Using microdialysis for early detection of vascular thrombosis after kidney transplantation in an experimental porcine model

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Abstract
Background. In kidney transplantation (KTx), vascular thrombosis has a major impact on morbidity and graft survival. The ischaemia, caused by thrombosis, can lead to interstitial metabolite changes. The aim of this experimental study was to create conditions in which the graft would be prone to vascular thrombosis following KTx and then to evaluate the role of microdialysis (MD) for its early detection.

Methods. Sixteen randomized pigs in the control group received heparin and immunosuppressive drugs, while the case group received none. Based on histopathological evidence of vascular thrombosis, the case group was subdivided into mildly and severely congested subgroups. Using MD, we evaluated the interstitial concentrations of glucose, lactate to pyruvate ratio, glutamate and glycerol in the transplanted grafts during different phases of KTx.

Results. Following reperfusion, we noted considerable changes. The severely congested subgroup showed a low and decreasing level of glucose. Only in this group did the lactate to pyruvate ratio continue to increase until the end of monitoring. The glycerol level increased continuously in the entire case group and this increase was most significant in the severely congested subgroup. In all of the study groups, glutamate concentration remained in a low steady state until the end of monitoring.

Conclusions. MD can be an appropriate method for early detection of vascular complications after KTx. Decreasing glucose levels, increased lactate to pyruvate ratio and
increased glycerol levels are appropriate indicators for early detection of vascular thromboses following KTx. Particularly, the glycerol level could predict the necessity and urgency of intervention needed to ultimately save the transplanted kidney.

**Keywords:** kidney transplantation; microdialysis; metabolic changes; vascular thrombosis

**Introduction**

In kidney transplantation (KTx), advances in surgical techniques, perioperative management and immunosuppressive regimens have reduced the incidence of graft complications. However, the incidence of post-operative vascular complications after KTx still remains as high as 10% [1–3]. Thrombosis is the major vascular complication that can lead to early graft loss in the first week after transplantation. Early diagnosis and urgent intervention could have a huge impact on improving the early graft survival rate [1, 3–5].

For detecting vascular thrombosis, various parameters including urine output, serum creatinine and blood urea nitrogen [6, 7] as well as diagnostic imaging techniques including color doppler ultrasound, computed tomography and magnetic resonance imaging [8] are currently used. However, because of their low effectiveness as a detecting tool at early phases, there is a clear need for a new technique to detect thrombosis in KTx before being detectable in blood or through the use of diagnostic imaging.

Microdialysis (MD) is a minimally invasive method of measurement capable of on-time and online monitoring of interstitial metabolic changes in organs [9–12]. The mechanism of MD is based on a simple diffusion through a semipermeable membrane located on the tip of the MD probe inserted into the tissue of interest. We have already demonstrated that MD could be used for monitoring kidney graft function and damage during and after transplantation through specific fluctuation in the patterns of interstitial metabolites in different phases of KTx [13]. Additionally, impaired graft function resulting from extended cold ischaemia time (CIT) in KTx can be also easily evaluated by this technique. The role of MD in detecting the interstitial metabolic changes during warm ischaemia in the kidney by complete arterial and venous clamping has been evaluated in some porcine studies [4, 14]. In the current study, we created conditions in which the graft was prone to vascular thrombosis after KTx. Following the hypothesis that MD can detect interstitial metabolite changes during ischaemia, we then evaluated the role of MD in early detection of vascular thrombosis in a porcine KTx model.

**Materials and methods**

**Study design**

In our study, we used a total number of 16 Landrace pigs with a mean body weight of 27.7 ± 1.8 kg. During the explantation phase, the organs were perfused with a standard histidine–tryptophan–ketoglutarate (HTK) solution (Custodiol; Dr F. Kohler Chemie GmbH, Alsbach-Hahlein, Germany). After a CIT of 24 h, the grafts were implanted using a standardized technique. The animals were randomized into two groups: the control group (n = 8) received heparin and an immunosuppressive drug after reperfusion, whereas in the case group (n = 8), none of those drugs were administered. The metabolic changes at the end of CIT, during warm ischemia time (WIT) and within 180 min after reperfusion were monitored using MD (Figure 1).

