

Experience of gastrojejunal intubation in the surgical treatment of pediatric patients with congenital abdominal wall defects in Kazakhstan

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ABSTRACT

Background: Abdominal compartment syndrome (ACS) is a serious complication of congenital abdominal wall defect repair and results from a rise in intra-abdominal pressure (IAP) after the herniated viscera are reduced. Intraoperative gastrojejunal intubation (GJI), in which a tube placed through a gastrostomy decompresses the stomach, duodenum and proximal jejunum, has been used at our center to limit the postoperative rise in IAP. We describe postoperative IAP, organ dysfunction and ACS in patients treated with GJI and in a cohort treated with conventional repair at a second hospital.

Method: Ambispective observational two-center cohort of infants aged 0-6 months with gastroschisis or omphalocele: 27 patients who underwent repair with GJI at a tertiary center (followed prospectively) and 30 who underwent conventional repair at a secondary-level hospital (records reviewed retrospectively via chart review). Treatment was determined by the hospital to which the patient was admitted, therefore, the effect of GJI cannot be separated from the effect of hospital, and the analysis is descriptive. ACS was considered as the primary outcome and was defined as intra-abdominal hypertension (mean IAP >10 mmHg on postoperative days 1 and 3) with the presence of at least two of three signs of organ dysfunction; alternative definitions were also considered. Secondary outcomes included in-hospital mortality, gastrointestinal recovery timing, and renal/respiratory trajectories. Categorical outcomes were compared using Fisher's exact test, and absolute risk differences (RD) are presented with 95% confidence intervals (CI).

Results: Baseline characteristics were broadly similar between cohorts, although staged closure was more frequent in the technique cohort (40.7% vs. 20.0%). ACS was observed on 5/26 evaluable technique-cohort vs. 1/26 evaluable comparison-cohort patients (RD 15.4 percentage points, 95% CI -3.1 to 34.3; $p = 0.191$; Firth odds ratio [OR] 4.35, 95% CI 0.63-29.98). In-hospital mortality was 5/27 vs. 0/30 (RD 18.5 percentage points, 95% CI 3.2 to 36.7; $p = 0.019$; Firth OR 14.91, 95% CI 0.75-298.05). The group $\times$ time interaction for IAP was significant ($p = 0.018$), with a slower decline in the technique cohort; interactions for creatinine, pCO₂, and PIP/FiO₂ trajectory were not significant.

Conclusion: In this exploratory observational study, ACS and in-hospital death were more frequent in the GJI cohort than in the comparison cohort, but the CIs were wide and the differences cannot be attributed to GJI, because the procedure, the treating hospital and its case mix cannot be separated in this design. These data neither support nor exclude the benefit or harm of GJI. A single-institution study with standardized IAP monitoring and complete outcome measurement is needed.

Keywords: abdominal compartment syndrome, intra-abdominal hypertension, gastrojejunal intubation, gastroschisis, omphalocele, neonatal surgery, congenital abdominal wall defects

INTRODUCTION

Abdominal compartment syndrome (ACS) is a critical condition in which a sustained or repeated increase in intra-abdominal pressure (IAP) causes new or worsening organ dysfunction [1]. While extensively studied in adults undergoing

trauma or massive volume resuscitation, pediatric ACS presents highly distinct challenges. Neonates born with congenital abdominal wall defects such as gastroschisis and omphalocele are at particular risk of developing ACS after reduction and wall repair [2]. In these defects, the abdominal viscera develop completely or partially outside the boundaries of the peritoneal cavity [3], and returning swollen organs to a

small, non-compliant abdominal cavity raises IAP and can cause multi-system organ dysfunction.

