Intravascular volume assessment using internal jugular vein ultrasonography in pediatric renal transplant surgery: a prospective observational study

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Purpose
Assessment of the intravascular volume status during surgery is challenging, especially in pediatric patients. Ultrasound has become a versatile noninvasive modality for assessing volume status. This study aimed to evaluate the reliability of ultrasonographic internal jugular vein (IJV) dimensions as a new tool to assess the intravascular volume status in pediatric patients undergoing living donor renal transplant surgery.
Patients and methods
This prospective observational study included pediatric renal transplant recipients, aged 3–12 years, weighing more than 10 kg, and having an end-stage renal disease. Hemodynamic data (heart rate, systolic, diastolic, and mean blood pressures), central venous pressure (CVP), sonographic measurement of IJV (diameter and cross-sectional area), and left ventricular end-diastolic area (LVEDA) were measured 1 min after induction, before clamping of renal vessels, and after declamping of renal vessels. The correlations between the ultrasonographic IJV dimensions and both LVEDA (primary outcome) and CVP were evaluated.
Results
Overall, 18 pediatric patients (12 females, six males) with end-stage renal disease were eligible for this study. The mean age was 9.33±2.57 years, and the mean weight was 21.67±5.99 kg. There was a poor correlation between IJV dimensions (diameter and cross-sectional area) and both LVEDA and CVP at the three-time points of assessments.
Conclusion
Ultrasonographic IJV dimensions (diameter and cross-sectional area) were not reliable for assessing intravascular volume status in living donor renal transplant surgery in pediatric patients.

Keywords:
central venous pressure, internal jugular vein ultrasonography, intravascular volume assessment, left ventricular end-diastolic area, pediatric renal transplant

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Background

Adequate perioperative fluid management is crucial for better outcomes after renal transplant surgery; too little fluid administration can cause allograft hypoperfusion, whereas too much fluid can induce pulmonary edema and endothelial glycocalyx injury [1].

Assessment of the intravascular status during surgery is challenging, especially in pediatric patients [2]. In renal transplant patients, intravascular volume status is traditionally assessed based on static monitoring parameters, mainly the central venous pressure (CVP) [1]. CVP is invasive and not without complications, and its accuracy to guide perioperative fluid therapy in kidney transplantation has been challenged [1,3].

There is an increased interest in noninvasive hemodynamic monitoring tools, especially in pediatric patients. In this context, the use of ultrasound has emerged as a potentially useful tool for intravascular volume assessment. Many echocardiographic parameters were suggested to assess intravascular status, including left ventricular end-diastolic area (LVEDA), which is a surrogate of left ventricular end-diastolic volume; however, echocardiography is operator dependent and needs a well-trained anesthesiologist [3]. The ultrasound inferior vena cava (IVC) diameter and respiratory variations of IVC diameter are also widely used as noninvasive assessors of intravascular volume and fluid responsiveness; however, they are not clinically practical

intraoperatively because they need transesophageal echocardiography (TEE) assessment [4].

In adults, many trials investigated the ultrasonographic internal jugular vein (IJV) and femoral vein as an easier accessible alternative to the superior vena cava (SVC) and IVC. Many IJV dimensions and parameters, such as IJV diameter and cross-sectional area, were reported to be potential measures of intravascular volume [5–12]. Bailey *et al.* [13] raised the hypothesis that point-of-care IJV ultrasonography might be helpful in intravascular status assessment in pediatric patients. Up to our knowledge, IJV ultrasonography is not well investigated as a possible tool to assess volume status and to guide fluid management in surgical patients under general anesthesia in adults and in pediatric patients.

This study aimed to evaluate the reliability of ultrasonographic IJV dimensions (IJV diameter and cross-sectional area) as tools to assess the intravascular volume status in pediatric patients undergoing living donor renal transplant surgery by correlating the ultrasonographic IJV dimensions to LVEDA and CVP.

Patients and methods

This prospective observational study was conducted in Abu El-Reesh (El-monira) Children's Hospital, Kasr Al-Ainy Hospital, Faculty of Medicine, Cairo University, after receiving Institutional research ethics committee approval (N-123-2018), provided by the Ethical Committee REC of Kasr Al-Ainy Hospitals, Cairo University. The study was registered at the clinical trials registry system before patient enrollment (clinical trial identifier: NCT04008953). Written informed consent was obtained from the parents or guardians of the children before enrollment.