**Animal preparation and anaesthesia**

All pigs fasted for 12 h with free access to water. Premedication with azaperone 8 mg/kg intramuscularly, midazolam 0.5–0.7 mg/kg intramuscularly, ketamine 5 mg/kg intravenously (i.v.) and atropine sulphate 1 mg i.v. was followed by endotracheal intubation. The animals were ventilated with a mixture of air (1.5–2 L/min), O2 (0.5–1 L/min), N2O (1.5–2 L/min) and isoflurane (0.75–1.5%) at a frequency of 20/min. Cardiovascular parameters, including mean arterial pressure (MAP) as well as heart rate, were continuously monitored.

**Surgical procedures**

**Graft explantation.** Through a midline laparotomy, the left kidney and its vessels were fully mobilized from the retro-peritoneum. After preparing the renal artery and vein, each donor received 20 000 IU heparin. The infrarenal aorta was cannulated and the subdiaphragmatic was then cross-clamped. Subsequently, the kidneys were perfused using HTK solution with a controlled pressure of 120 mmHg. The nephrectomy was performed containing the carrel patch of the aorta, renal vein and ureter. The organs were preserved in HTK solution for 24 h at 4°C. Afterwards, one MD catheter was placed in the renal cortex at a 45° angle and fixed by a single stitch suture using prolene 6-0.

**Graft implantation.** Following anaesthesia induction and intubation of the recipient pigs, a central venous catheter was inserted through the left external jugular vein and an arterial catheter was placed in the common carotid artery. Arterial oxygen saturation (SaO2), rectal temperature and MAP were continuously monitored during operation. The control group received Methylprednisolone (Urbason; Sanofi-Aventis, Frankfurt, Germany) with a dosage of 250 mg i.v. After laparotomy, the kidney graft was implanted in the right lower abdominal fossa. The venous reconstruction was done through an end-to-side Anastomosis between the renal vein and the inferior vena cava with continuous monofilament single layer sutures (prolene 5-0). A similar arterial end-to-side Anastomosis was performed between the aortic carrel patch and recipient aorta (prolene 5-0). At the end of CIT and during vascular reconstruction (WIT), the metabolic changes of the graft were monitored. The control group received heparin with a dosage of 200 IU/kg. After declamping the renal vein and artery, MD samples were collected during reperfusion and again after 180 min. Intraoperatively, recipients received metamizol 500 mg i.v. and isotonic solution (NaCl 0.9% or Ringer).

**Collection and analysis of the microdialysis samples**

We used a CMA 20 microdialysis catheter (CMA Microdialysis, Sweden). The dialysing membrane was 10 mm in length and the catheter membrane cut-off was 20 000 Da. Insertion into the tissue was achieved with the help of a unique slit cannula introducer which left the catheter in place when it was withdrawn. The catheter was connected to a CMA 102 pump (CMA microdialysis) through inlet tubes and perfused a special fluid (Na: 147 mmol/L, K: 4 mmol/L, Ca: 2.3 mmol/L and Cl: 156 mmol/L) at a flow rate of 2 μL/min into the catheter. The outlet tube extends to a microdialysis collector CMA 142 (CMA Microdialysis) holding the microcyls. After collecting the samples, all microcyls were stored at −80°C for further assessment. The samples were then analysed by a CMA 600 Microdialysis analyser. The measured parameters included glucose (millimoles per litre), lactate to pyruvate ratio, glycerol (micromoles per litre) and glutamate (micromoles per litre).

**Measurement protocol**

In both groups, a single sample was collected at the end of CIT. Three samples were collected during WIT and nine samples were obtained in the post-reperfusion phase over 20 min intervals for 3 h. In order to standardize our experimental study in each group, blood samples were obtained from donors (one sample during procurement) and from recipients (one sample before and another one at the end of the reperfusion phase). The serum haemoglobin, haematocrit and creatinine values were determined in the central laboratory of our clinic. In addition, for further standardization of interstitial measurements, the glucose and lactate concentration were measured in plasma samples.
Macroscopic and histopathological evaluations

The colour of the organs was observed after reperfusion by three different individuals. Biopsy samples were taken before and 180 min after reperfusion. All samples were fixed in formaldehyde 5% and analysed by the same experienced pathologist, who was blinded to the randomization. The biopsies were analysed in order to detect histopathological evidence of graft congestion regarded to be a typical sign of vascular thrombosis in the transplanted kidney as described by Salmela and Kooijmans [15–17]. Following our histopathological analysis, the transplanted kidneys in our case group were divided into a ‘mildly’ and a ‘severely’ congested group.

