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Original Article

Effect of peritoneal dialysis on intra-abdominal pressure and cardio-respiratory function in infants following cardiac surgery

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Abstract *Objective:* To investigate the relationship between dialysate volume, intra-abdominal pressure, and cardio-respiratory function in infants following cardiac surgery. *Design:* Prospective pilot study. *Setting:* Paediatric intensive care unit. *Patients:* Six infants undergoing peritoneal dialysis within 24 h of cardiopulmonary bypass. *Interventions:* Manipulation of the volume of dialysate at levels of 0, 10, 20, and 30 ml/kg in variable order. *Measurements and main results:* Intra-abdominal pressure was measured at each volume of dialysate via a pressure transducer connected to the dialysis catheter. Haemodynamic data was collected, including cardiac output, which was measured by thermodilution via a 3.5-French gauge catheter placed in the pulmonary arterial pathway. Respiratory data included PaO_2, $PaCO_2$, and dynamic compliance. Intra-abdominal pressure increased with increasing volume of dialysate ($p < 0.001$), though there was considerable variation between patients in the magnitude of increase. Intra-abdominal pressure remained low even with 30 ml/kg in the abdomen. In three infants, intra-abdominal pressure was re-measured in the absence of muscle relaxants, and was found to be higher in each case. No negative effects on cardiac output, markers of delivery of oxygen, or respiratory function were seen even at volumes of 30 ml/kg. Cardiac index was significantly higher with 10 ml/kg than when the abdomen was empty or contained a larger volume ($p < 0.05$). *Conclusions:* In this small group of infants, intra-abdominal pressure increased with increasing volumes of dialysate but remained low, even with 30 ml/kg in the abdomen, and was not associated with any deleterious effects on cardio-respiratory performance.

Keywords: Congenital heart disease; lung function; compliance; cardiac output

PERITONEAL DIALYSIS IS USED IN THE postoperative period following cardiac surgery to aid in the removal of fluid or, less frequently, to remove urea and other solutes in established acute renal failure. An audit at Royal Children's Hospital, Melbourne has shown that peritoneal dialysis is used in approximately half the neonates and infants undergoing surgery for complex congenital heart disease (data not shown). It is routine clinical practice in many centres to insert a catheter for potential peritoneal dialysis at the time of surgery in all infants undergoing complex repairs on cardiopulmonary bypass.

Previous studies in patients without cardiac disease have shown that cardiovascular performance can be greatly affected by altering intra-abdominal pressure, whether this is the result of instilling fluid or gas into the peritoneal cavity[1–3] or by the presence of ascites in patients with liver disease.[4] From evidence in children with end-stage renal failure undergoing peritoneal dialysis, it is known that intra-abdominal pressure is influenced by the volume of fluid instilled for peritoneal dialysis,[5] and by body position, being considerably higher in the upright in comparison to the supine position.[6] As a result of concern about the potential detrimental cardiovascular effects of raised intra-abdominal pressure, the volumes used for peritoneal dialysis in infants following cardiac surgery are

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typically small, in the region of 10 ml/kg, and considerably lower than those required to achieve satisfactory clearance of solutes in end-stage renal failure, which requires around 30 ml/kg.

The haemodynamic and respiratory effects of peritoneal dialysis have been assessed in small groups of patients.[7–9] Thus, Ryan et al.[7] evaluated the haemodynamic status at four different phases of the cycle for peritoneal dialysis in three children following open heart surgery. They found no change in cardiac index, or systemic or pulmonary vascular resistances, following instillation of 20 ml/kg of fluid for dialysis. Dittrich et al.[8] performed a similar evaluation in six infants with acute renal failure, five of whom had an open thorax. The volume used for dialysis was only 10 ml/kg in this study. Once again, no significant change in cardiac index or systemic vascular resistance was seen at the four phases of dialysis. To the best of our knowledge, however, no previous study has systematically examined the relationship between dialysate volume, intra-abdominal pressure, and haemodynamic effect.