Gastroschisis and omphalocele are the two most common congenital abdominal wall defects [2-4]. Reported combined incidence approximates 1 in 3,500 births; in United States surveillance data, prevalence was 4.3 per 10,000 live births for gastroschisis and 2.1 per 10,000 live births for omphalocele, and unlike the relatively stable incidence of omphalocele over recent decades, the incidence of gastroschisis has risen three- to four-fold [5]. A global systematic review of 103 population-level studies likewise found gastroschisis to be the most frequently reported major gastrointestinal anomaly, with geographic heterogeneity in the prevalence of both defects [4]. Gastroschisis is most strongly associated with young maternal age: a contemporary Western Australian population-based registry study reported a birth prevalence of 3.7 per 10,000 births and a relative risk of 4.50 (95% confidence interval [CI] 3.68-5.49) for mothers under 25 years of age relative to older mothers [6], consistent with earlier European registry data showing a rising prevalence concentrated among younger mothers [7]. Omphalocele occurs more frequently with advancing maternal age and is often accompanied by other anomalies, particularly cardiac defects, and by chromosomal defects that strongly determine survival [8].

ACS is not a rare or incidental complication in this population but a major, quantifiable driver of morbidity and mortality after ventral wall defect repair. In a retrospective series of infants with gastroschisis and omphalocele, clinical signs of postoperative ACS were documented in approximately 13% of patients, the large majority of whom had undergone primary abdominal wall closure [9]. The downstream consequences of developing ACS are substantial: in a cohort of 159 neonates with gastroschisis, multivariable analysis identified the development of ACS as one of the strongest independent predictors of death, conferring an approximately 7.8-fold increase in mortality risk – a larger effect than low birth weight or sepsis in the same model [10].

The primary aim of surgical intervention in both conditions is to return the herniated viscera to the abdominal cavity and restore abdominal wall continuity, but this reduction is not without risk. When bowel and, in omphalocele, solid organs are returned to an abdominal cavity that has not accommodated their volume during gestation, the resulting rise in IAP can precipitate intra-abdominal hypertension (IAH) and, in its most severe form, ACS – a syndrome of progressive multiorgan dysfunction driven by impaired venous return, reduced splanchnic and renal perfusion, and compromised diaphragmatic excursion [1]. Raised IAP causes intestinal and renal ischemia in infants undergoing closure of abdominal wall defects, and bladder pressure monitoring has been used to guide the decision between primary closure and staged reduction, altering management in 64% of infants in a prospective series [11].

Because forced primary closure can be complicated by ACS, staged closure using a silo, with gradual reduction of the viscera over several days, has been proposed as a strategy to limit the rise in IAP at the time of definitive closure. Comparative and meta-analytic data suggest that a staged approach may reduce ventilator dependence and complications related to raised IAP relative to forced primary closure, although findings across studies are heterogeneous and a randomized trial found no significant difference in short-term outcomes between primary and delayed closure [12-14].

This lack of consensus has motivated continued interest in adjunctive techniques – including routine IAP monitoring and interventions aimed at intestinal decompression – that might reduce the incidence of ACS regardless of the closure strategy chosen [9].

Diagnostic criteria for ACS in children differ meaningfully from those used in adults. While adult consensus definitions require sustained IAP above 20 mmHg, the pediatric subcommittee of the World Society of the Abdominal Compartment Syndrome (WSACS) has proposed that IAH in children be defined as sustained or repeated IAP > 10 mmHg, with ACS defined as IAH accompanied by new or worsening organ dysfunction – reflecting the lower physiological reserve of neonates and infants relative to adults [15, 16]. Despite this guidance, awareness and application of pediatric-specific IAH/ACS definitions remain inconsistent among neonatal and pediatric intensivists, and the true incidence of pediatric ACS is likely underestimated as a result of under-recognition and inconsistent IAP monitoring practices [16, 17], although prompt recognition and surgical decompression can reverse organ dysfunction even in small infants [18]. Organ dysfunction in pediatric ACS may involve renal (oliguria or anuria), respiratory (worsening oxygenation or ventilatory requirement), hemodynamic (hypotension refractory to volume expansion), and metabolic (acidosis) systems [17, 19]. More recently, early biomarkers of renal tubular injury, including neutrophil gelatinase-associated lipocalin (NGAL) and cystatin C, have been shown to rise before conventional markers such as serum creatinine in other pediatric populations, including cardiac surgery with cardiopulmonary bypass, raising the possibility that these biomarkers could detect IAP-mediated renal injury earlier and more sensitively than creatinine-based definitions in the ventral-wall-defect population as well [20-23].