Animal rights

The experiment was approved by the Governmental Committee on Animal Care and the animals were given human care in compliance with institutional guidelines. Following completion of the experimental protocol, the animals were sacrificed with a bolus i.v. infusion of kalium chloride (2 mmol/kg) under deep anaesthesia.

Statistics

The analysis was performed using SPSS 14.0 (Stata Corp., College Station, TX) for windows. The variable analysis was performed using t-tests and analysis of variance when needed. All metabolic parameters were expressed as mean ± SEM. The laboratory results were expressed as mean ± SD. A P-value <0.05 was considered statistically significant.

Results

In both study groups, the monitored cardiovascular parameters during the implantation and post-reperfusion phase, including MAP and heart rate, did not show any significant differences (Table 1). Due to the use of warm blankets during the procedures, the body temperature was kept above 36°C in all animals. This means that haemodynamic status was maintained stable and comparable in all evaluated phases in our study groups. The mean values of the laboratory results are summarized in Table 1. As demonstrated, in both study groups, during different phases of KTx (explantation, WIT and postreperfusion) no significant fluctuations were seen in any of the above-mentioned variables.

Macroscopic and histopathological analysis

In the late post-reperfusion phase, all kidneys in the case group demonstrated macroscopically considerable changes from a normal to a dark blue colour. In all the samples from both our case and control groups, cytoplasm vacuolization, focal denudation from epithelial basement membrane and

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**Table 1.** The mean values of haemodynamics and laboratory results in both case and control groups during organ procurement and kidney transplantation

<table>
<thead>
<tr>
<th></th>
<th>Puls rate (per min)</th>
<th>MAP (mmHg)</th>
<th>Haemoglobin (g/dL)</th>
<th>Haematocrit (%)</th>
<th>Glucose (mg/dL)</th>
<th>Creatinin (mg/dL)</th>
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<tbody>
<tr>
<td><strong>Explantation</strong></td>
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<tr>
<td>Control group</td>
<td>81 ± 10.4</td>
<td>66.0 ± 5.8</td>
<td>9.9 ± 0.4</td>
<td>31 ± 2</td>
<td>106.5 ± 33.1</td>
<td>1.2 ± 6.2</td>
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<tr>
<td>Case group</td>
<td>79 ± 10.3</td>
<td>71.3 ± 4.3</td>
<td>10.6 ± 0.1</td>
<td>33 ± 4</td>
<td>117.2 ± 36.6</td>
<td>1.1 ± 0.1</td>
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<td><strong>Warm ischaemia time</strong></td>
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<tr>
<td>Control group</td>
<td>77.2 ± 11.6</td>
<td>67.0 ± 8.5</td>
<td>9.6 ± 0.5</td>
<td>29 ± 1</td>
<td>125.6 ± 27.1</td>
<td>1.1 ± 0.1</td>
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<tr>
<td>Case group</td>
<td>82 ± 8.7</td>
<td>70.3 ± 5.2</td>
<td>9.8 ± 1.2</td>
<td>30 ± 4</td>
<td>108.6 ± 43.1</td>
<td>0.9 ± 0.1</td>
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<tr>
<td><strong>Post-reperfusion</strong></td>
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<tr>
<td>Control group</td>
<td>83.7 ± 12.1</td>
<td>67.5 ± 6.0</td>
<td>10.4 ± 1.2</td>
<td>32 ± 4</td>
<td>138.8 ± 34.4</td>
<td>1.0 ± 0.1</td>
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<tr>
<td>Case group</td>
<td>81.6 ± 10.2</td>
<td>69.3 ± 3.8</td>
<td>10.4 ± 2.0</td>
<td>34 ± 4</td>
<td>172.6 ± 48.0</td>
<td>1.0 ± 0.2</td>
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</table>
Pyknosis were reported (Figure 2A). In the case group, we also detected congestion and interstitial bleeding (Figure 2B). Based on the histopathological evidence, these last two events (congestion and interstitial bleeding) were accepted as signs of vascular thrombosis. According to the severity of congestion and interstitial bleeding, the case group was divided into the mildly \((n = 3)\) and the severely \((n = 5)\) congested subgroups.