The effect of intra-abdominal pressure on cardiac output is thought to be principally related to its effect on venous return, though left ventricular afterload is also increased in the presence of significantly raised intra-abdominal pressure.[10] The overall effect on venous return to the heart has been shown to depend on the relationship between intra-abdominal pressure and the pressure within the abdominal venous system, which will in turn relate to right atrial pressure,[11] or common atrial pressure in a patient with a functionally univentricular heart. When intra-abdominal pressure increases above the pressure within the inferior caval vein, venous return to the heart will be reduced. An increase in intra-abdominal pressure which does not exceed inferior caval venous pressure, nonetheless, may augment venous return and cardiac output.[10,11] These findings concur with the clinical observation made in some patients that blood pressure increases when dialysate is infused into the peritoneal cavity, and falls when dialysate is drained out of the abdomen.[12] Such an observation in a neonate undergoing peritoneal dialysis following cardiac surgery prompted us to perform a pilot study looking at the influence of the volume of dialysate on intra-abdominal pressure and cardio-respiratory function in a small group of infants following biventricular repair of congenital heart defects.

Materials and methods

Case report

A 7-day-old infant weighing 3.2 kg underwent complete repair of tetralogy of Fallot with pulmonary atresia and aorto-pulmonary collateral arteries. The following day, peritoneal dialysis was commenced because of poor urinary output, related to a low cardiac output state. The volume used for dialysis was increased in increments of 10–30 ml/kg. Cardiac output was measured prior to commencing dialysis, and at each subsequent volume, using dye dilution with indocyanine green. At least two reproducible curves were recorded at each time-point. Cardiovascular support remained constant at 5 μg dopamine/kg/min and 7.5 μg amrinone/kg/min. Intra-abdominal pressure was not measured.

Pilot study

With the approval of the Royal Children's Hospital Ethics Committee, and after obtaining written consent, we studied six infants, with a median age of 3.5 months, ranging from 2.0 to 11.5 months, and median weight of 4.6 kg, ranging from 3.2 to 8.9 kg within 24 h of biventricular repair of congenital heart defects on cardiopulmonary bypass. In three instances, the patients had ventricular septal defect, with two having atrioventricular septals and the other tetralogy of Fallot. The study was undertaken between October 1996 and February 1997. In each case, an echocardiogram was performed after surgery to exclude any residual intra-cardiac shunt. Measurements of haemodynamics, the compliance of the respiratory system, blood gases in arterial and mixed venous blood, blood lactate, and intra-abdominal pressure were made under four conditions. These were first an empty abdomen, then situations involving 10, 20, and 30 ml/kg as the volume of dialysate. The order of the four conditions was varied randomly between individuals, and measurements were made 10 min after infusion of the dialysate. Cardiac output was measured by thermodilution, administering 2 ml aliquots of iced saline via a 3.5-French gauge catheter placed in the pulmonary arterial pathway at the time of surgery. Three reproducible curves were obtained at each time-point. Abdominal pressure was measured using a pressure transducer connected to the dialysis catheter, and the zero point was taken at mid-axillary level. Dynamic compliance was measured using a commercially available monitor of lung mechanics (Ventrak, Novametrix Medical, Wallingford, CT, USA). Chest closure was achieved in all infants prior to returning to intensive care. All infants were receiving an infusion of dopamine at between 5 and 7.5 μg/kg/min, two were receiving an infusion of glycerine trinitrate at 2 μg/kg/min, and one was receiving noradrenaline at 0.05 μg/kg/min. Cardiovascular support was not altered for the duration of the study. All infants were receiving morphine for analgesia, midazolam for sedation, and pancuronium as a muscle relaxant, and had a urinary

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catheter in place. Peritoneal dialysis fluid was a 1.36% solution of Dianeal (Baxter Healthcare Ltd, Northampton, UK).

