

Integrated Masimo and MostCare Monitoring in Pediatric Kidney Transplantation: A Case Report

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ABSTRACT

Introduction: Pediatric kidney transplantation poses major hemodynamic challenges; donor–recipient size mismatch means the graft demands roughly 25% of the recipient's cardiac output, so accurate assessment is essential to protect graft perfusion and prevent delayed graft function. We demonstrate the value of integrating noninvasive (Masimo Root) and invasive (MostCare PRAM) monitoring to optimize goal-directed anesthesia.

Case Description: A 10-year-old boy (24 kg) with end-stage kidney disease underwent living-related kidney transplantation using combined monitoring. Masimo Root provided continuous hemoglobin (SpHb), volume status (Pleth Variability Index), and sedation depth (Patient State Index, PSI); MostCare PRAM provided beat-to-beat stroke volume variation (SVV), cardiac output, and arterial elastance (Ea). Real-time integration guides precise fluid titration. Adequate sedation (PSI 25–50) and stable hemodynamics (SVV <10%, Ea 1.19 mmHg/mL) were maintained, and the crystalloid was restricted to 700 mL. The patient remained stable throughout the 8-hour procedure and was extubated in the operating room with prompt urine output and immediate graft function.

Conclusion: Integrated Masimo Root and MostCare PRAM monitoring enables individualized goal-directed anesthesia, balancing hypovolemia and fluid overload risks, enhancing intraoperative stability, optimizing graft perfusion, minimizing fluid-related complications, and facilitating rapid recovery with early graft function in high-risk pediatric kidney transplant recipients.

Anesthesia In Pediatric Transplantation, Goal-Directed Fluid Therapy, Hemodynamic Monitoring, Masimo Root, Mostcare PRAM

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INTRODUCTION

Chronic kidney disease (CKD) and uremia in children compromise multiple organ systems, resulting in growth retardation, fatigue, and psychomotor development delay. Growth failure that persists despite adequate nutrition is a hallmark of progressive CKD and end-stage kidney disease (ESKD); accordingly, early evaluation for transplant candidacy is warranted in every child with stage 4–5 CKD or dialysis dependence [1,2]. Dialysis is only a temporary bridge, whereas kidney transplantation is the definitive therapy for long-term survival and quality of life. Candidacy for kidney transplantation is assessed by a multidisciplinary team of nephrologists, transplant surgeons, psychologists, nutritionists and pharmacists. [3]. The surgical technique is dictated by the recipient size: a retroperitoneal approach through a modified Gibson incision is favored in larger children, whereas an intraperitoneal route affords easier access to the aorta and inferior vena cava in smaller recipients [4]. Implanting an adult-sized kidney into a small child imposes a distinctive hemodynamic burden because the graft's perfusion demand (approximately 0.5 L/min) must be met from a total cardiac output of only approximately 2.5 L/min [5,6]. As the graft claims 20–25% of the cardiac output, precise real-time monitoring of preload, afterload, and contractility becomes essential, as under-perfusion predisposes to

delayed graft function (DGF) or thrombosis, whereas fluid overload and hypervolemia independently impair early graft recovery. Therefore, both extremes are clinically significant and require deliberate intraoperative hemodynamic control.