Monitoring of metabolic changes

The glucose, lactate, pyruvate, glutamate and glycerol levels in graft interstitium were measured during different phases of the experiment (at the end of CIT, during WIT and post-reperfusion) and values were compared for the three groups (the control group, the mildly congested and the severely congested groups). Mean blood glucose levels remained constant in both trial and control groups during different phases \((123.2 \pm 31.5 \text{ versus } 132.8 \pm 42.5 \text{ mg/dL})\) (Table 1). Also, the mean systemic lactate levels in both groups were not significant \((22.5 \pm 2.8 \text{ versus } 20.2 \pm 2.3 \text{ mg/dL})\).

Glucose

At the end of CIT, glucose levels with values around 0.06 mmol/L showed no significant differences between the three groups. At the end of WIT, an increasing trend was observed in all three groups, with a similar slope in the two case groups and a sharper slope in the control group. This trend continued with the same pattern during the early reperfusion phase and 20 min after reperfusion. This led to a significantly higher value in the control group compared to the two case groups \([\text{control group: } 2.03 \pm 0.39 \text{ versus case groups (mildly congested group: } 0.72 \pm 0.39, P\text{-value } = 0.049 \text{ and severely congested group: } 0.73 \pm 0.07 \text{ mmol/L, } P\text{-value } = 0.01)]\). Subsequently, in the control group, the increasing trend continued and reached a peak of 2.94\( \pm 0.33\), while it decreased in both case groups. Eighty minutes after reperfusion, glucose levels in all three groups were significantly different from each other \([\text{control: } 2.47 \pm 0.30 \text{ versus mildly congested group: } 0.40 \pm 0.25 \text{ versus severely congested group: } 0.15 \pm 0.05 \text{ mmol/L, } P\text{-value } = 0.001])\). From the mid-point to the end of the postreperfusion phase, glucose levels decreased in the control group \((180 \text{ min after reperfusion: } 1.9 \pm 0.29 \text{ mmol/L})\) and the severely congested group \((180 \text{ min after reperfusion: } 0.15 \pm 0.05 \text{ mmol/L})\) but increased slightly in the mildly congested group \((180 \text{ min after reperfusion: } 0.41 \pm 0.29 \text{ mmol/L})\). The reached glucose values showed significant differences in both groups \([\text{control: } 1.92 \pm 0.87 \text{ versus mildly congested group: } 0.41 \pm 0.63 \text{ versus severely congested group: } 0.05 \pm 0.03 \text{ mmol/L, } P\text{-value } = 0.003 \text{ mmol/L}]\) (Figure 3).

Lactate to pyruvate ratio

For our three study groups, we also calculated the lactate to pyruvate ratio. The three groups showed different fluctuating trends. Immediately after reperfusion, there were no significant differences among the groups \([\text{control group: } 25.08; \text{mildly congested group: } 18.9 \text{ and severely congested group: } 41.6])\). This ratio briefly increased in the severely congested group, while a steady low level was maintained in the mildly congested and control groups. At the end of our post-reperfusion phase, no significant difference could be found between the groups.

Fig. 2. Histopathological samples of the evaluated biopsies at the end of monitoring in both control (A) and case (B) groups. There is focal cytoplasm vacuolization of tubular epithelium (A and B). Additional distinct hyperaemia of small vessels (showed by arrows) in the case group (B) (trichrome100\( \times \)) can be seen as an evidence of graft congestion and a typical sign of vascular thrombosis.

Fig. 3. Glucose values measured during kidney implantation and after reperfusion in our control group as well as mildly and severely congested subgroups using microdialysis.

Fig. 4. Glutamate values measured during kidney implantation and after reperfusion in our control group as well as mildly and severely congested subgroups using microdialysis.
Glycerol

During WIT, in all three groups, there was an initial sharp increase in the glycerol measurements, which reached a peak with values around 1000 \( \mu \text{mol/L} \). These levels subsequently declined. Twenty minutes after reperfusion, we noted a sharp decrease in all groups with no significant differences among them (control group: 796.4 \( \pm \) 97.8 versus mild group: 553.4 \( \pm \) 136.0 versus severe group: 630.2 \( \pm \) 97.8 \( \mu \text{mol/L} \)). During the second 20-min interval following reperfusion, the decreasing trend continued in all three groups. Sixty minutes after reperfusion, glycerol levels reached a steady state in the control group and remained unchanged until the end of monitoring. On the other hand, in both case groups, 100 min after reperfusion, the glycerol levels started to increase and showed a sharper slope in the severely congested group. At this point, the differences among the groups were significant (control group: 21.7 \( \pm \) 2.69 versus mild group: 66.9 \( \pm \) 50.6 versus severe group: 113.9 \( \pm \) 97.8 \( \mu \text{mol/L} \), \( P \)-value = 0.04). In all groups, this trend was maintained until the end of post-reperfusion, which then showed significantly different values (severe group: 178.4 \( \pm \) 9.56 versus mild group: 82.1 \( \pm \) 62.3 versus control group: 31.6 \( \pm \) 4.04 \( \mu \text{mol/L} \), \( P \)-value = 0.006) (Figure 5).

