Overcoming the Physiological Challenges Encountered in Recent Advances in Surgery

BS Perera Oration 2020 – College of Anaesthesiologists and Intensivists of Sri Lanka

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1. Introduction and Background

The mainstay of the field of Anaesthesia and Critical Care is based on maintaining the physiological balance to handle the derangement of the physiology in many instances in peri-operative practice. Hence, the knowledge of applied physiology is the basis for predicting and planning peri anaesthetic procedures and events. It could be related to the surgery, anaesthesia per se or a combination of both. These problems will be compounded by patient factors which will compromise physiological homeostasis. This is especially important in complex surgeries and patients with limited physiological reserve.

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Received: 28/01/2024

Accepted: 28/01/2024

DOI: https://doi.org/10.4038/slja.v32i1.9319

The range of surgical procedures handled by the anaesthetic department at Teaching Hospital Peradeniya is diverse. The challenges encountered in selected different types of major surgeries, the Physiological alterations present in these patients, how the changes of physiology are handled and adaptations made to bridge the gap and the Beneficial results of these adaptations were presented in this oration.

Out of the range of complex surgeries requisite to the author's contribution, the following complex surgeries were chosen to present

1. Minimally access surgeries
    1. Thoracoscopic thymectomy
    2. Laparoscopic pancreatic surgeries
2. Paediatric renal transplants

2. Thoracoscopic Thymectomy

Thymectomy may be performed using different surgical approaches, such as either

Open access by median sternotomy or Video-assisted Thoracoscopic approach (VATS). Until the time of this oration(from 2009 to 2019), our team At THP had done 161 VAT surgeries, out of which 25 were for thymectmies.

Anatomical considerations in Thymectomies embrace the restricted space, the risk of major haemorrhage due to the proximity to major vessels and the fact that the Thymic vein drains directly to the left brachio-cephalic vein, and the risk of phrenic nerve injury. The CECT enables surgical decisions on the most suited approach to the chest- whether right or left.

Video-assisted Thoracoscopy (VATS) has many advantages. It Avoids median sternotomy and associated complications, less peri-operative blood loss, shorter operating period, less post-operative ventilatory problems, less analgesic requirements, and reduced risk of wound infection and dehiscence that may be disastrous, particularly following sternotomy. It also Permits early mobilisation and discharge. Also, it has disadvantages, such as difficulty in controlling major bleeding.

2.1 The challenges and the adaptations

Challenges we faced during VATS Thymectomies are a combination of both the disease and VAT. Pre-operative optimisation, Anatomical concerns, Creation of space for surgery, Ventilatory and CVS disturbances, Post-operative care, and Pharmacological management of pain in Myasthenic patients are included.

2.1.1 Provision of adequate space for dissection

Traditionally, to obtain adequate space, single lung ventilation (SLV)with the use of a double-lumen endotracheal tube is used. Once acquired, the ipsilateral lung collapse was created, and space was filled for the capnothorax. This will need only a small volume of CO2 insufflation. This was also helped by positioning the patient to enable the collapsed lung to fall away from the dissection field.

However, the use of SLV has its own disadvantages. The Double-lumen tubes used for SLV have their own cautions, including traumatic laryngitis and tracheobronchial rupture and are few to mention. Ideally, it Requires a fiberscope to ensure correct placement.

SLV carries a danger of hypoxemia and increases the risk of dynamic hyperinflation. The collapsing of one lung physiologically can cause a Right to left shunt. All these necessitate meticulous monitoring. Also, it may cause multifactorial pulmonary oedema.

Adaptations:

We avoided the SLV with the Double-lumen tube and instead used the Conventional single-lumen ET tube and ventilated both lungs. The anticipated problem was to provide adequate space and access for surgery. This was achieved by the continuous insufflation of CO_2 (capnothorax) and the resultant partial lung collapse during continuous insufflation.

This also relieves us of many expected problems with the double-lumen tube insertion, as stated above. ,

Expected Challenges with this Adaptation :

The pressure and the volumes of CO_2 may be different since we are entirely dependent on the maintenance of the capnothorax. The expected Increased intra-thoracic pressure due to a greater volume of continuous CO_2 insufflation could cause more significant reductions in venous return and cardiac output. Therefore, the pressure of the capnothorax needs to be carefully regulated.

2.1.2 Position of the patient for VATS Thymectomy

What could be the Optimal Position of the Patient for VATS Thymectomy?