After repair, enteric decompression is almost universal: in a survey of 467 neonatal providers, 99% used an enteric drainage tube after abdominal closure [24], and gastric decompression is part of standard initial care [2]. A nasogastric or orogastric tube, however, drains only the stomach. Gastroschisis is characterized by severe gut dysmotility [25], and fluid and gas retained in a dilated, poorly contractile duodenum and proximal jejunum add to intra-abdominal volume during the period when visceros-abdominal disproportion is greatest [26]. Gastrojejunal intubation (GJI) was developed to decompress the stomach and the proximal small bowel together, with the aim of lowering intraluminal volume, and therefore IAP, more effectively than gastric drainage alone. The approach also has potential costs: it requires a gastrostomy and a post-pyloric tube, which can leak, become dislodged or obstructed, cause local infection or, with jejunal tubes, perforate the bowel; in a national cohort of children undergoing gastrojejunostomy tube placement for feeding, surgical complications occurred in 27-35% of infants [27].

To our knowledge, the GJI has not been evaluated in published studies on abdominal wall defect repair. We describe postoperative IAP, organ dysfunction, gastrointestinal recovery and ACS in a prospectively followed cohort treated with GJI and in a cohort treated with conventional repair at a second hospital, with an exploratory analysis of NGAL and cystatin C in a subset of the GJI cohort.

As each hospital used only one specific surgical technique, the effect of GJI cannot be separated from the effect of the

hospital. The purpose of this study is descriptive and hypothesis-generating rather than evaluating the effect of GJI.

METHOD

Design and Setting

Ambispective observational two-center cohort study: the technique cohort was enrolled and followed prospectively, while the comparison cohort was assembled retrospectively via chart review. This is not a randomized or controlled comparison: treatment and treating center are structurally confounded by design, since all technique-cohort patients were treated at one center and all conventional-repair patients at a second center. The study aim is to describe postoperative outcomes in each cohort and to generate hypotheses about their association with technique, not to estimate a causal treatment effect. Technique-cohort patients ($n = 27$) underwent abdominal wall defect repair with intraoperative GJI at a tertiary referral center and were followed prospectively from the time of surgery; comparison-cohort patients ($n = 30$) underwent conventional repair at a second center, and their data were extracted retrospectively from medical records. The difference in data-collection approach between cohorts is a likely contributor to the greater proportion of missing values observed in the comparison cohort.

The tertiary referral center was the Mother and Child Center affiliated to University Medical Center (UMC), a national-level referral institution. Its neonatal intensive care unit (NICU) comprises six beds. The intensive care unit is located within the department of neonatal surgery. The center performs approximately 8-10 surgical repairs of abdominal wall defects annually. The second center was a secondary-level hospital, Multidisciplinary Children's City Hospital No. 2, with a 10-bed NICU, where approximately 3-4 surgical repairs of abdominal wall defects are performed annually.

The technique-cohort patients were enrolled from May 2023 to March 2026 and the comparison-cohort patients were identified by retrospective review of hospitalization chart records from January 2017 to March 2023. Treatment was determined by the hospital of admission: GJI was performed in all eligible patients according to stated criteria: at the tertiary center, whereas repair at the second center did not include the GJI. The two hospitals therefore also differed in referral role and case mix.

Population

Neonates undergoing surgical repair of a congenital abdominal wall defect were included in both cohorts. Diagnoses in the final cohort included gastroschisis ($n = 38$), omphalocele ($n = 19$); patients with hiatal hernia were excluded. One technique-cohort patient classified as omphalocele underwent surgery for bowel evisceration after a laparotomy for teratoma and was first operated on at 210 days of age, outside the defect definition and the age limit; this patient was retained as recorded, and a sensitivity analysis excluding the patient is reported.