A total of 18 pediatric patients, of both sexes, aged 3–12 years, weighing more than 10 kg, having end-stage renal disease, and scheduled for living donor renal transplant surgery were included in the study. Exclusion criteria were infection at the site of CVP line, cardiac diseases, history of neck radiotherapy, IJV or SVC thrombosis, and the use of vasoactive drugs.

Detailed preoperative history was taken from patients. All patients were assessed clinically thoroughly, and the laboratory work needed was complete blood count, serum electrolytes, arterial blood gases, liver functions, kidney functions, and coagulation profile. Other investigations including echocardiography, chest radiograph, and abdominal ultrasound were performed on all patients.

Anesthetic management

Atropine (0.01–0.02 mg/kg) was given as premedication to all participants. Monitors included ECG, pulse oximetry, invasive and noninvasive arterial blood pressure, end-tidal CO_2 concentration, and temperature. Anesthesia was induced using fentanyl (1 μg/kg), propofol (1.5–2.5 mg/kg), and atracurium (0.5 mg/kg). A central venous line was inserted in the right IJV guided by real-time ultrasonography.

Anesthesia was maintained with sevoflurane in O_2 and 0.01 mg/kg atracurium every 20 min. Intravascular volume expansion was made by infusion of crystalloids (0.9% saline), 5% human albumin, or packed red blood cells (when needed to maintain hemoglobin level around 8–10 g/dl) to attain a targeted CVP around 12–18 mmHg before the release of renal vessel cross-clamps.

Hemodynamic data (heart rate, systolic, diastolic, and mean blood pressures), CVP, sonographic measurement of IJV (diameter and cross-sectional area), and LVEDA were recorded at three-time points: T1–1 min after induction of anesthesia, T2–before clamping of renal vessels, and T3–after declamping of renal vessels.

Sonographic measurement of internal jugular vein diameter and cross-sectional area

The ultrasound device used was the General Electric LOGIQ C5 Premium (General Electric, Milwaukee, Wisconsin, USA), and the measurements were performed using a linear probe (5–12 MHz). The IJV measurements were performed by an anesthesiologist skilled in critical care ultrasound for more than 2 years. The measurements were obtained at the level of the cricoid cartilage on the side of the neck contralateral to the central line. The linear probe was placed lightly on the neck to scan the IJV in the short-axis plane. The probe position was adjusted to ensure that the image plane was perpendicular to the vein and that there was no pressure applied to the probe–skin interface; then a 10-s B-mode cine loop was obtained, reviewed frame by frame to identify the largest IJV dimensions, and the largest diameter and cross-sectional area of IJV were measured.

Measurement of left ventricular end-diastolic area by transthoracic echocardiography

LVEDA was performed by a skilled anesthesiologist in transthoracic echocardiography (TTE) using an echocardiography ultrasound machine (General Electric LOGIQ C5 Premium; General Electric) with a 1.5–3.6MHz 18.5-mm footprint phased array probe. LVEDA was measured at the mid-papillary level of the left parasternal short-axis view; the image was frozen to

identify a frame showing the left ventricle in end-diastole, then the caliper was used to trace along the endocardium to measure the area of the left ventricle at end-diastole [14].

Study outcome measures

Primary outcome

Correlation of sonographic IJV dimensions (diameter and cross-sectional area) to LVEDA was the primary outcome measure.

Secondary outcomes

Correlation of sonographic IJV dimensions (diameter and cross-sectional area) to CVP the secondary outcome measure.

The primary and secondary outcomes were assessed at the three-time points: T1–1 min after induction of anesthesia, T2–before clamping of renal vessels, and T3–after declamping of renal vessels.

Statistical analysis

Using MedCalc Software, version 14.10.2 (MedCalc Software Ltd, Ostend, Belgium), we calculated a minimum number of 16 patients to detect a statistically significant correlation (r=0.6) between IJV diameter measurements and LVEDA and to have a study power of 80% and an alpha error of 0.05. The number was increased to 18 patients to compensate for possible dropouts.

All statistical calculations were done using computer program SPSS (statistical package for the social science; SPSS Inc., Chicago, Illinois, USA) release 15 for Microsoft Windows (2006). Categorical data were presented as frequency (%). Continuous data were presented as mean±SD, and repeated measures were analyzed using analysis of variance for repeated measures with post-hoc pairwise comparisons. Correlations were carried out to test for linear relations between quantitative variables by Pearson correlation coefficient. A P value) less than 0.05 was considered statistically significant.