The goal of intraoperative hemodynamic management is to sustain cardiac output and oxygen delivery while avoiding both hypovolemia and overload [7]. Static indices such as central venous pressure (CVP) and mean arterial pressure (MAP) poorly predict fluid responsiveness, a limitation amplified in children by immature compensatory reflexes and altered vascular compliance. Dynamic indices — stroke volume variation (SVV), pulse pressure variation (PPV), and pleth variability index (PVI) — track beat-to-beat changes induced by positive-pressure ventilation and provide more reliable, real-time guidance for fluid boluses and vasopressor titration, reducing both fluid-related complications and unnecessary transfusion [8,9]. Among these technologies, the MostCare PRAM (Pressure Recording Analytical Method) system delivers continuous, beat-to-beat cardiac output (CO) from high-frequency pulse-contour analysis of an existing arterial line, integrating into standard perioperative monitoring without additional invasive access. Beyond CO, PRAM reports SVV, PPV, cardiac cycle efficiency (CCE) — an index of the balance between cardiovascular performance and energy expenditure — total cardiovascular impedance (Z_t), arterial elastance (E_a) as a marker of afterload, and dP/dt as an index of contractility [10-12]. The Masimo Root platform provides the complementary noninvasive dimension: PVI, derived from respiratory variation in the plethysmographic waveform, is a validated dynamic preload indicator, and continuous hemoglobin (SpHb) permits real-time hemoglobin tracking without repeated phlebotomy, informing rational transfusion decisions and protecting oxygen delivery while avoiding the volume load of unnecessary blood products [13-15]. Pairing invasive dynamic indices (SVV, PPV, dP/dt , E_a) with noninvasive perfusion monitoring (PVI, SpHb) is an integrated strategy increasingly adopted in adult anesthesia yet seldom described in pediatric renal transplantation. Together, these data streams enable precise, individualized fluid therapy and sidestep the pitfalls of static markers such as CVP, whose weak correlation with fluid responsiveness contributes to overload and delayed graft function — hazards magnified in children with limited physiologic reserve. Concurrent monitoring of anesthetic depth by the SedLine EEG-derived Patient State Index (PSI) adds a further safeguard, guarding against over-sedation (which depresses myocardial contractility) and under-sedation (which provokes stress-induced tachycardia and hypertension). Integrating invasive PRAM parameters with noninvasive dynamic indices thus supports rational, moment-to-moment titration of fluids, vasopressors, and anesthetic depth, promoting hemodynamic stability and graft perfusion across every surgical phase — including the critical reperfusion period — and facilitating early recovery.

To our knowledge, few reports document the simultaneous intraoperative use of the Masimo Root and MostCare PRAM platforms in a small number of pediatric kidney transplant recipients. We present a case in which this multimodal, goal-directed approach guided restrictive fluid therapy and enabled on-table extubation with immediate graft function, and we discuss the complementary roles of the two systems and the practical implications for pediatric transplant anesthesia.

CASE DESCRIPTION

Patient History and Preoperative Evaluation

A 10-year-old boy weighing 24 kg and measuring 128 cm was scheduled for living-related kidney transplantation. The patient had a complex medical history, including anorectal malformation (ARM) with prior anoplasty and colostomy performed in 2015. Chronic kidney disease was diagnosed in July 2024 after anemia and elevated creatinine were discovered during preoperative evaluation for hypospadias repair. The underlying etiology of CKD was attributed to obstructive uropathy related to the prior anorectal malformation. Hemodialysis was initiated on November 30, 2024, and the patient underwent twice-weekly sessions (3.5 hours each) via a right internal jugular central venous catheter until the time of transplantation.

Preoperative investigations included transthoracic echocardiography (ejection fraction 67%, no structural abnormalities), computed tomography angiography of the iliac vessels (favorable anatomy for transplantation at the right iliac fossa), and video-urodynamic studies (neurogenic bladder features compatible

with a history of ARM). Laboratory studies showed hemoglobin 8.9 g/dL (on erythropoietin supplementation), serum creatinine 7.1 mg/dL, blood urea nitrogen 89 mg/dL, potassium 5.8 mEq/L, and albumin 3.2 g/dL. The patient was classified as having American Society of Anesthesiologists (ASA) physical status III due to ESKD and associated comorbidities.

Anesthetic Technique and Monitoring Setup

The patient fasted for 6 hours preoperatively. Standard monitoring (electrocardiography, pulse oximetry, and capnography) was established. An arterial catheter was placed in the left radial artery using a 20-gauge cannula under local anesthesia and ultrasound guidance before the induction. Two peripheral intravenous lines (18-gauge) were secured for fluid administration and blood product availability. General anesthesia was induced with intravenous midazolam (2 mg), fentanyl (150 µg), propofol (100 mg), and rocuronium (30 mg). The trachea was intubated with a 6.0-mm cuffed endotracheal tube positioned at 16 cm at the lips and secured appropriately. Lung-protective ventilation was initiated in pressure-controlled mode: pressure control 14 cmH₂O, positive end-expiratory pressure (PEEP) 5 cmH₂O, respiratory rate 14 breaths/min, and inspired oxygen fraction (FiO₂) 50%, with tidal volume titrated to 7 mL/kg (actual body weight) to achieve end-tidal CO₂ (ETCO₂) of 35–40 mmHg.