Inclusion criteria were:

- (1) age 0-6 months,
- (2) a congenital abdominal wall defect requiring surgical repair, and
- (3) admission to one of the participating centers.

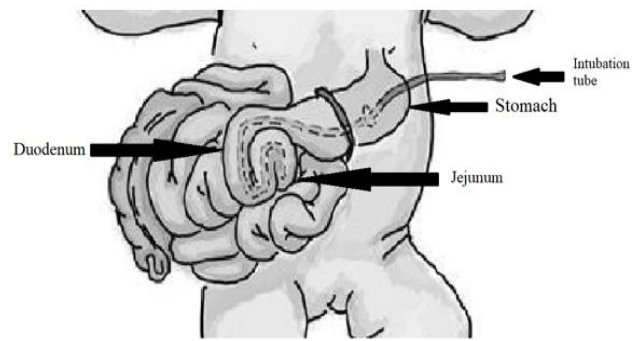


Figure 1. Gastrojejunal intubation (created by the authors)

Exclusion criteria: children who did not undergo surgery because of the severity of their overall condition, and patients admitted in a critical state, which had high risk mortality intraoperatively and were not able to tolerate anesthesia and surgery. Patients who met the exclusion criteria were those with multiple congenital anomalies incompatible with life. Because these patients are at the highest risk of ACS, their exclusion means that the frequencies reported here apply to patients well enough to undergo repair and are likely lower than in an unselected population.

Necrotizing enterocolitis, congenital diaphragmatic hernia, purulent (fecal) peritonitis, and grade 2-3 intestinal paresis were among the diagnoses eligible for inclusion; however, no patients presenting with these diagnoses during the study period met the full inclusion criteria, and the final cohort therefore comprises only the diagnoses listed above (gastroschisis, omphalocele).

Gestational age, birth weight, prematurity (< 37 weeks), sex, age at first operation, diagnosis and closure type (primary fascial closure or staged closure with a silo) were available for both cohorts. Defect size, bowel condition (simple vs. complex gastroschisis), associated anomalies and preoperative respiratory support were not recorded in the study dataset.

Surgical Technique (Study Group)

During surgical correction of the wall defect, a gastrostomy was formed and an intubation tube (6-10F) was passed through the stomach and duodenum into the jejunum, with the distal tip positioned 15-20 cm distal to the ligament of Treitz (**Figure 1**).

Three to four side holes were positioned within the gastric lumen, and distal holes within the duodenum and proximal jejunum, placing tube openings across multiple functional segments of the gastrointestinal tract. This configuration was intended to provide simultaneous decompression of two functional zones of intestinal motility involved in generating migrating motor complexes. Intubation was performed intraoperatively during wall-defect correction, and postoperative decompression was achieved by evacuation of gastric, duodenal, and intestinal contents through the tube. The tube remained in place until intestinal transit had resumed, enteral feeding had been initiated, and spontaneous stool passage had occurred. These clinical milestones were used to indicate the recovery of gastrointestinal function and guide tube removal. Comparison-cohort patients underwent conventional repair, either primary or staged, without this adjunctive decompression tube; gastric decompression was achieved by nasogastric tube.

Intra-Abdominal Pressure Measurement

IAP was measured indirectly via the intravesical (bladder) route using an indwelling urethral (Foley) catheter, the reference-standard technique originally described in [28] and subsequently modified in [29] into a closed-system method endorsed by the WSACS consensus guidelines [15]. The urinary catheter was connected via a three-way stopcock to a pressure transducer and to a syringe of sterile 0.9% saline. Prior to each measurement, the bladder was fully drained, and the drainage line was clamped. A bolus of sterile saline was then instilled into the bladder through the catheter at a pediatric-adjusted volume of 1 mL/kg body weight (minimum 3 mL, maximum 25 mL), consistent with WSACS pediatric recommendations, to avoid bladder-wall coaptation around the catheter tip while minimizing the risk of volume-related overestimation of IAP.