Results

Case report

Cardiac index prior to commencing peritoneal dialysis was 1.30 l/min/m^2, consistent with a low output state (Fig. 1). After instillation of 10 ml/kg of fluid for peritoneal dialysis, the cardiac index increased to 1.44 l/min/m^2 as a result of an increase in stroke index from 6.7 to 7.5 ml/m^2. Cardiac index remained above the baseline value after 20 and 30 ml/kg of fluid had been instilled. Central venous pressure increased from 8 mmHg at baseline to 14 mmHg at 30 ml/kg. With the abdomen empty following drainage of the peritoneal dialysis fluid, the cardiac index fell to 1.19 l/min/m^2, central venous pressure fell from 14 to 9 mmHg, and heart rate increased from 184 to 195 beats/min (Fig. 1). Intra-abdominal pressure was not measured.

Pilot study

Intra-abdominal pressure increased with increasing volume of dialysate (Table 1), though there was considerable variation in pressure readings between individuals (Fig. 2). Intra-abdominal pressure remained low even with 30 ml/kg dialysate in the peritoneal cavity, with no value exceeding 10 cmH_2O. There was considerable variation between patients in

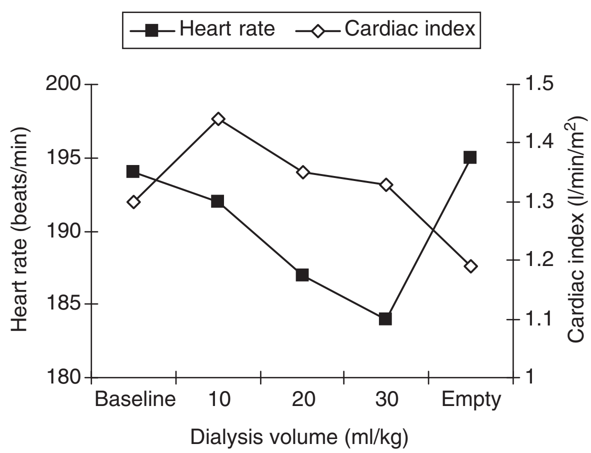

Figure 1.
Changes in heart rate and cardiac index with initiation of peritoneal dialysis and manipulation of the volume used as dialysate in an infant weighing 3.2 kg.

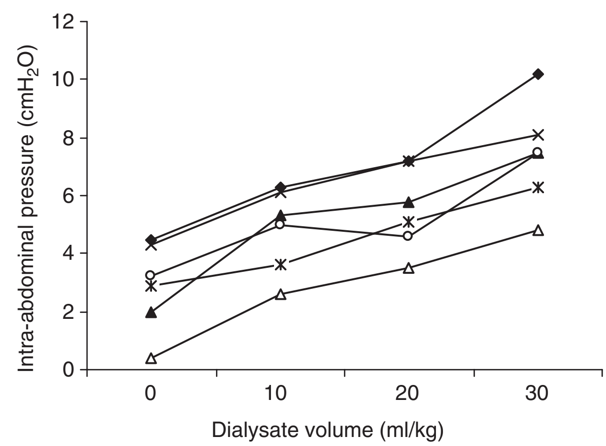

Figure 2.
Relationship of intra-abdominal pressure to the volumes used as dialysate in our six individual patients.

Table 1. Group data (mean (standard deviation)) for intra-abdominal pressure, haemodynamic measurements, respiratory system compliance, and blood gas variables under the four PD conditions. $^{\#}p < 0.05$; 0 vs. 10, $^{\$}p < 0.05$; 10 vs. 30, using ANOVA.