A thoracic epidural catheter was placed at the T10–T11 level prior to incision using a standard midline approach. Ropivacaine 0.2% was infused at 5 mL/h throughout the intraoperative period and continued postoperatively for analgesia, reducing the need for opioid supplementation and supporting early recovery. Two complementary hemodynamic monitoring technologies were employed. The Masimo Root platform (Masimo Corporation, Irvine, CA, USA) provided continuous noninvasive monitoring, including the PVI for dynamic preload assessment, continuous hemoglobin (SpHb), peripheral perfusion index (Pi), and sedation depth via the SedLine EEG-derived Patient State Index (PSI). The MostCare PRAM system (Vygon/Vytech, PRAM technology) provided invasive beat-to-beat parameters via the arterial catheter, including cardiac output (CO), stroke volume (SV), stroke volume variation (SVV), pulse pressure variation (PPV), cardiac cycle efficiency (CCE), arterial elastance (Ea), and dP/dt (maximum rate of change of aortic pressure, a contractility index). Both monitors were displayed simultaneously on separate screens, allowing real-time integration of invasive and noninvasive data streams for clinical decision-making.

Intraoperative Course

Post-induction phase (07:37). Immediately after induction and initiation of mechanical ventilation, hemodynamic parameters reflected sympathetic activation: heart rate (HR) 148 bpm, arterial pressure 142/88 mmHg (MAP 106 mmHg), SpO₂ 99%, and respiratory rate 46 breaths/min. Masimo Root showed SpHb 13 g/dL, PVI 10% (borderline elevated, suggesting preload responsiveness), and Pi 6.7 (adequate perfusion). PSI was 36, confirming appropriate anesthetic depth. Initial management consisted of a 500-mL crystalloid bolus (Ringer's lactate), reducing PVI to 8% and indicating improved preload status.

Pre-incision optimization phase (09:56 min). By mid-morning before the surgical incision, the hemodynamics had stabilized: HR 93 bpm, MAP 70 mmHg, SpO₂ 97%. MostCare PRAM showed an SVV of 8%, PPV of 7%, CO of 4.8 L/min, and cardiac index (CI) of 5.2 L/min/m². The Masimo Root displayed a PVI of 6% (normalized), SpHb of 12.8 g/dL, and PSI of 28. The total crystalloid administered by this point was 500 mL (maintenance only). An additional 200-mL bolus was titrated to achieve SVV 5–6%, optimizing the stroke volume to 85–95 mL/beat and CO to 5.2–5.6 L/min in preparation for the incision and anticipated blood loss. Surgical preparation phase (10:00–13:00 h). The surgical team accessed the right iliac vessels via a modified Gibson incision and exposed the iliac artery and vein for anastomosis under general anesthesia. During vessel isolation and graft preparation, stability was maintained with MAP 65–75 mmHg, HR 85–95 bpm, and SVV consistently <10%, indicating adequate but not excessive preload without vasopressor support. The SpHb remained stable at 12.6 g/dL, PSI ranged 25–30, and fluid management relied exclusively on real-time PRAM parameters (SVV and PPV) rather than CVP, which was not monitored.

