

## Hemodynamic Effects of Primary Closure of Omphalocele/ Gastroschisis in Human Newborns

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To determine whether they could establish reliable, objective criteria that would predict safe, primary closure of abdominal wall defects (omphalocele/gastroschisis) in newborn infants, the authors measured intraoperative changes in intra-gastric pressure (IGP), central venous pressure (CVP), cardiac index (CI), systolic arterial blood pressure (BP), and heart rate (HR). Eleven neonates, who averaged 2.7 kg (range 1.5-4.1 kg) and 36 weeks gestation (range 30-41 weeks) were anesthetized with fentanyl (7.5-12.5 µg/kg), metocurine (0.3 mg/kg), and oxygen. Three infants had defects that were too large to close primarily. Of the eight infants who underwent primary closure, four required re-operation within 24 h because of oliguria or poor peripheral perfusion. Infants who required re-operation had intra-gastric pressures of 20 mmHg or more, a decrease in CI of 0.78 l · min · m<sup>2</sup> or more, and an increase in CVP of 4 mmHg or more. Heart rate, BP, and systemic vascular resistance did not differ in infants requiring and not requiring re-operation. The authors conclude that intraoperative measurement of changes in IGP, CVP, and/or CI can reliably predict success or failure of primary operative repair of abdominal wall defects in human neonates. (Key words: Anesthesia: pediatric. Surgery, pediatric: gastroschisis; omphalocele.)

THE TREATMENT OF CHOICE for omphalocele and gastroschisis defects in newborn infants is primary repair whenever possible.<sup>1,2</sup> Primary closure of congenital abdominal wall defects carries the risk of placing the abdominal contents under pressure and producing hypotension,<sup>3,4</sup> a reduction in cardiac output,<sup>4,5</sup> postoperative respiratory failure,<sup>6</sup> bowel ischemia,<sup>1,7</sup> and anuria.<sup>8</sup> When primary closure cannot be achieved, either because of the large size of the defect or because it compromises respiratory or cardiovascular function, the alternative approach is a staged repair utilizing a silastic pouch.<sup>1,7,9</sup> This staged repair carries an increased risk of infection, as well as the need for multiple anesthetic and surgical procedures.<sup>1</sup>

Traditional criteria for deciding upon a primary operative reduction of the herniated viscera or creation of a silastic chimney have been the size of the defect, associated neonatal problems, and clinical observations of the infant's respiratory rate, blood pressure, skin color, and tissue turgor.<sup>1-9</sup> Unfortunately, these clinical observations are not entirely reliable, particularly in paralyzed, anesthetized infants. Several laboratory studies have found that acute elevations in intra-abdominal pressures are associated with significant reductions in cardiac output and in regional blood flow.<sup>3,5</sup> This study was designed to see if the development of increased intra-gastric pressures (IGP) at the time of primary surgical repair would be associated with postoperative organ system failure. Furthermore, we sought to determine whether other physiologic measurements might provide objective, predictive criteria for safe, primary closure of these defects.

### Materials and Methods

Eleven ASA physical status III-IV newborns, less than 24 h old, averaging 2.7 kg (range 1.5-4.1 kg) and 36 weeks gestation (range 30-41 weeks), undergoing emergency surgical repair of a congenital abdominal wall defect were studied. Approval was obtained from the institution's Committee on Clinical Investigation and from the Department of Anesthesiology/Critical Care Medicine's Human Subject Protection Committee. Following atropine pretreatment (0.1 mg) and awake oral intubation of the trachea, all infants were anesthetized with fentanyl (7.5-12.5 µg/kg) and paralyzed with metocurine (0.3 mg/kg).<sup>10</sup> Patients were manually ventilated using a Mapleson D circuit with oxygen and air to maintain PaCO<sub>2</sub> between 30-35 mmHg, as determined by repeated analysis of arterial blood gases and by continuous end-tidal CO<sub>2</sub> measurement. Heart rate, rhythm, arterial blood pressure (BP) (via radial artery catheterization), central venous pressure (CVP) (via internal or external jugular venous catheterization), temperature, preductal oxygen saturation (via pulse oximetry, Nellcor® Model N-100, sensor placed on the right hand), and intra-gastric pressure<sup>3-5</sup> (via a fluid filled, 12 Fr. oral gastric tube) were continuously measured. All pressure measurements were obtained utilizing Bell and Howell® 4-327-I transducers, amplified by Hewlett Packard® 78305D amplifiers, and