The pressure transducer was zeroed at the level of the mid-axillary line at the iliac crest (the phlebostatic axis), with the patient positioned fully supine. Measurements were taken approximately 30-60 seconds after saline instillation, to allow relaxation of the detrusor muscle, and were read at end-expiration in the absence of active abdominal muscle contraction; sedated or ventilated infants were assessed during a period of ventilator synchrony to avoid transient pressure artifacts from respiratory effort. IAP was expressed in mmHg. Measurements were obtained on postoperative days 1, 3, and 7 in order to track the immediate postoperative, peak stress and early recovery phases, respectively. In the technique cohort, the IAP was measured 6 times a day on each of these days in accordance with the study protocol, and the daily mean value was used for the analysis. In the comparison cohort, IAP was measured using the same intravesical technique and measurement protocol as in the technique cohort. Measurements were obtained six times daily on postoperative days 1, 3, and 7, and the daily mean of the six readings was used for analysis. Additional measurements could be obtained at the discretion of the treating team when clinically indicated, particularly when IAH was suspected. If clinically indicated (e.g., suspicion of evolving IAH), additional measurements were obtained at the discretion of the treating team. Because bladder-pressure measurement can be inaccurate or contraindicated in the presence of bladder trauma, neurogenic bladder dysfunction, or pelvic hematoma, these conditions were considered exclusionary for this specific measurement in affected patients, consistent with WSACS guidance.

Outcome Definitions

IAH was defined as a daily mean IAP > 10 mmHg on both postoperative day 1 and day 3 (the two consecutive scheduled assessment days), consistent with pediatric WSACS criteria [15, 16]. ACS was defined as IAH accompanied by ≥ 2 of the following organ-dysfunction domains:

- (1) renal – oliguria (urine output < 1 mL/kg/h) or a > 50% rise in creatinine from postoperative day 1 to day 3,
- (2) respiratory – a > 20% rise in PIP/FiO₂ ratio or a > 5 mmHg rise in pCO₂ from day 1 to day 3, and
- (3) hemodynamic – need for cardiotoxic/inotropic support.

A metabolic/acid-base domain could not be constructed from available variables and is noted as a limitation. Patients were evaluable for ACS if IAP was recorded on both day 1 and day 3; a domain component that could not be assessed because of missing values was counted as not met.

The WSACS pediatric definition requires new or worsening dysfunction in at least one organ system [15]. We required two domains because the domains were constructed from scheduled day-1 and day-3 values rather than from clinical adjudication, and isolated abnormal values are common in the early postoperative period; the stricter threshold was intended to reduce misclassification of expected postoperative physiology as ACS. The o PIP/FiO₂ ratio was intended to capture a rising ventilatory pressure requirement relative to oxygen requirement, as expected when diaphragmatic splinting reduces respiratory-system compliance; it is not a validated index. ACS was therefore also assessed under alternative definitions: (B) IAH with at least one domain, corresponding to the consensus concept; (C) daily mean IAP > 10 mmHg on at least two of days 1, 3 and 7 with at least one domain; (D) IAH alone; (E) a sensitivity definition requiring all 3 domains.

In-hospital death was defined as death before discharge from the treating center. Vital status was recorded for all 27 technique-cohort patients. In the comparison cohort, 9 patients were recorded as alive at discharge; for the other 21, the vital-status field was empty, but a discharge date was recorded and no date of death was documented, and these patients were classified as having survived to discharge. In the technique cohort, every death was recorded with a date of death.

Additionally, the tube-related complications were not recorded systematically in the study.

Units: urine output mL/kg/h, pCO₂ mmHg, PIP cmH₂O, FiO₂ fraction, creatinine μ mol/L, blood urea nitrogen (BUN) mmol/L, NGAL ng/mL and cystatin C mg/L.