Pre-reperfusion optimization phase (~13:10 h). Before releasing the vascular clamp, the anesthesia team performed deliberate optimization in anticipation of sudden volume shifts and inflammatory responses accompanying reperfusion. Crystalloid boluses were titrated to PRAM-derived SVV/PPV targets to achieve SVV 5–6%, CO 5.5–6 L/min, and CI 6–6.5 L/min/m². Masimo Root confirmed stable PVI 6%, SpHb 12.5 g/dL, and PSI 25. Norepinephrine was initiated at 0.05 µg/kg/min (~1.2 µg/min total) approximately 3 minutes before graft unclamping to preemptively maintain systolic pressure above 120 mmHg and ensure renal perfusion pressure during reperfusion. Reperfusion phase (13:15–13:30 min). Upon releasing the clamp, the hemodynamic response was pronounced but well managed. The cardiac index acutely increased to 7.1 L/min/m² (reflecting increased output to the newly perfused vascular bed), systemic vascular resistance index (SVRI) decreased from 1,850 to 726 dyn·s·cm⁻⁵·m² (expected vasodilation from graft-vessel recruitment), and arterial elastance (Ea) remained stable at 1.19 mmHg/mL, indicating favorable ventricular–arterial coupling. The HR increased transiently to 118 bpm and then stabilized at 95–105 bpm. MAP was maintained at 75–85 mmHg with norepinephrine at 0.05 µg/kg/min. The PRAM parameters were optimal: PPV 5%, dP/dt_{max} 1.27 mmHg/ms (preserved contractility), and CCE 0.17 (normal efficiency). The Masimo Root showed SpHb of 12.3 g/dL, PVI of 6%, and PSI of 26. Brisk urine output appeared immediately after reperfusion, indicating excellent immediate graft function. No arrhythmia or instability was observed.

Anastomosis completion and mid-surgical phase (11:47–13:51). After reperfusion and securing of vascular anastomoses, the parameters remained stable. At 11:47, the HR was 89 bpm, respiratory rate 16 (normalized), and SpO₂ 100%. SpHb declined slightly to 12.5 g/dL, and PVI rose to 9% (still within the responsive range but prompting vigilance). Pi decreased to 3.8 (mild vasoconstriction, likely from norepinephrine), while PSI remained 24–25. By 13:51, near closure, PRAM showed BP 123/58 mmHg, HR 123 bpm (mild tachycardia as emergence approached), dP/dt_{max} 1.27 mmHg/ms, CCE 0.17, CI 7.1 L/min/m², SVRI 726 dyn·s·cm⁻⁵·m², and PPV 5% (optimal intravascular volume status). Emergence phase and closure (13:58). At final closure, the patient remained stable: SpO₂ 99%, HR 124 bpm, respiratory rate 16. SpHb decreased to 11.5 g/dL (reflecting estimated blood loss of ~300 mL over the 8-hour procedure). PVI was 6%, Pi 1.0 (transient vasoconstriction from vasopressor use and surgical stress), and oxygen content (SpOC) 15 (preserved oxygenation). PSI increased to 31, indicating appropriate emergence readiness and a depth suitable for prompt extubation. Total intraoperative fluid was restrictively limited to 700 mL of crystalloid (~29 mL/kg), with an estimated blood loss of 300 mL and no colloid or blood-product transfusion required.

Throughout the 8-hour procedure, hemodynamic parameters were continuously monitored and recorded at key surgical transitions, demonstrating the effectiveness of goal-directed management guided by dynamic indices. Table 1 summarizes the crucial hemodynamic parameters across each surgical phase, illustrating how integrated monitoring enabled responsive titration of fluids, vasopressors, and anesthetic agents to maintain optimal preload, afterload, and contractility throughout the operation.

Table 1. Intraoperative hemodynamic summary by surgical phase

Surgical phase	Time	HR (bpm)	MAP (mmHg)	SVV (%)	CI (L/min/m ²)	SpHb (g/dL)	PSI	Key management
Post-induction	07:37	148	106	—	—	13.0	36	Fluid bolus for sympathetic response
Pre-incision	09:56	93	70	<10	5.2	12.8	28	Optimized preload, ready for incision
Surgical prep	10:00–13:00	85–95	65–75	<10	—	12.6	25–30	Stable; no vasopressor needed
Pre-reperfusion	~13:10	90	72	5–6	6.0–6.5	12.5	25	Optimized; norepinephrine started
Post-reperfusion	~13:15	105	78	<5	7.1	12.3	26	Excellent hemodynamic response
Anastomosis / closure	13:30–13:58	85–124	65–85	5–8	7.1	11.5	24–31	Stable; emergence readiness reached

Note: HR, heart rate; MAP, mean arterial pressure; SVV, stroke volume variation; CI, cardiac index; SpHb, continuous hemoglobin; PSI, Patient State Index. Dashes (—) indicate parameters that were not recorded at that time point.