	Dialysate volume (ml/kg)			
	0	10	20	30
IAP (cmH_2O)	2.9 (1.5)	4.8 (1.5)$^{\#\$}$	5.6 (1.5)	7.4 (1.8)
Cardiac index (l/min/m^2)	3.32 (1.08)	3.54 (1.17)$^{\#\$}$	3.24 (0.96)	3.33 (1.09)
Heart rate (beats/min)	146.7 (20.8)	149.7 (19.2)$^{\$}$	145.3 (18.1)	142.8 (18.2)
Mean SAP (mmHg)	49.3 (4.5)	48.2 (3.4)	50.8 (7.1)	50.8 (6.1)
Mean PAP (mmHg)	16.0 (2.8)	17.2 (3.2)	16.7 (3.4)	17.0 (3.6)
LAP (mmHg)	5.8 (1.6)	5.7 (1.4)	6.2 (1.6)	6.7 (1.4)
CVP (mmHg)	8.5 (2.1)	8.7 (2.1)	8.5 (1.9)	8.8 (2.0)
SVRI (dyn·s·cm^5/m^2)	12.3 (3.4)	11.2 (3.6)	13.1 (4.1)	12.6 (3.8)
MV O_2 sat (%)	59.7 (3.9)	62.2 (9.8)	61.1 (3.7)	61.1 (2.9)
Blood lactate (mmol/l)	1.38 (0.49)	1.33 (0.51)	1.35 (0.41)	1.35 (0.47)
Dynamic compliance (ml/cmH_2O)	5.9 (3.5)	5.4 (2.5)	6.0 (2.9)	5.0 (1.9)
PaO_2 (mmHg)	93.4 (32.3)	93.9 (27.8)	95.0 (25.9)	97.3 (26.9)
$PaCO_2$ (mmHg)	37.1 (3.2)	37.6 (3.3)	39.5 (5.9)	40.0 (4.8)

Abbreviations: SAP: systemic arterial pressure; PAP: pulmonary artery pressure; LAP: left atrial pressure; CVP: central venous pressure; SVRI: systemic vascular resistance index; IAP: intra-abdominal pressure; MV O_2 sat: mixed venous oxygen saturation

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intra-abdominal pressure at 0 ml/kg, from 0.4 to 4.5 cmH_2O. Within each individual, the rate of increase in intra-abdominal pressure was fairly constant with an increasing volume of dialysate. Abdominal elastance, that is the increase in pressure per unit increase in volume, varied across individuals from 0.11 to 0.19 cmH_2O/ml/kg, with a mean value of 0.15 and standard deviation of 0.03.

In three of the infants, intra-abdominal pressure was measured again the following day with 30 ml/kg dialysate in the peritoneal cavity after muscle relaxants had been metabolised, and was found to be higher in each case, with values of 4.8–5.1, 7.5–11.0, and 7.5–14.0 cmH_2O, respectively.

We found no significant change in the compliance of the respiratory system, or in gas exchange, relating to the volume of dialysate instilled (Table 1). No negative effects on cardiac output, pulmonary arterial pressure, or systemic vascular resistance were seen even when the volume used was 30 ml/kg (Table 1). Mixed venous saturations of oxygen and blood lactate, the indirect markers of delivery of oxygen, did not change significantly with the changes in volume of the dialysate (Table 1).

Cardiac index was higher with 10 ml/kg dialysate in the abdomen than when the abdomen was empty or contained a greater volume of dialysate ($p < 0.05$) (Table 1). This increase was not accompanied by an increase in mean left atrial pressure or central venous pressure, but was associated with an increase in heart rate (Table 1). Figure 3 demonstrates the individual data relating to cardiac index. The curve for one infant, in open triangles, reveals a different response to the remaining five. In this infant, cardiac index increases progressively with increasing volumes of dialysate.