The traditional position for VATS with SLV was the Lateral Decubitus Position, which provided the best exposure and gravity-dependent blood flow to the dependent and ventilated lung, resulting in a better V/Q match.

As an added advantage, If the need arises to convert to an open Thoracotomy./Sternotomy, a change to the supine position will be easy.

Adaptations

As our adaptation, we selected the supine posture as we adopt for all other anterior mediastinal surgeries. This posture enabled the lung to fall away (back)from the field of surgery, providing adequate exposure. Though conversion to open thoracotomy was not required in our series, sternotomy would be easier in the supine position.

Table 1: Comparison of Variables with SLV (Single Lung Ventilation) and DLV (Double Lung Ventilation)

	Number of patients	Average time taken	Use of Additional ports	Mean Blood loss	Conversion	Insufflation pressures mmHg	Total CO_2 volume (L) (mean)
SLV with Double Lumen Tube	2	3.5 hr	None	150ml	Nil	3-4	2
DLV with conventional tube	25	3.8 hr	None	150ml	Nil	6-8	27.4

The surgical compliance, the absence of the necessity for additional ports for instrumentation, and the visual outcome of the surgery revealed that the space created for surgery using both lung ventilation was adequate. Also, it was noted that the insufflation pressure needed to provide adequate lung collapse was 6-8mmHg, which is safe.

Table 2: The Respiratory and Cardiovascular Parameters during Both Ventilatory Strategies

	Peak airway pressure cmH_2O	Oxygen saturation change%		End Tidal CO2 mmHg		Heart Rate change from the baseline		Blood Pressure change (Sys) mmHg			Blood Pressure change (Diast) mmHg	
Changes from the baseline	1-5	1-3	3-5	10-20	10-20	10-20	20-30	10-20	20-30	30-40 above	10-20	20-25
(OLV) 2	2	1	1	2	2	2	-	-	1	1	2	-
(DLV)25	6	6	-	5	5	5	1	-	6	-	6	-

It was noted that, though there were numerically marginal increased changes in parameters with DLV, overall CVS and RS stability were maintained within very safe limits without intra-operative and post-operative complications. There was no necessity to increase infusions or use inotropic support.

Results using this supine posture also showed adequate exposure and no necessity for additional ports for retractors. Median blood loss was 150 ml, and the time range was 3.5 hours. No conversion to open surgery was noted.

These findings concluded that the use of a conventional tube and ventilation of both lungs with a partial collapse with the capnothorax provided adequate space for surgery and did not increase the surgical time or bleeding, whilst the required continuous CO_2 insufflation pressure was 6-8 mm Hg, The use of the supine position provided adequate exposure and maintenance of physiological variables.

We confidently recommend this technique for VAT thymectomies.

3. Laparoscopic Pancreatic Surgery

3.1 Unique problems at complex and prolonged minimally access Laparoscopic surgeries

There are problems caused by the pneumoperitoneum, leading to Increased intraperitoneal pressure, causing Diaphragmatic splinting and reducing lung volumes and compliance. This can be reduced by using a head-up tilt if it doesn't interfere with surgery. Prolonged laparoscopic surgery can lead to CO_2 load, requesting ventilation to clear the excess CO_2 load, risk of entrapment neuropathies with various extreme positions, Risk of sudden haemorrhage and Hypothermia are also some to consider.

Maintaining cardiovascular stability is another challenge. The compression of IVC reduces the venous return and possibly compromises renal and mesenteric blood flow, a major concern. Often, this can be compounded by the right lateral position adopted during some surgeries. The CVP monitoring may not accurately reflect the circulating blood volume. The risk of significant bleeding in complex procedures where quick, direct compression of vessels is impossible.

3.2 Challenges Specific to Laparoscopic Pancreatic Surgery

Pancreatic surgery could be regarded as one of the most complex and risky surgical procedures. The surgical unit of Teaching Hospital Peradeniya pioneered laparoscopic pancreatic surgeries in Sri Lanka. The range of laparoscopic pancreatic surgeries included Pancreaticoduodenectomy (Whipple's procedure- PD), Distal pancreatectomy(DP), Laparoscopic cysto-gastrostomy for pancreatic pseudocysts and Splanchnicectomy for chronic pancreatic pain.