The true clinical value of integrating the Masimo Root and MostCare PRAM systems is evident through their complementary contributions. While the MostCare PRAM provided beat-to-beat quantitative data on cardiac mechanics, the Masimo Root offered real-time qualitative confirmation of tissue perfusion and oxygen delivery. Table 2 details how each monitoring system addressed specific clinical questions and how their combined use provided comprehensive hemodynamic surveillance of the patient.

Table 2. Comparative monitoring insights: Masimo Root (non-invasive) versus MostCare PRAM (invasive).

Monitoring aspect	Masimo Root (noninvasive)	MostCare PRAM (invasive)	Clinical integration
Preload assessment	PVI (6–10%) guided fluid boluses; visual plethysmographic waveform analysis	SVV / PPV (<10%) quantified beat-to-beat preload responsiveness with precision	PVI confirmed PRAM trends; together they provided complementary preload assessment, avoiding both hypovolemia and overload
Hemoglobin monitoring	SpHb tracked continuously (13.0→11.5 g/dL) without invasive blood draws; guided transfusion avoidance	Not applicable	Reduced phlebotomy-related blood loss in a pediatric patient with limited blood volume; critical for limiting iatrogenic anemia
Contractility & afterload	Pi trends reflected peripheral perfusion adequacy	dP/dt, Ea, CCE quantified contractility, afterload, and efficiency directly	PRAM provided granular beat-to-beat contractility data; Masimo confirmed adequate peripheral tissue perfusion
Sedation depth	PSI (SedLine EEG-derived) prevented over-sedation (myocardial depression) and under-sedation (stress-induced tachycardia)	Not applicable	Maintained PSI 25–30 intraoperatively and 31 at emergence; prevented hemodynamic complications from anesthetic-depth extremes
Oxygen delivery	SpO ₂ and SpHb trends ensured adequate systemic oxygenation	CO, SV, Ea data quantified oxygen-delivery determinants	Combined approach ensured both oxygen content and cardiac output were optimized; prevented anemia-related hypoxia and cardiogenic shock
Clinical decision-making	Real-time qualitative perfusion trends; noninvasive, repeatable without blood draws	Real-time quantitative CO / SV / afterload data; precise beat-to-beat accuracy	PRAM guided fluid and vasopressor titration; Masimo confirmed clinical adequacy; together they prevented both hypovolemia and hypervolemia complications

Note: PVI, pleth variability index; SVV, stroke volume variation; PPV, pulse pressure variation; SpHb, continuous hemoglobin; Pi, peripheral perfusion index; CCE, cardiac cycle efficiency; Ea, arterial elastance; PSI, Patient State Index; CO, cardiac output; SV, stroke volume.

Postoperative Outcomes and Early Recovery

The patient was successfully extubated in the operating room immediately after meeting all extubation criteria: spontaneous breathing effort, response to commands, normothermia (36.8 °C), stable hemodynamics (MAP >65 mmHg, HR 95–110 bpm), and adequate oxygenation (SpO₂ >95% on supplemental oxygen). Early extubation was accomplished without complications, avoiding prolonged mechanical ventilation and reducing the risk of ventilator-associated pneumonia (VAP) — a significant achievement in pediatric transplant anesthesia. Total intraoperative fluid was restrictively limited to 700 mL of crystalloid (~29 mL/kg), with an estimated blood loss of 300 mL and no colloid or blood-product transfusion required. The patient was transferred directly to the pediatric intensive care unit (PICU) in a stable condition.