Results

A total of 18 eligible patients with end-stage renal disease (12 females, six males) were included in this study. The mean age of the patients was 9.33±2.57 years, and the mean weight was 21.67±5.99 kg. The mean intravenous fluid intake was 100±20 ml/kg and the mean packed red blood cells transfusion was 341.6 ±86.2 ml. The causes of renal failure in transplant recipients are summarized in Table 1.

CVP and LVEDA measurements before and after renal vessels declamping were higher than measurements after induction of anesthesia, whereas the IJV dimensions (diameter and cross-sectional area) were higher only after vascular declamping; this is demonstrated in Table 2, which summarizes the mean±standard deviation of the hemodynamic, the sonographic, and the echocardiographic measurements at the three-time points of assessment.

There was a poor correlation between IJV dimensions (diameter and cross-sectional area) and both LVEDA and CVP at the three-time points of assessments, as demonstrated in Fig. 1 and Tables 3 and 4.

Discussion

Results of our study revealed that ultrasonographic IJV dimensions, namely, IJV diameter and cross-sectional area, were not reliable for assessment of intravascular volume status in pediatric patients in the setting of renal transplantation. This was demonstrated by the poor correlation between the ultrasonographic IJV dimensions and both LVEDA and CVP.

Assessment of intravascular volume status in pediatric patients depends mainly on static clinical monitoring parameters such as urine output, CVP, and LVEDA. Some dynamic monitoring parameters have been suggested, including respiratory variation in aortic blood flow peak velocity, time integral, and IVC diameter [2,15]. In our clinical study, we correlated the ultrasonographic IJV dimensions to CVP and LVEDA. CVP remains the most frequently used variable to guide fluid management in renal transplant surgery [1]. CVP is considered a surrogate of right ventricular preload; however, many limitations and factors should be taken into consideration while interpreting CVP values such as right ventricular dysfunction, as well as raised intraabdominal and thoracic pressures [1]. Moreover, venous return does not depend only on CVP, as it is inversely related to the gradient between mean systemic pressure and CVP [16]. On the contrary, TTE and

Table 1 Causes of renal failure in transplant recipients

Cause of renal failure	*n* (%)
Obstructive uropathy	5 (27.7)
Vesicoureteric reflux disease	4 (22.2)
Renal dysplasia	3 (16.6)
Pyelonephritis	2 (11.1)
Focal segmental glomerulosclerosis	2 (11.1)
Interstitial nephritis	2 (11.1)
Total	18 (100)

Table 2 Hemodynamic, internal jugular vein dimensions, and echocardiography data

Data	T1	T2	T3	*P* value
CVP (mmHg)	4.11±1.32	13.56±2.85*	17.39±2.35*†	<0.001
IJV diameter (mm)	10.1±4.5	10.9±±5.0	11.6±5.9*	0.007
IJV CSA (cm^2)	0.87±0.47	0.95±0.54	0.99±0.57*	0.029
LVEDA (cm^2/m^2)	8.91±2.90	9.41±2.93*	9.86±2.78*	0.003
HR (beats/min)	112.17±8.5	110.94±10.22	114.33±9.99	0.323
SBP (mmHg)	123.11±15.71	123.78±10.62	131.39±16.57	0.060
DBP (mmHg)	72.89±12.49	70.17±11.74	76.89±15.37	0.066
MBP (mmHg)	88.11±15.74	86.83±13.78	95.33±19.42†	0.002

Data are presented as mean±SD. BP, systolic blood pressure; CSA, cross-sectional area; CVP, central venous pressure; DBP, diastolic blood pressure; HR, heart rate; IJV, internal jugular vein; LVEDA, left ventricular end-diastolic area; MBP, mean blood pressure; T1, time after induction of anesthesia; T2, time before clamping renal vessels; T3, time after renal vessels declamping. *Significant difference compared to T1. †Significant difference compared to T2. *P* value less than 0.0.

TEE permit a visual assessment of ventricular volume, which can reflect cardiac preload better than CVP; left ventricular end-diastolic volume can be reliably estimated by measuring LVEDA, as 90% of the stroke volume is obtained by ventricular shortening in the short axis [16,17].