The mean time for surgery is usually prolonged. Hence, the surgery consumes a massive CO_2 load of about 60-80 litres, which has to be handled. Often, the surgeon requests a High insufflation pressure of CO_2 during the dissection of the portal vein or major veins to facilitate dissection and reduce bleeding. This will aggravate the effect of the pneumoperitonium. We need to be cautious in interpreting CVP in view of this raised intra-abdominal pressure.

3.3 Measures taken to overcome the physiological challenges

The optimal insufflation pressure was limited to 12-14 mmHg, with only short periods of high insufflation pressure (up to 20 mmHg) during portal vein dissection. The Optimal tidal volume used was 10-11 ml/kg. A head-up tilt with the patient on the left lateral side was used. The warmed fluids and warming blankets were used as usual for prolonged surgeries. The changes and observations are presented in Tables 1 and 2

Oxygen saturation was noted to be kept within acceptable limits and did not change by 5%, whilst the Increase of End-tidal CO_2 were within permissible limits.

The optimal insufflation pressure was limited to 12-14 mmHg, which managed to overcome the adverse effect of pneumoperitoneum. The Optimal tidal volume used was 10-11 ml/kg, adequate to to overcome the mechanical impact of diaphragmatic splinting. The resultant Minute ventilation minimises the accumulation of CO_2. The use of a head-up tilt with the patient on the left lateral side reduced IVC compression and diaphragmatic splinting and provided a more relevant interpretation of the CVP.

Table 3 Parameters used and observations

	Age (yr)and gender distribution	Average time taken for surgery	Average blood loss	Position adapted	Tidal volume (Median) ml/Kg	CO_2 volume used (median)Litres	Important surgical details
Whipple's (Pancreatico-duodenectomy) (PD) (32)	35-70 M 14 F 18	222 min	265 ml	Supine, Head Up, Left Lateral	10	60	Conversion to open surgery at various stages of resection-5 (15%)
Laparoscopic Distal Pancreatectomy (DP) (6)	24-63 M- 2 F-4	261 min	158 ml	Right lateral tilt, head up	11	40	In 5 en bloc resection, the spleen was preserved In 1 – splenectomy included

There could be many challenges during an event of sudden bleeds. The direct compression of bleeding vessels was not possible, and the conversion to open surgery would take time. Conversion to open surgery due to bleeding was required during three pancreatico-duodenectomies. The bleeds were from the portal vein. This required active resuscitation and maintenance of fluid status during the varying durations. Another observation was that even though we expect hypothermia in prolonged laparoscopic surgery, The initial temperature drop ranged from 0.5- 1.4 C ˚. within the first hour. There was no detectable change after that, indicating that using warmed fluids and warming blankets was adequate to minimise hypothermia even though the surgery was prolonged.

1. Paediatric Renal Transplantation (KT)

Children generally receive transplants from adults. The availability, relatively less complex surgery, and less likelihood of delayed graft function were added as reasons for the preference. In children, many of the diseases that cause renal failure do not recur, and successful transplantation could, in theory, be a permanent cure.

Table 4: Observed Respiratory and Hemodynamic Parameters

	Peak airway pressures cm H_2O Changes		Saturation change %		End Tidal CO2 mmHg		CVP cm H_2O (baseline 12-15)	IAP mmHg	Heart Rate /min Changes			Blood Pressure (Sys) mm Hg			Blood Pressure (Diast) mm Hg		
	1-5	5-10	1-3	3-5	↑ 1-5	↑ 5-10			10 - 20	20 - 30	30 - 40	10 - 20	20 - 30	30-40 above	10 - 20	20 - 25	25-30 above
PD	21	1	10	2	22	-	10-18	12-14	20	2	-	11	8	3	16	5	1
DP	2		2		2		14-19	12-14	1	1		2			2		

The transplanted kidney is often much larger than the recipient's. Anatomically, the procedure requests different surgical techniques. When compared to adults, children often differ in their responses and tolerance to medications, and they vary considerably as regards co-morbidities. In contrast to adults, there is a necessity to ensure average growth and cognitive and psychological development for decades.

Increased graft survival can be credited to multiple factors, including refinements in pre-transplantation preparation, enhanced surgical techniques, better choice of donors, more potent immunosuppressive medications, greater understanding of pediatric-specific pharmacokinetics, use of evidence-based medication protocols and improvements in anaesthesia techniques.