Immediate postoperative urine output was brisk (>2 mL/kg/h), appearing within minutes of reperfusion and continuing robustly, indicating rapid establishment of graft function. Postoperative hemoglobin measured 1 hour after surgery was 10.8 g/dL, requiring observation but no transfusion. Serum creatinine decreased from

7.1 mg/dL preoperatively to 4.2 mg/dL on postoperative day 1 and 2.8 mg/dL on day 3, demonstrating excellent early graft function and rapid adaptation to the recipient's metabolic needs. The patient remained hemodynamically stable on postoperative day 1 with minimal vasopressor support, which was successfully weaned by 8 hours postoperatively. No episodes of hypertension, hypotension, or cardiac arrhythmia were recorded during the immediate postoperative period. The patient was transferred out of the PICU on postoperative day 2 to the pediatric surgical ward, indicating an uncomplicated early course. No pulmonary edema, acute kidney injury, delayed graft function, or signs of acute rejection were observed during the first postoperative week.

The patient was discharged on postoperative day 7 in stable condition with excellent renal function (serum creatinine 1.8 mg/dL at discharge, a 75% reduction from the preoperative value) on appropriate immunosuppressive therapy (induction with an interleukin-2 receptor antagonist; maintenance with tacrolimus, mycophenolate mofetil, and corticosteroids) and antihypertensive medication as needed. At the 2-week follow-up, the serum creatinine level remained at 1.6 mg/dL, confirming stable graft function. No delayed complications or rejection episodes were observed.

DISCUSSION

Pediatric kidney transplantation is a complex, high-risk procedure that relies on precise intraoperative hemodynamic and perfusion control. Although it is the preferred renal replacement therapy for ESKD, access remains limited, particularly in low- and middle-income countries, where fewer than four pediatric kidney transplants are performed per million children annually [16]. Several factors contribute to this low rate, including the scarcity of suitable donor organs, anatomical and physiological complexity of pediatric recipients, and frequent comorbidities (e.g., poor nutrition, cardiovascular disease, infection, anemia, and renal osteodystrophy) that can delay surgery. A size mismatch between the donor kidney and recipient vessels may further delay transplantation until the child grows [17]. The present case is instructive because it illustrates how these physiological constraints can be navigated intraoperatively when monitoring is tailored to the demands of the procedure.

Children pose unique physiological and technical challenges to the anesthesiologist. Their relatively small circulating volume, immature baroreceptor responses, and high metabolic demand render them vulnerable to rapid hemodynamic fluctuations; even minor deviations in preload or afterload can significantly alter cardiac output and graft perfusion [18-20]. Pediatric transplantation with a large donor–recipient size mismatch requires a marked increase in cardiac output to ensure graft perfusion. In this case, the adult donor kidney required approximately 25% of the recipient's total cardiac output, which is a considerable load for a 24-kg child with limited circulating volume and immature compensatory mechanisms. However, excessive fluid or vasopressor therapy aimed at supraphysiologic targets may paradoxically cause early graft injury, as inadequate perfusion can lead to delayed graft function or thrombosis, both of which are associated with reduced graft survival and higher rejection risk [21,22]. Perioperative hypovolemia is often underdiagnosed because fluid loss may be masked by altered vascular resistance and capillary leakage [23]. Not all patients in shock present with hypotension, and delaying treatment until it appears risks progression to tissue hypoxia [24]. Ischemia–reperfusion injury further threatens the graft: oxygen deprivation during nephrectomy and storage, followed by reperfusion, triggers endothelial injury, impaired autoregulation, and medullary hypoperfusion; the resulting edema worsens oxygen diffusion and increases the risk of oxidative stress, fibrosis, and functional loss [25].

Maintaining optimal graft perfusion is central to intraoperative management. Because microvascular flow cannot be measured directly, hemodynamic optimization relies on arterial pressure, fluid balance, and systemic flow. A MAP above 70 mmHg is typically targeted, extrapolated from adult data linking lower MAP with delayed graft function [26]. Both hypovolemia and overload must be avoided, as each impairs oxygen delivery, and traditional CVP-guided therapy is unreliable and associated with pulmonary edema and delayed recovery in children [27]. Advanced monitoring systems, such as MostCare PRAM and Masimo Root, are thus increasingly favored for individualized optimization: by integrating invasive waveform analysis with

noninvasive perfusion indices, they enable precise assessment of fluid responsiveness and oxygen delivery, supporting graft perfusion while minimizing iatrogenic risk [28].