IVC point-of-care ultrasound analysis is widely used to assess the intravascular status and fluid responsiveness, especially in mechanically ventilated patients [4]. The SVC and IVC are elastic venous structures that connect to the right side of the heart, and they are the final drainage of many central veins such as IJV and femoral vein, which are more accessible and easier to scan [6]. Many ultrasound IJV dimensions and parameters were reported to be potential measures of intravascular volume in adults including IJV height, diameter, cross-sectional area, as well as IJV collapsibility and the ratio between IJV cross-sectional area and common carotid artery ratio [5–12]. Bailey *et al.* [13] reported a positive correlation between IJV/common carotid artery cross-sectional area and CVP in pediatric burn patients.

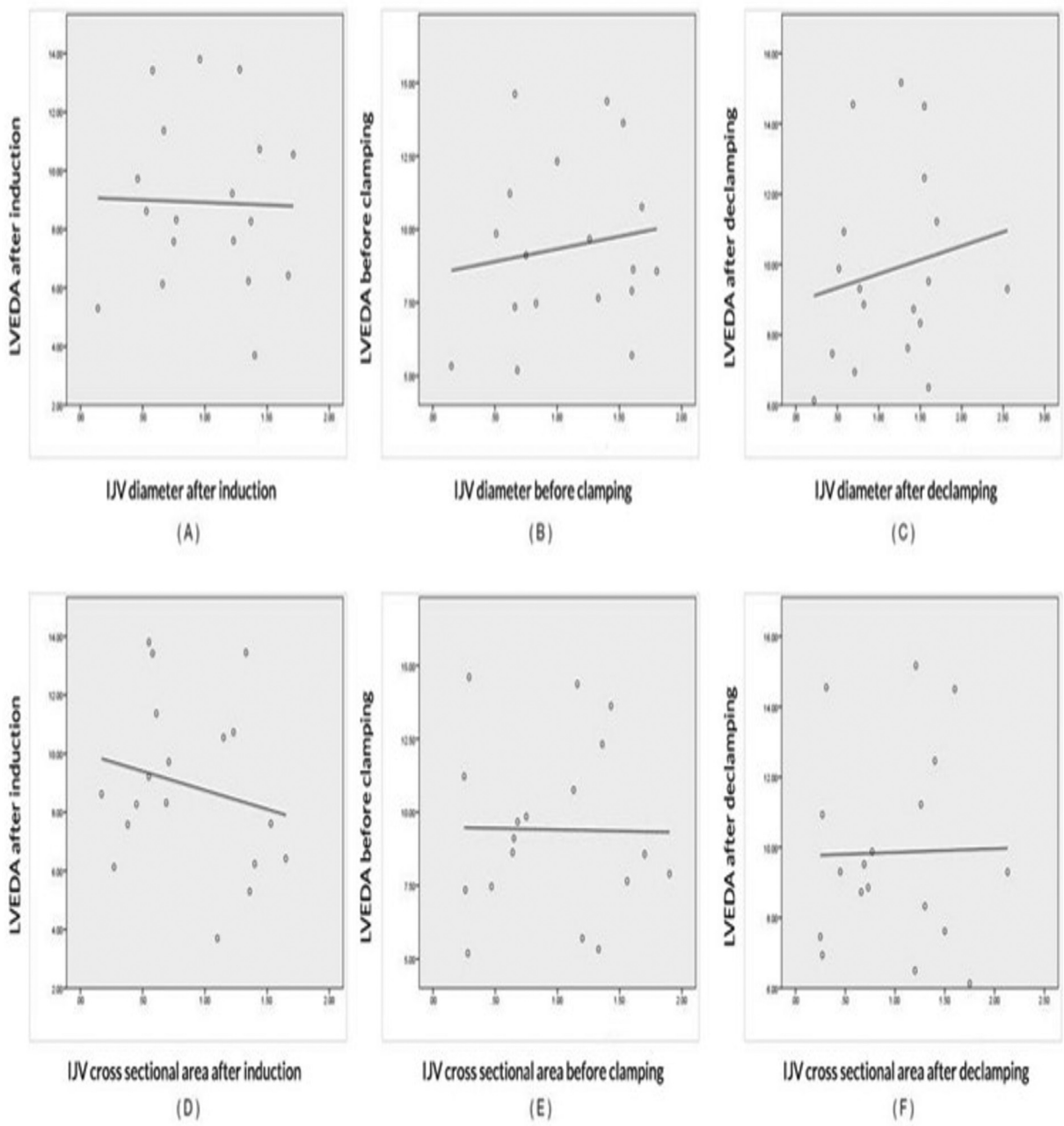
In the present study, we observed a poor correlation between IJV dimensions and LVEDA and CVP. In previous reports, the IJV maximal diameter and IJV area sensitivity and specificity values were higher for low CVP levels. This low ability of jugular vein measurements to reflect high CVP can be related to the physiology of the venous structures which can expand to a certain extent, then the expansion ratios may not significantly change, even though the CVP is still increasing, and this might explain our results, as we were investigating the IJV dimensions in renal transplant surgery, which is a setting of higher CVP values [6].