At THP, even though the program started with relatively older children, later, with the development of the learning curve, it evolved to achieve younger recipients, the youngest being the age of 1 and half years and weight of 8 kg. The age distribution of Kidney transplantation recipients ranges from 1 year to 21 years. There are 14 children in the age group of 0-5 years showing remarkable survival. The major portion of transplants were in the age group of 6-10.

We have only performed live donor kidney transplants, as cadaveric renal transplantations are not performed in the paediatric population in Sri Lanka. 68% of the donors were related to the patient, while 11% were nonrelated. Of the related donors, biological mothers constituted the majority (44%).

Our experience over 15 years has enabled us to observe outcomes associated with quality of life. A satisfactory number of recipients achieved a good quality of life with a good education.

4.1 Overview of Physiological Disturbances/ Challenges with Donor-recipient size mismatch

4.1.1 Surgical Technique with the Donor-Recipient size mismatch

In paediatric patients with a body weight > 20 kg, the surgical technique is similar to that used for an adult KT; the renal artery is anastomosed to the common iliac artery, the renal vein to the common iliac or external iliac vein. The kidney is placed extra-peritoneally in the ileac fossa. In contrast, when an adult kidney is transplanted into a very small child (<20 kg), The external iliacs are too small and unsuitable for anastomose. Hence, the alternative strategy is to use a larger vessel; the kidney is sewn directly onto the aorta and vena cava.

Still, most of the time, the kidney is placed extra peritoneally. If the extraperitoneal placement is not possible in some of these patients, the kidney is placed intraperitoneally. This technique needs cross-clamping of both the aorta and inferior vena cava, which results in many significant physiological changes.

4.1.2 Nephroprotection and maintenance of renal Blood flow and GFR

Usually, 20% of cardiac output reaches the kidneys (10% to each kidney). When a child receives an adult kidney, the blood flow to the transplanted kidney will be the same as it was. To maintain the same level of perfusion as to the adult donor kidney, half the child's cardiac output would have to be directed to the transplanted kidney. This is likely to compromise the recipient child's cardiovascular system. This cardiovascular burden in paediatric patients needs to be cautiously looked at. Also, from the kidney point of view, the previous perfusion pressure of the donated kidney, which was used to, is relatively higher than it will be subjected to in a small child with a significantly lower resting blood pressure.

Possible hypoperfusion or hypovolaemia in the transplanted kidney predisposes to acute tubular necrosis and graft thrombosis, infarction, or renal vascular thrombosis; the incidence ranges from 3 -12.5%, leading to poor or delayed graft function. Hence, meticulous care should be taken to maintain normovolaemia and normotension "In the TRANSPLANTED KIDNEY" to avoid these complications.

Keeping this possibility in mind, there were many practices for maintaining the perfusion of the allograft and the CVS requirements. Preoperatively and intraoperatively keeping the patient more hydrated, administration of large quantities of intravenous fluids or blood transfusions, central venous pressure to be raised to a much higher level -to at least 18 before reperfusion, concomitant use of inotropes if necessary, to maintain the systemic blood pressure at least 20% higher than the pre-operative value to tolerate cross-clamp release are known practices. However, these management regimens can increase the burden on the cardiovascular system of the small child.

The required volume to fulfil the above may be much greater than the child's calculated blood volume. The aggressive volume loading prior to unclamping needs to be cautious with the risk of pulmonary oedema. Some of these children already have existing cardiovascular complications. Some children (not all)with renal disease have hypertension, uraemia-induced cardiomyopathy, congestive cardiac failure, and pulmonary oedema.

4.1.3 Other Issues on care during perfusion of the allograft

The surgical techniques involve the cross-clamping of major vessels. The release of the major vessel clamps results in ischaemic byproducts from the lower extremities, and the kidney entering the central circulation, too, will be subjected to vasodilatation. Apart from an already requested major portion of the cardiac output to the adult kidney, another fraction of the child's cardiac output may shunt through the newly added kidney due to this increased vasodilatation. Another unseen complication would be the cold preservation technique for preserving the donor's kidney, which may cause a decrease in cardiac contractility.

Considering all these, the imperative question would be what the ideal blood pressure to maintain is, what vasopressors to use, and when to use them. There are currently no clear recommendations on haemodynamic targets during pediatric kidney transplantation, and most anesthesiologists rely on empiric targets or adult reference values when managing pediatric kidney transplantation.

The adults have more precise recommendations for maintaining mean BP. However, there is no consensus on what vascular supports to use for haemodynamic stability, and there is a heterogeneity in drugs used for hemodynamic management.