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were recorded on a Hewlett Packard® 7758A eight-channel thermal recorder. Cardiac output was measured in duplicate using the indicator dilution technique<sup>11,12</sup> before and after primary abdominal closure of the herniated viscera. In this technique of cardiac output measurement, indocyanine green dye is injected as a bolus into the central circulation (CVP). Arterial blood is then aseptically withdrawn, *via* a Harvard pump, into an optical cuvette where the concentration of dye in the arterial blood is measured over time. Cardiac output curves were recorded on a Hewlett Packard® 7758A eight-channel thermal recorder. We excluded from our data analysis any curve in which recirculation (shunt), faulty injection technique, or rising baseline (photodetector drift) was present on visual inspection of the tracings.<sup>11,12</sup> Additionally, the optical measuring system was calibrated each time with a sample of the patient's blood. All of the blood that was withdrawn for cardiac output determinations was returned to the patient. Systemic vascular resistance (SVRI) was calculated according to the following formula:  $([\text{mean arterial pressure} - \text{CVP}] / \text{cardiac index} \times 80)$ .

Five percent dextrose in 0.2% saline was infused in a peripheral vein at maintenance rates calculated according to a standard formula.<sup>13</sup> Lactated Ringer's solution was infused at a rate of 8–10 ml · kg<sup>-1</sup> · h<sup>-1</sup> to replace third space fluid loss. Estimated blood volume and allowable blood loss were calculated according to standard formulae.<sup>13</sup> Blood loss was measured by weighing sponges and measuring the volume of blood in suction bottles, and by hourly hematocrit determinations. Blood was replaced with 3 ml of lactated Ringer's solution for each milliliter of blood lost until either the calculated allowable blood loss was reached or a measured hematocrit of 40% or less was obtained. At that point, lost blood was replaced with an equal volume of transfused packed red blood cells.

Primary closure of the abdominal wall was attempted in every patient.<sup>1,2</sup> At initial surgery, the omphalocele/gastroschisis defect could not be closed in three patients because the abdominal cavity could not accommodate the herniated viscera. These patients were eliminated from the study. Patients whose defects were surgically closed but who developed either anuria, oliguria (urine output of <0.5 ml · kg<sup>-1</sup> · h<sup>-1</sup>), thrombocytopenia (platelet count of <50,000), or evidence of cardiovascular collapse (poor capillary refill, cool extremities, or the need for inotropic support) were treated by decompression and placement of the herniated bowel into a silastic chimney.<sup>1,2,7</sup> These patients were considered a failure of primary repair. Physiologic measurements were available to the surgeon at the time of primary closure.

Additionally, all infants were ventilated, paralyzed, and sedated with fentanyl (0.003 mg · kg<sup>-1</sup> every 2 h) for 24 h in the neonatal intensive care unit following surgery.

Differences between pre- and post-closure measurements in each patient were compared to zero using a paired *t* test. Differences between successful and unsuccessful closure groups were analyzed using Fisher's exact test for dichotomous variables. The Wilcoxon rank sum test (a non-parametric equivalent of Student's *t* test) was used to compare those patients whose defects were successfully and unsuccessfully closed with respect to continuous variables, including IGP and hemodynamic measures, and differences in pre- and post-closure hemodynamic measures.<sup>14</sup> A *P* value of less than 0.05 was considered significant. All values are presented as averages ± standard deviation.

### Results

Eight infants underwent primary closure; four (group I) required re-operation within 24 h and four (group II) had unremarkable postoperative courses. All four infants requiring re-operation were either oliguric or anuric. Additionally, two of these infants appeared to be poorly perfused, had thrombocytopenia, and required inotropic support with dopamine postoperatively. These later two neonates, while undergoing surgical re-exploration, were found to have either ischemic or necrotic bowel.