MostCare PRAM: Quantitative Hemodynamic Profiling

The pressure-recording analytical method is an invasive arterial waveform analysis technique that calculates CO, SV, SVV, PPV, CCE, Ea, and $dP/dt_{\max}$. Unlike other pulse contour methods, the PRAM does not require external calibration (via thermodilution, esophageal Doppler, or transpulmonary lithium dilution) or population-based nomograms. This is particularly advantageous in pediatric use, where (i) frequent recalibration is impractical because of limited vascular access, (ii) population-derived nomograms are less accurate in children whose physiology differs substantially from that of adults, and (iii) invasive calibration procedures carry a disproportionate risk in small patients with limited circulating volume [29].

By analyzing the area under the systolic pressure curve at high frequency (1,000 Hz), PRAM provides a beat-to-beat assessment of ventricular performance and vascular impedance. In this case, SVV and PPV trends guided fluid administration, ensuring that crystalloids were infused only when preload responsiveness was likely, thereby preventing unnecessary fluid loading. The restrictive strategy (700 mL total intraoperative crystalloid) was possible precisely because dynamic indices provided beat-to-beat guidance. Ea and $dP/dt_{\max}$ offered real-time feedback on afterload and contractility, allowing precise norepinephrine titration to maintain systolic pressure above 120 mmHg and preserve graft perfusion during reperfusion [30,31]. Cardiac cycle efficiency reflects the ratio between mechanical energy expenditure and hemodynamic performance, adding context on cardiovascular efficiency during critical phases; stable CCE (0.17) during reperfusion indicated favorable ventricular–arterial coupling and preserved myocardial function despite the significant hemodynamic shifts of graft revascularization [32]. PRAM delivered high-resolution, trend-based data for fluid optimization without invasive calibration or pulmonary-artery catheterization — well suited to pediatric patients with limited vascular access.

Masimo Root: Noninvasive Perfusion and Oxygenation Monitoring

In contrast, the Masimo Root platform contributed continuous, noninvasive assessment of perfusion and oxygen transport. Its pleth variability index reflects dynamic changes in the plethysmographic waveform amplitude during the respiratory cycle, offering an indirect yet reliable estimate of preload responsiveness in mechanically ventilated patients. When interpreted alongside the PRAM-derived SVV, the PVI provided cross-validation of fluid status and helped determine whether volume expansion would likely improve cardiac output [33,34]. In this case, the PVI remained at 6% throughout, confirming PRAM-guided optimization and validating the restrictive fluid strategy.

Continuous hemoglobin (SpHb) monitoring allowed real-time tracking of hemoglobin concentration without repeated blood draws, which is a significant advantage in pediatric patients with limited blood volume. SpHb decreased from 13.0 to 11.5 g/dL over the 8-hour procedure (reflecting ~300 mL estimated blood loss); however, it never approached the transfusion threshold. Avoiding unnecessary transfusion is critical not only to prevent volume overload but also to reduce immunologic risk that can compromise graft survival [35]. The SedLine-derived patient state index added a further dimension by quantifying the anesthetic depth. Pediatric patients are particularly sensitive to anesthetic fluctuations, and both excessive and inadequate depth can cause cardiovascular instability; maintaining a PSI of 25–30 intraoperatively allowed the team to avoid over-sedation (which depresses myocardial contractility and blood pressure) while ensuring sufficient hypnosis to prevent stress-induced tachycardia and hypertension [34].

Synergistic Integration in Goal-Directed Hemodynamic Management

The true value of multimodal monitoring emerged through the synergistic integration of quantitative PRAM data with qualitative Masimo perfusion trends. Rather than treating each system independently, the team used PRAM-derived parameters (SVV, PPV, $dP/dt_{\max}$, Ea) to guide fluid and vasopressor titration while

simultaneously confirming clinical adequacy through Masimo-derived indices (PVI, SpHb, Pi, PSI). This combined approach enabled precise optimization tailored to the child's immediate physiologic needs.