Discussion

One of the most serious problems following KTx is vascular complication [1, 18]. Early detection of this complication could impact the morbidity and subsequent survival of the graft and patient. The parameters currently used for monitoring graft function, including urinary output, serum creatinine and blood urea nitrogen, have functioned as ‘delayed markers’ of graft condition because of the lag in time between graft injury and detection of pathological changes [6, 7]. MD seems to be ideal for online monitoring of metabolic changes in grafts during solid organ transplantation [9–11, 13, 19]. It has been shown that MD can rapidly detect ischaemia both in arterial or venous occlusions [10]. Additionally, it has been reported that through the use of MD, a 60% decrease in blood flow of the organ leading to alteration in interstitial metabolite concentration can be detected within 30 min [14]. Therefore, MD could be an appropriate tool for the detection of vascular complications in the early reversible phases of organ ischaemia.

The present study assesses the effects of vascular thrombosis on interstitial metabolites in an experimental porcine model of KTx using MD. We used a porcine model, which is well established for our research in solid organ transplantation [9, 13, 19]. The porcine model can also simulate the clinical situation in the case of venous thrombosis after KTx. In our study, in order to avoid undesirable factors, the anaesthesia and surgical techniques were done in a standardized fashion, by the same operating team experienced in experimental and clinical KTx. We preserved our grafts using HTK because of its demonstrated ability to maintain graft function comparable with University of Wisconsin solution after a long preservation period of 30 h [20]. As indicated previously, the study groups showed no fluctuations either in cardiovascular parameters or in various laboratory values. Interstitial bleeding and congestion of peritubular capillaries, in combination with macroscopic evidence are considered early signs of vascular thrombosis. Based on previous studies [16, 17] demonstrating the early stage of an outflow problem after KTx, we found that all grafts in our case group were developing thrombosis. We divided these cases into a ‘mildly congested’ and a ‘severely congested’ subgroup and compared them with a control group using the degree of interstitial bleeding and tissue congestion as primary markers.

In our experiment, glucose levels increased considerably after reperfusion in all study groups. This increase depended on the occurrence of hyperperfusion and ‘flow-metabolism’ mismatch [12]. In our control group, the increase showed a sharper slope compared with the congested groups and remained at a higher level until the end of the post-reperfusion phase. This higher glucose level could be explained as an effect of glucocorticoids, which had been administered only in our control group [21–23].
Forty minutes after reperfusion, we noticed a decrease in glucose level in all study groups. This effect is a result of the recovery of glycolytic enzymes, which improves the glucose consumption in the graft. In our study, the glucose level in the severely congested subgroup continuously decreased until the end of monitoring due to perfusion deterioration and the subsequent lack of oxygen and glucose supply to the organ. In this hypoxic state, cell metabolism becomes primarily anaerobic in order to provide energy. The less effective use of glucose in anaerobic metabolism increases the substrate consumption. A decreased supply of glucose and its increased consumption in the ischaemic graft leads to a lowered interstitial glucose level [24, 25]. Thus, the low level and decreasing trend of glucose in the interstitium can be regarded as a suitable marker for early detection of a disturbance in organ perfusion.