There was no difference between groups I and II in HR, BP, CVP, SVRI, CI, or IGP before closure of the abdominal wall defect (table 1). Heart rate, BP, CVP, IGP, and SVRI increased significantly in all patients following repair (*P* < 0.025, paired *t* test). Cardiac index, on the other hand, decreased significantly in all patients following repair (*P* < 0.025, paired *t* test) (table 1). There were no differences in the volume of intravenous fluids administered to these patients during surgery on a per kilogram basis. Patients in group I received an average of 95 ± 17 ml · kg<sup>-1</sup>, whereas patients in group II received 93 ± 13 ml · kg<sup>-1</sup>.

Patients in whom primary repair failed (group I) had significantly greater increases in IGP and CVP and decreases in CI than successfully closed (group II) patients (each *P* < 0.04, Wilcoxon rank sum test) (fig. 1). Increases in HR, BP, and SVRI, on the other hand, tended to be higher in group I than group II patients following closure, but these differences were not significant (each *P* < 0.06, Wilcoxon rank sum test) (fig. 1).

The highest IGP measured in group II patients was 18 mmHg (range 6–18 mmHg), whereas the lowest measured IGP in group I patients was 22 mmHg (range 22–28 mmHg) (fig. 2). Thus, the range of intra-gastric pressures between 19 and 21 mmHg reliably separated

TABLE 1. Hemodynamic Changes Before and After Primary Closure of Abdominal Wall Defects in Neonates

	Pre-closure		Post-closure	
	Group 1 Failed (n = 4)	Group 2 Success (n = 4)	Group 1 Failed (n = 4)	Group 2 Success (n = 4)
HR	166 ± 16	167 ± 10	177 ± 16*	172 ± 13*
SAP	50 ± 6	51 ± 2	61 ± 7*	56 ± 4*
CVP	4 ± 2	4 ± 1	10 ± 1*	5 ± 1*
CI	2.89 ± 0.72	2.65 ± 0.39	1.84 ± 0.71*	2.29 ± 0.38*
SVRI	1342 ± 380	1445 ± 208	2093 ± 1009*	1756 ± 369*
IGP	0 ± 1	0 ± 1	25 ± 2*	12 ± 5*

Heart rate (HR) is expressed in beats per minute, systolic arterial blood pressure (SAP), central venous pressure (CVP), and intragastric pressure (IGP) in mmHg, cardiac index (CI) in  $l \cdot \text{min}^{-1} \cdot \text{m}^2$ , and systemic vascular resistance (SVRI) in  $\text{dyne} \cdot \text{sec}^{-5}$ . All data are presented as mean ± SD.

\*  $P < 0.05$  compared to preclosure.

the two groups ( $P < 0.02$ , Fisher's exact test). Similarly, the largest increase in CVP in group II patients was 2 mmHg (range 0–2 mmHg), whereas, in group I patients, the smallest increase in CVP was 4 mmHg (range 4–7 mmHg) ( $P < 0.02$ , Fisher's exact test) (fig. 2). Thus, an increase in CVP of 4 mmHg or more following closure reliably separated the two groups ( $P < 0.02$ , Fisher's exact test). Finally, CI decreased in all patients. The smallest decrease in CI in group I patients was 0.79  $l \cdot \text{min} \cdot \text{m}^2$  (range 0.79–1.84  $l \cdot \text{min} \cdot \text{m}^2$ ), whereas the greatest decrease in CI in group II patients was 0.4  $l \cdot \text{min} \cdot \text{m}^2$  (range 0.3–0.4  $l \cdot \text{min} \cdot \text{m}^2$ ) ( $P < 0.02$ , Fisher's exact test) (fig. 2). Thus, a decrease in CI of 0.78  $l \cdot \text{min} \cdot \text{m}^2$  or more following primary closure of an abdominal wall defect reliably separates successfully and unsuccessfully closed patients ( $P < 0.02$ , Fisher's exact test).