Table 5: Donor- Recipient Size Mismatch; Age Difference and Commonest aetiologies

Age range at KT	Number of Patients	Commonest Aetiologies	Donor age range* (years)			
			20 - 30	31 - 40	41 - 50	51 - 60

0-5	8	Congenital malformations, obstructive nephropathy and polycystic kidney disease.	1	6	1	
6-10	35	Congenital malformations glomerulonephritis	2	17	16	
11-15	30	Congenital malformations glomerulonephritis	4	10	15	1
16-20	15	obstructive nephropathy	-	2	11	2

*Age ranges indicate the likely differences in the size of the donated kidney.

The use of "renal doses" of dopaminergic agents was not recommended since it was not associated with graft function or survival. However, evidence still lacks to recommend any alternative regimen (norepinephrine, epinephrine, or both). Most centres use epinephrine and/or norepinephrine as continuous vasopressors after reperfusion. Tables 5 and 6 indicate the variation of the donor by means of age and mean blood pressure compared to that of the paediatric population subjected to receiving the kidney.

Table 6: Donor Mean Blood Pressure

Age range at KT	Donor Mean Blood Pressure mm Hg			
	40-50	51-60	61-70	71-80
0-5 (8)			2	6
*6-10 (30)		4	5	21
**11-15 (26)		1	4	19
16-20 (15)			14	1

4.2 The Protocol practice on intraoperative haemodynamics and intravenous fluid

1. An intraoperative maintenance solution used was crystalloid; NS or N/2
2. Additional vascular filling: Normal Saline boluses 10 mL/ kg
3. Target CVP - careful only to increase > 5 measures higher than the baseline value

4. For vascular filing effects, we used FFP, Albumin or blood after crystalloid administration as the first-line treatment

5. Prefill the patient with 10 ml/Kg blood before releasing the clamp

6. Aggressive volume loading prior to unclamping, if necessary, bears a risk of pulmonary oedema. (Therefore, an individualised decision)

   Hemodynamic Endpoints

7. Targeted mean arterial pressure was according to THE DONOR MEAN BLOOD PRESSURE

   a. Iliac grafts: Maintain the MAP value of the donor MAP during the reperfusion.

   b. Aortic grafts: Maintain the MAP value > 10- 20 more above the donor MAP during clamping

8. Maintain the BP to the donor MAP at and after reperfusion, which was the intended target.

9. Hemodynamic endpoints:

   a. Keep mean blood pressure ≥ just above the donor MAP mm Hg,

   b. central venous pressure (CVP) ≥5 measures of baseline or ≥15 bars during and after reperfusion

10. Failure to achieve donor MAP was considered as the indication to start vasoconstrictor /inotrope

11. A vasopressor infusion was used if needed after reperfusion and often needed continuation after that

12. The most commonly used vasopressor/ inotrope

    a. Dopamine was titrated from 5 to 20 mic/kg/ mn or adrenaline infusions

    b. In some cases required Dobutamine 5 to 20 mic/kg/ mn

13. Since the haemodynamic triggers were lower, the usage of vasopressors was infrequent and often in lower dosage

14. The blood pressure goal was adjusted when required following a surgical opinion of kidney reperfusion

15. In patients who were being treated for hypertension, the morning dose of antihypertensives was discontinued

16. Post-operative replacement of urine output by using Hartman's solution (equal volume of loss)

Table 7: Mean Blood Pressure Maintenance During The Transplant (analysed in 61 Patients)

	Mean arterial pressure			
	Iliac graft Recipient N= 40 (mean)	Donor (Mean)	Aortic graft Recipient N= 21 (mean)	Donor (mean)
Before Induction	72.6	71.9	69.08	72.73
During anastomosis	74.1		80.8	
After Anastomosis	72.08		73.69	

The success of the transplant and the patient's stability were interpreted by the level of creatinine, high-resolution Doppler ultrasound of the renal allograft, and post-operative complications.

We were aware that in very young pediatric recipients who have an allograft-size mismatch, which can lead to a high glomerular filtration rate, interpretation of serum creatinine results is more difficult, as acute rejection may initially occur without an elevation of the serum creatinine level. This may lead to errors in management.