The lactate to pyruvate ratio has been described as a marker of cell ischaemia [9]. While a cell depends mainly on anaerobic glycolysis in the ischaemic phase, pyruvate is converted to lactate to provide the essential nicotine amide adenine dinucleotide NAD⁺ for glycolysis, which leads to an increased lactate to pyruvate ratio [26, 27]. In our control group, this ratio decreased after reperfusion and remained in a steady state until the end of monitoring. This could be a result of an adequate supply of oxygen and glucose as well as recovered mitochondrial function after reperfusion. In our severely congested group, the lactate to pyruvate ratio continued to increase until the end of monitoring. This may be caused by mitochondrial dysfunction and energy perturbation following disruption of perfusion [28]. In the severely congested group, at the early post-reperfusion phase, the lactate to pyruvate ratio reached a level higher than 40 and the increasing trend continued until the end of monitoring. Vespa et al. [29] reported that a lactate to pyruvate ratio above 40 can be characterized as a threshold of energy crisis in the graft. Unexpectedly, in contrast to the work of Frykholm et al. [12], in our mildly congested subgroup, we did not observe the same increasing trend in the lactate to pyruvate ratio. Therefore, only in severe ischaemic states, can the lactate to pyruvate ratio be used as a significant marker for early detection of vascular thrombosis.

Glutamate as a marker of bioenergetic insufficiency is almost always located intracellularly [27]. All three study groups showed the same trend of considerable glutamate level decrease following reperfusion. Glutamate levels in the mildly and the severely congested subgroups did not increase until the end of monitoring. These data on glutamate in our study differ from other studies stating that the glutamate level increases after ischaemia [7, 10]. This difference in our study could be caused by a prolonged CIT (24 h), whereas other studies determined glutamate levels in KTx after CITs of up to 145 min [4, 6, 7, 14]. It is known that under normal physiological condition, specific carriers exchange intracellular glutamate with extracellular K⁺. After a long CIT with extended tubular damage [30], the increased level of extracellular K⁺ could not lead to an exchange of K⁺-glutamate. This event can explain the constant low levels of interstitial glutamate in the mildly and severely congested groups [10].

Glycerol, an integral component of the cell membrane, has been recognized as one of the important markers of cell injury [31, 32]. In all three groups, glycerol levels decreased sharply after reperfusion as a result of the washout phenomenon in which disintegrated cell membrane compounds are transported away by the systemic circulation [33]. One hundred minutes after reperfusion, glycerol levels in the mildly and in the severely congested groups started to increase. This delay is comparable with other published studies [10, 14]. The glycerol increase in our study continued in both congested groups. This increase could be explained using the data from the report of Frykholm et al. [28], which showed a positive correlation between the interstitial glycerol level and the duration as well as severity of the ischaemia. Weld et al. [7] suggested that glycerol values higher than 167 μmol/L are associated with irreversible renal damage. In our study, the severely congested subgroup showed a level of glycerol higher than 167 μmol/L in the late post-reperfusion phase. In accordance with Weld et al. [7], we also show that glycerol has a direct relationship with the severity and the duration of graft ischaemia and could be considered a useful marker in the detection of cell injury caused by ischemia even before the injury becomes irreversible. In other words, glycerol levels can determine the need and the urgency of interventions required to save the transplanted kidney.

Vascular thrombosis is one of the most serious complications following KTx and 93% of cases occur within the first 7 days after transplantation [1]. Currently used parameters such as urine output, serum creatinine and blood urea nitrogen [6, 7] as well as diagnostic imaging techniques [8] do not provide an early and rapid warning. Considering the fact that early detection of vascular thrombosis can allow for an urgent intervention resulting in recovery of graft function, MD could be considered as an appropriate minimally invasive monitoring tool for early detection of vascular thrombosis in KTx patients. On the other hand, due to a generally low incidence of vascular thrombosis, one needs to consider whether MD should be used in all KTx patients or only in high-risk groups. It may be that high-risk patients such as children [34] or recipients with vascular atherosclerosis and prolonged CIT would be a suitable candidates for MD monitoring following KTx [4]. While the decreasing interstitial glucose can be considered a proper marker for early detection of graft perfusion disturbances, particularly glycerol with its direct relationship to the duration and severity of graft ischaemia can indicate whether we are approaching an irreversible phase in transplanted graft injury. In conclusion, MD is a minimally invasive method for measurement of on-time and online interstitial metabolic changes in transplanted kidneys. We believe that, especially in high-risk patients, MD can be an appropriate method for early detection of vascular complications after KTx. Decreasing low glucose levels, increased lactate to pyruvate ratio and increased glycerol levels are significant indicators for early detection of vascular complications following KTx. The key point is that glycerol levels can predict early on the necessity and urgency for interventions to save the transplanted kidney. Other studies evaluating the potential of MD in the detection of arterial problems or acute graft rejection after KTx are likely to achieve significant results.
Microdialysis for early detection of thrombosis

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References


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