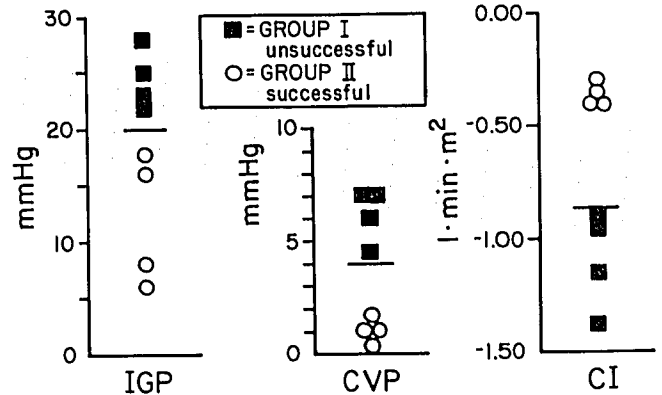


FIG. 2. Intraoperative changes in intra-gastric pressure (IGP), central venous pressure (CVP) following primary closure of abdominal wall defects reliably separate (horizontal bar) unsuccessful, group I, patients (closed square, ■) from successful, group II, patients (open circle, ○). Each symbol represents the difference between postclosure and preclosure values for individual patients.

## Discussion

This preliminary, retrospective study suggests that success or failure of primary operative closure of an abdominal wall defect in the human newborn infant can be successfully and reliably predicted by the intraoperative measurement of either IGP, CVP, or CI, but not by HR, BP, or SVRI. The intraoperative development of either an intra-gastric pressure of 20 mmHg or more, a fall in CI of 0.78  $l \cdot \text{min} \cdot \text{m}^2$  or more, or an increase in right atrial pressure of 4 mmHg or more were associated with the postoperative development of bowel ischemia or oliguria.

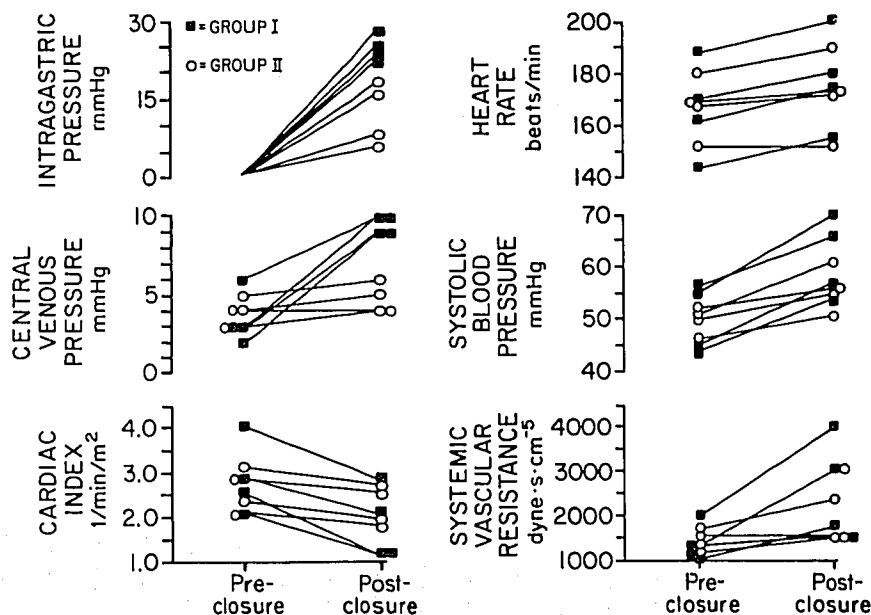


FIG. 1. Hemodynamic and intragastric pressure responses to primary closure of abdominal wall defects are depicted. Each line represents an individual patient's response. Unsuccessfully closed patients, group I, are represented by a closed square (■), whereas successfully closed patients, group II, are represented by an open circle (○). Group I patients had significantly greater increases in intra-gastric pressure and central venous pressure and decreases in cardiac index than group II patients.

Previous studies<sup>3,5,8</sup> have suggested that intra-abdominal pressures should be kept below 20 mmHg during surgical repair of an omphalocele or gastroschisis defect. Masey *et al.*<sup>3</sup> demonstrated, in newborn lambs, that acute elevations in intra-abdominal pressure above 15–20 mmHg resulted in reductions in cardiac output of 20% or more and in decreases of 20–40% in the regional distribution of gastrointestinal and renal blood flow. Lynch *et al.*<sup>5</sup> found a significant decrease in blood pressure and cardiac output in newborn piglets following acute elevations in intra-abdominal pressure above 20 mmHg. Using different animals and means of increasing intra-abdominal pressure, several investigators<sup>3,8</sup> have demonstrated substantial decreases in renal blood flow and renal function following elevations in intra-abdominal pressure above 15–20 mmHg as well. Our findings of decreased cardiac output and compromised abdominal organ blood flow in four infants who developed intra-gastric pressures of 20 mmHg or more confirm these results.