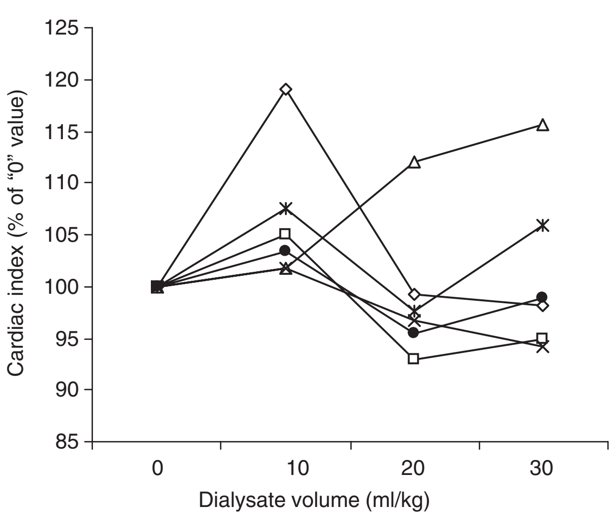

Figure 3.
Data for individual cardiac indexes expressed as a percentage of the measurement obtained with an empty abdomen.

This infant, with Down's syndrome and undergoing repair of an atrioventricular septal defect, had the lowest absolute cardiac index of the group, at 1.67 l/min/m^2 at 0 ml/kg, increasing to 1.93 l/min/m^2 at 30 ml/kg. The same infant also showed the lowest response of intra-abdominal pressure to abdominal filling, with a pressure of only 4.8 cmH_2O with 30 ml/kg of dialysate instilled. By comparison, in the other five infants the mean intra-abdominal pressure at only 10 ml/kg dialysate was 5.3 cmH_2O.

Within this small group of infants, we were unable to demonstrate a clear relationship between intra-abdominal pressure relative to central venous pressure, nor a related change in cardiac index, at different volumes of dialysate.

Discussion

This small pilot study of infants undergoing peritoneal dialysis following biventricular repair of congenital heart defects has shown a correlation between the volume of fluid used for peritoneal dialysis and intra-abdominal pressure, though we found considerable variation in abdominal pressure between the individuals studied. The reason for this variation is not apparent. In all six infants, the highest recorded intra-abdominal pressure was less than 10 cmH_2O, well below the level of intra-abdominal pressure at which features of so-called "abdominal compartment syndrome" have been demonstrated in other groups of patients.[13–15] No significant negative effects on cardiac output, delivery of oxygen, or respiratory function were seen, even when the largest volume of 30 ml/kg was instilled.

The case that prompted our pilot study highlights a well recognised clinical observation, namely that a proportion of infants on peritoneal dialysis after cardiac surgery show a more favourable haemodynamic profile when the peritoneal cavity is filled with fluid than when it is empty. Werner et al.[12] in a study of 32 children undergoing peritoneal dialysis following cardiac surgery, documented haemodynamic instability in one-sixth of their infants when the fluid used for peritoneal dialysis was drained out of the abdomen.

A number of factors may influence the individual cardiovascular response to peritoneal dialysis. Takata et al.[11] studied the effect of abdominal pressure on venous return to the heart, and described different conditions for various abdominal vascular zones, which they felt were analogous to the conditions of pulmonary vascular zones described by West et al.[16] They found that venous return is augmented if the increase in intra-abdominal pressure results in an absolute intra-abdominal pressure that is less than the transmural inferior caval venous pressure at the level of

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the diaphragm, but that venous return falls once intra-abdominal pressure exceeds the pressure in the inferior caval vein. It follows, therefore, that the response to instillation of fluid for peritoneal dialysis is likely to be influenced by the resulting intra-abdominal pressure, and by the relationship between intra-abdominal pressure and transmural inferior caval venous pressure. Infants in a low cardiac output state following complex cardiac surgery will usually have elevated left atrial and central venous pressures. They would, therefore, be more likely to show a beneficial haemodynamic response to a modest increase in intra-abdominal pressure. A novel technique to improve cardiac output, mediating its effect via an increase in intra-abdominal pressure, has previously been described in which a reservoir bag is placed beneath a tight cloth wrap on the abdomen of the patient. The bag is then intermittently inflated by a ventilator to sufficient pressure to result in abdominal compression, with concomitant improvements in cardiac output.[17]

