. The works published to date present statistically significant and consistent results in the line of thought. However, studies with a larger population sample are required that include this patient's group to achieve reference and therapeutic values.

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The authors declare not having received support from any sponsor or resources outside those granted by the medical institution.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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