Central venous pressure rose significantly only in those patients with intra-gastric pressure above 20 mmHg. This represented an increase of almost 100% or greater above control values, and occurred despite the fact that there was no difference in the amount of intravenous fluids these neonates received. Newborn infants with abdominal wall defects have significantly increased fluid requirements because of the increased insensible losses that occur when eviscerated bowel is exposed to the environment.<sup>15,16</sup> Additionally, they have enormous “third space” losses due to the traumatized, inflamed bowel and adynamic ileus that develops perioperatively.<sup>15,16</sup> Why CVP rose among the patients with elevated IGP is unclear. Unfortunately, we did not measure pleural (esophageal), pulmonary capillary wedge, or left atrial pressures in this study. Presumably, the increase in right atrial pressure was due to an increase in pleural pressure transmitted from the abdomen by the cephalad movement of the diaphragm,<sup>17</sup> or was secondary to decreased right ventricular compliance or, possibly, heart failure.

Several mechanisms may contribute to the decrease in cardiac output and the regional distribution of blood flow following acute elevations of intra-abdominal pressure. Cardiac output is most likely decreased secondary to decreased venous return. Increased abdominal pressure will initially translocate blood out of the abdominal compartment, producing flow-limiting conditions at the entrance of the thorax as the inferior vena caval transmural pressure becomes zero.<sup>18</sup> Venous return from the lower extremities would be decreased because of the increased intra-abdominal pressure. Venous return from the upper extremities and head may be decreased because of the increased right atrial (downstream) pres-

sure. In addition, cardiac output may be decreased due to an increased afterload imposed on the left ventricle by the increased abdominal pressure, which will tend to redistribute arterial blood flow away from the abdomen and toward the head.<sup>3,17</sup>

The best way to measure intra-abdominal pressure is controversial. Decramer *et al.*,<sup>19</sup> using a variety of maneuvers to increase intra-abdominal pressure in adult dogs, demonstrated differences in intra-gastric, intra-intestinal, and subdiaphragmatic pressures unless the abdomen was first filled with a large volume of fluid. Masey *et al.*,<sup>3</sup> using newborn lambs, found little correlation between intra-abdominal and intra-gastric pressures. Wesley *et al.*,<sup>4</sup> on the other hand, advocated the use of IGP, as measured *via* a gastrostomy tube, as a guide for reducing and closing a silastic chimney in the staged repair of an omphalocele or gastroschisis defect in human newborns. In this study, we used IGP, as measured *via* a fluid-filled, 12 Fr oral gastric tube, as our means of measuring intra-abdominal pressure because it is the only practical way of obtaining this measurement in human newborns.

Intraoperative changes in BP, HR, and SVRI were not predictive of success or failure of the primary repair. Caution must be exercised in interpreting the increase in SVRI. Systemic vascular resistance was calculated using the CVP as the “downstream pressure.” This may not be the true “downstream pressure” following closure of the abdominal wall defect, because pressure in the abdominal compartment may exceed the CVP.<sup>20</sup>

In summary, this study demonstrated that measurement of changes in IGP, CVP, and/or CI can reliably predict success or failure of primary operative repair of abdominal wall defects in human neonates. The development of intra-gastric pressures greater than 20–21 mmHg was associated with a significant decrease in cardiac output and a rise in CVP. This decrease in cardiac output and/or increase in IGP was associated with anuria, bowel ischemia, and, ultimately, necessitated reoperation and creation of a silastic pouch. This suggests that primary closure of omphalocele or gastroschisis defects with intra-gastric pressures greater than 20–21 mmHg compromises abdominal organ blood flow. On the other hand, the development of intra-gastric pressures of less than 20 mmHg seems to be predictive of safe primary closure.

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