In our pilot study, we found a small increase in cardiac index at 10 ml/kg dialysate compared to an empty abdomen, but this was no longer evident at higher volumes of dialysate. Although this is consistent with the theory of vascular zones, we were unable to document a clear relationship between intra-abdominal pressure, relative to central venous pressure, and the change in cardiac index at different volumes of fluid. In addition, we did not observe a significant increase in central venous pressure in association with the increase in cardiac index. This may be due to the limited statistical power of our small pilot study. Alternatively, it is possible that the lack of pericardial constraint following pericardiotomy may allow a substantial increase in preload before any change is seen in absolute atrial pressure. In addition, we cannot comment on changes in true transmural right and left atrial pressures, as pleural or mediastinal pressures were not measured.

The anatomical lesion and operation carried out may also influence the response to a change in intra-abdominal pressure. As an example, central venous pressure will be high following a Fontan procedure, as the flow of blood to the lungs is passive, and a pressure gradient is needed between the caval veins and the left atrium. Typically, inferior caval venous pressure will be greater than 10 mmHg, and may be as high as 20 mmHg, particularly in the immediate postoperative phase. In this situation, it is not uncommon for ascites to develop, and for a peritoneal catheter to be inserted to drain fluid. It is conceivable that venous return, and thereby the flow of blood to the lungs, and cardiac output, would be better with sufficient intra-peritoneal fluid left in the abdomen to result in a small increase in intra-abdominal pressure. This hypothesis would need to be tested in a further study.

In our study, we found considerable variation in the response of intra-abdominal pressure to differing volumes of dialysate across the six infants, reflecting differences in abdominal elastance. In three of the infants, intra-abdominal pressure was re-measured in the absence of muscle relaxants, and was found to be higher, probably reflecting a fall in abdominal compliance, or an increase in elastance, with the return of muscle function. In adults with raised intra-abdominal pressure suffering from the "abdominal compartment syndrome", muscle relaxants have been shown to lower intra-abdominal pressure.[18] A number of factors need to be considered, therefore, when determining the ideal volume of dialysate. Frequently, exchanges at low volumes, of around 10 ml/kg, are adequate to assist in removal of fluid, but should larger volumes be needed for improved clearance of solutes, or should haemodynamics be seen to vary with the phase of the dialysis cycle, then it may be helpful to monitor intra-abdominal pressure. A patient in whom the cardiac output improves with dialysate in the abdomen may be haemodynamically more stable using a regime that does not allow complete emptying of the abdomen, so-called tidal dialysis.[19]

There are a number of significant limitations to this study. The number of infants studied was small, all underwent a biventricular repair, and all were in a stable condition. The effects of peritoneal dialysis may be different in older children, or in infants with functionally univentricular physiology, or those in a low cardiac output state. We measured global cardiac output, but cannot exclude a significant change in regional flow of blood. Previous studies have shown a reduction in flow of blood to the liver and kidneys at levels of intra-abdominal pressure that are not associated with a fall in global cardiac output.[10,20] We consider this unlikely to have occurred in our infants, as regional abnormalities in the flow of blood have not been reported at intra-abdominal pressure levels as low as 10 cmH_2O.

Conclusions

This small pilot study of infants following cardiac surgery has shown that intra-abdominal pressure is influenced by the volume of dialysate, and whether or not the patient is receiving muscle relaxants. Intra-abdominal pressure remained below 10 cmH_2O in all six patients, even when we instilled 30 ml/kg as dialysate. No detrimental effect on cardio-respiratory function was evident at this level of infusion. The findings of our pilot study would support a larger study evaluating the haemodynamic consequences of changes in intra-abdominal pressure in a more

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heterogeneous group of postoperative patients with differing pathophysiological conditions. Such a study would need to investigate effects on regional flows of blood, particularly the flows to the abdominal organs.

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