Table 8: Vasoactive drugs usage

	Vasoactive drugs used (25)	Details not available
0-5 (8)	7	1
6-10 (35)	11	4
11-15 (30)	5	3
16-20 (15)	2	-

4.2.1Post Operative Fluid

The urine output from the adult kidney can be profound (i.e., 80 mL/kg per hour), and the choice of replacement fluid should be either N/2 or Hartman's solution. For infants and older children, we found that the replacement of urine output by millilitre per millilitre using Hartman's solution was safe and adequate. Replacement of the fluid due to diuresis was continued up to 2 days following surgery.

Table 9: Pre-Transplant and Post-Transplant Decreases in Creatinine

Age range	Pre OP & Post OP Serum Creatinine Drop of											
	0-100	101-200	201-300	301-400	401-500	501-600	601-700	701-800	801-900	901-1000	1001-1100	Data not available
0-5	1	1	1	2	0	3						
6-10	1	2	8	3	5	3	2	1				6
11-15	2	0	8	5	2	1	1	0	0	0	2	9
16-20	2	0	3	1	0	4	0	0	2			3

Table 10: Post-Operative Doppler Studies

	6 hrs- 12 hrs			24 hr		
	Satisfactory	Not Satisfactory	Not available	Satisfactory	Not Satisfactory	Not available
0-5 (8)	6	1	1	7	-	1
6-10 (35)	25	-	10	26	2	7
11-15 (30)	20	3	8	22	1	7
16-20 (15)	12	1	2	10	3	2

4.2.2 Post-operative Complications

With the view of the imbalance of fluid homeostasis, Pulmonary oedema due to the large amounts of fluid administered to small children is a possibility. The existing cardiovascular instabilities could also contribute to this. In this group, 11% of patients developed pulmonary oedema.

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Table 11: Requirement of Post-Operative Surgical Interventions

	Needed surgical interventions	Reason for reopening			
		Bleeding	Urinary Leak	Abdominal distension	Inadequate flow in the renal artery
0-5 (8)	3	2			1
6-10 (35)	5	2	2	1	
11-15 (30)	5	1	2	1	
16-20 (15)	2			1	1

The presence of a large adult kidney in a small paediatric abdomen poses a significant problem with abdominal wall closure. It causes obvious abdominal distention and possible abdominal compartment syndrome, which can potentially jeopardise graft perfusion. As respiratory complications were expected with Donor-Recipient mismatch, these patients were managed with mechanical ventilation in the intensive care unit postoperatively. A possibility of lung collapse, which was expected, was observed in a few patients(8%).

As complications of existing hypertension, Hypertensive episodes– 32%, Hypertensive encephalopathy – 16%, Convulsions – 35%. This also may have contributed to transient electrolyte disturbances.

Bleeding was experienced in 14% of patients, probably due to the etiological connection. Urinary tract infections – 11%, Sepsis– 8%, were noted. All these complications were managed successfully.

One patient resulted in early graft loss due to vascular thrombosis

Conclusion

The MAP of the recipient maintaining as close to the donor's MAP during and postoperatively can be used as the target. The post-operative creatinine clearance and the renal arterial flow were estimated to be satisfactory in the recipients with high graft survival. As such, this may be considered a valid clinical target for anesthesiologists trying to avoid excessive afterload and maintain cardiac output.

The successful pediatric renal transplant has three main pillars: the transplant surgeon, the transplant Nephrologist, and the pivotal role of the transplant Anaesthetist, which involves peri-operative and Intensive Care.

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ACKNOWLEDGEMENTS

I would like to acknowledge the partnership of the teams from Teaching Hospital, Peradeniya. The brilliant surgical team Prof KB Galketiya (Professor in Surgery), Prof MD Lamawanse (Professor of Surgery), Prof Bandula Samarasinghe (Professor in Surgery), Dr Rochana Perera (Consultant Anaesthetist), Dr S. Wasala (Senior Lecturer in Anaesthesia and Critical Care) Prof A, Abeygunawardena and Prof S.Thalgahagoda (Paediatric Nephnologysts)Prof Bhadra Hewavitharana and Prof Shanthini Rosairo (RadiologyDepartment,) for arranging imaging studies, Prof . NRatnathunga (Pathology Department, for the Pathology and laboratory support, All the Registrars and Medical Officers of Anaesthesia and Surgery, involved to the surgeries, all the nursing and supportive staff in both departments, operating theatres and ICU for their assistance. I also gratefully acknowledge all the patients and their families who trusted us.

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