The comparative strength of the two systems lies in their complementary domains. MostCare PRAM excels at quantifying central hemodynamics (CO, SV, afterload, and contractility) through beat-to-beat waveform analysis, directly reflecting cardiovascular mechanics; its invasive nature enables continuous accuracy, ideal for critical stages, such as reperfusion or vascular clamping. Masimo Root, conversely, offers broad noninvasive monitoring of systemic oxygenation and perfusion, with PVI and SpHb trends providing a macroscopic view of how hemodynamic adjustments translate into effective tissue oxygen delivery. In this case, PRAM served as the quantitative guide, dictating fluid and vasopressor titration based on preload responsiveness and contractility, while Masimo provided qualitative confirmation of perfusion adequacy and oxygen transport. Used together, they offered a near-comprehensive hemodynamic profile, balancing precision with safety and minimizing invasive interventions. This synergy was particularly valuable during reperfusion, when the cardiovascular system must rapidly adapt to sudden volume shifts and changes in vascular resistance. While PRAM detected the beat-to-beat increase in cardiac index ($5.2 \rightarrow 7.1$ L/min/m²) and the fall in SVRI ($1,850 \rightarrow 726$ dyn·s·cm⁻⁵·m²), the stable SpO₂ (99%) and SpHb (12.3 g/dL) from Masimo confirmed that systemic oxygenation and perfusion were maintained. This parallelism — PRAM quantitative improvement matching Masimo qualitative adequacy — provided confidence that graft reperfusion was physiologically successful.

Clinical Outcomes and Significance

A key outcome was successful on-table extubation, a major milestone in pediatric transplant anesthesia that shortens mechanical ventilation duration, reduces VAP risk, and accelerates recovery. This was enabled by precise multimodal hemodynamic management using PRAM and Masimo monitoring, which allowed for real-time adjustment of anesthetic depth, volume status, and perfusion targets. Effective pain control with epidural analgesia minimized opioid use and supported early recovery. Immediate graft function was excellent, with brisk urine output within minutes of reperfusion, and serum creatinine levels decreased from 7.1 mg/dL preoperatively to 1.8 mg/dL by postoperative day 7.

Although PRAM and PVI are well established in adult critical care and anesthesia, their combined intraoperative use in pediatric transplantation is rarely described. To our knowledge, this is among the first reports to deploy invasive PRAM and noninvasive Masimo Root monitoring together in a small pediatric kidney transplant recipient, and it demonstrates their feasibility and clinical value for optimizing intraoperative stability, promoting early graft function, and enabling fast-track recovery. The approach translated directly into a smoother postoperative course — immediate graft function, on-table extubation, and avoidance of ICU-related complications — rather than benefiting intraoperative numbers alone.

Limitations and Considerations

This study has several limitations. First, this single case at a tertiary center with advanced monitoring cannot be generalized to resource-limited settings that lack equipment. Second, the patient had favorable vascular anatomy without complications, and outcomes may differ in complex cases involving reconstructive surgery or donor vessel size mismatch. Third, implementation requires familiarity with hemodynamic indices and staff training, which may be limited in centers without routine PRAM or Masimo. Fourth, the generalizability across donor–recipient size ratios, donor types, and immunologic profiles requires multicenter validation. Finally, the cost may limit its adoption in low- and middle-income countries.

CONCLUSION

MostCare PRAM and Masimo Root provided hemodynamic surveillance in pediatric kidney transplantation. Goal-directed therapy guided by indices (SVV <10%, PPV <10%) permitted restrictive crystalloid administration (700 mL total) while preserving graft perfusion and avoiding overload. Continuous noninvasive

assessment of oxygen delivery (SpHb, PVI, SpO₂) confirmed targets and enabled transfusion-sparing management, contributing to on-table extubation, early graft function, and fast-tracking recovery.

DECLARATIONS

This case report was prepared in accordance with the CARE (Case REport) guidelines to ensure complete and transparent reporting.

CONSENT FOR PUBLICATION

The Authors agree to be published in the Journal of Society Medicine.

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L.L.J. conceived the report, managed the anesthetic case, collected data, and drafted the manuscript. A.A.R. supervised perioperative management, critically revised the manuscript, and approved the final version. Both authors read and approved the final manuscript.

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