In a number of clinical contexts, IJV measurements may not be affected only by the circulating blood volume as the IJV parameters can reflect the changes in SVC and IVC which are affected by other factors such as high PEEP, as well as right and left ventricular dysfunction [4]. Moreover, the results of IVC parameters are controversial in pediatric patients when compared with adults, and this may be owing to higher arterial and venous vessel elastance, lower tidal volumes, and higher chest wall compliance, resulting in increased damping of transpulmonary pressure gradients [2,18].

Based on our findings, we suggest that sonographic IJV dimensions (diameter and cross-sectional area) are not reliable for volume status assessment in pediatric renal transplant recipients, and they cannot be used alone to decide further fluid management.

Our study has some limitations. We measured sonographic IJV dimensions in one type of surgery; thus, our findings might differ in other procedures and different settings. The use of TTE was thought to be difficult and unfeasible regarding access to the patient, where the patients' small size would make application of the ultrasound probe on the chest wall interfere with the surgeons' work, but with the cooperation of the urology surgeons, this was made feasible. Finally, our study was based on static monitoring parameters that can assess preload, but they are less sensitive than dynamic parameters to predict whether a patient will benefit from the additional fluid. However, many dynamic parameters validated for the prediction of fluid responsiveness in adults failed to be sensitive in pediatric patients owing to anatomic and physiologic differences from adults [2,15]. Furthermore, the flow-based dynamic variables, which are more sensitive than pressure-based dynamic parameters in pediatric patients, need TTE or TEE and special skills, and trying to find an easier alternative is of help [15].

Figure 1



Relationship between internal jugular vein (IJV) diameter and (a) left ventricular end-diastolic area (LVEDA) after induction of anesthesia, (b) LVEDA before clamping renal vessels, (c) LVEDA after declamping of renal vessels. Relationship between IJV cross-sectional area and (d) LVEDA after induction of anesthesia, (e) LVEDA before clamping renal vessels, (f) LVEDA after declamping of renal vessels.

Table 3 Correlation between internal jugular vein diameter and left ventricular end-diastolic area, central venous pressure

	T1		T2		T3	
	r value	*P* value	*r* value	*P* value	*r* value	*P* value
LVEDA	0.022	0.932	0.073	0.772	0.187	0.458
CVP	0.248	0.321	0.375	0.125	0.228	0.363

CVP, central venous pressure; LVEDA, left ventricular end-diastolic area; *r* value, Pearson's coefficient; T1, time after induction of anesthesia; T2, time before renal vessels clamping; T3, time after renal vessels declamping. *P* value less than 0.05..

Table 4 Correlation between internal jugular vein cross-sectional area, and left ventricular end-diastolic area, central venous pressure

	T1		T2		T3	
	r value	*P* value	*r* value	*P* value	*r* value	*P* value
LVEDA	0.157	0.534	0.009	0.971	0.026	0.919
CVP	0.116	0.647	0.193	0.443	0.028	0.911

CVP, central venous pressure; LVEDA, left ventricular end-diastolic area; *r* value, Pearson's coefficient; T1, time after induction of anesthesia; T2, time before clamping renal vessels; T3, time after declamping renal vessels. *P* value less than or equal to 0.05 is considered statistically significant.

Conclusion

Ultrasonographic IJV dimensions (IJV diameter and cross-sectional area) were not reliable for assessing intravascular volume status in living donor renal transplant surgery in pediatric patients.

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Conflicts of interest

There are no conflicts of interest.

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