Statistical Analysis

This study is reported in accordance with the strengthening the reporting of observational studies in epidemiology guidelines for cohort studies [30]. Descriptive analysis of cohort and outcome variables was performed; variables were compared between cohorts using the Mann-Whitney U test (continuous variables) and Fisher's exact test (categorical variables). Absolute risk differences for ACS are reported with 95% CIs calculated by Newcombe's hybrid score method [31]. These comparisons are descriptive and associational, not tests of a causal treatment effect, given the non-randomized, center-confounded design. Given sparse events for ACS (n = 6), Firth's penalized logistic regression was used in place of standard maximum-likelihood logistic regression [5]; penalized regression addresses sparse data but cannot correct the confounding between technique and center. Models were fit unadjusted and adjusted for gestational age; adjustment is intended to describe how much of the observed association is attributable to a measured baseline difference, not to isolate a causal technique effect, since center-level confounding by indication cannot be fully addressed with the covariates available. Repeated postoperative measurements (IAP, creatinine, pCO₂, and PIP/FiO₂ ratio) were analyzed using cluster-robust regression with a group $\times$ time interaction term, clustering standard errors by patient. The number of patients with available data is reported for each variable and time point, and missing values were not imputed. A two-sided $p < 0.05$ was considered statistically significant; given the number of comparisons performed, secondary findings are interpreted as hypothesis-generating rather than confirmatory. Comparison-cohort patients with a recorded discharge date and no

Table 1. Baseline characteristics of study population

Characteristic	Technique cohort (n = 27)	Comparison cohort (n = 30)	p-value
Gestational age, weeks, median [IQR]	38.0 [37.0-38.0] (n = 27)	37.0 [36.0-38.8] (n = 26)	0.630
Birth weight, g, median [IQR]	2,999 [2,725-3,460] (n = 27)	2,853 [2,507-3,283] (n = 30)	0.350
Age at first operation, days, median [IQR] (range)	0 [0-1] (0-210)	0 [0-1] (0-8)	0.663
Female sex, n/N (%)	15/27 (55.6)	19/30 (63.3)	0.597
Preterm (< 37 weeks), n/N (%)	5/27 (18.5)	8/26 (30.8)	0.352
Diagnosis, n/N (%)			
Gastroschisis	17/27 (63.0)	21/30 (70.0)	0.589
Omphalocele	10/27 (37.0)	9/30 (30.0)	
Closure type, n/N (%)			
Primary fascial closure	16/27 (59.3)	24/30 (80.0)	0.146
Staged closure with silo	11/27 (40.7)	6/30 (20.0)	

Note. Continuous variables: Median [IQR], Mann-Whitney U; Categorical: n/N (%), Fisher's exact test

Table 2. Primary and secondary outcomes

Outcomes	Technique cohort (n = 27)	Comparison cohort (n = 30)	p-value
ACS, primary definition, n/N evaluable (%)	5/26 (19.2)	1/26 (3.8)	0.191*
In-hospital death, n/N (%)	5/27 (18.5)	0/30 (0.0)	0.019**
Day of first stool, postoperative day	7.0 [4.0-12.0] (21)	5.0 [3.0-13.5] (23)	0.357
Day feeding started, postoperative day	6.0 [3.0-6.5] (23)	7.0 [5.0-9.0] (24)	0.087
IAP day 1, mmHg	10.9 [9.2-13.1] (27)	12.8 [10.9-13.4] (26)	0.115
IAP day 3, mmHg	9.1 [7.4-10.6] (26)	8.6 [7.9-9.3] (30)	0.282
IAP day 7, mmHg	8.6 [7.6-11.1] (22)	7.0 [6.3-8.0] (30)	< 0.001
Urine output day 1, mL/kg/h	4.8 [3.7-5.8] (26)	2.0 [0.9-3.2] (27)	< 0.001
Urine output day 3, mL/kg/h	4.3 [3.9-5.5] (24)	3.6 [3.2-4.2] (22)	0.026
pCO ₂ day 1, mmHg	37.2 [35.3-43.3] (25)	33.4 [28.8-43.3] (27)	0.156
pCO ₂ day 3, mmHg	44.7 [39.8-47.9] (23)	35.6 [33.2-43.4] (27)	0.011
Creatinine day 1, µmol/L	54.1 [48.5-62.3] (25)	48.0 [34.7-55.4] (20)	0.123
Creatinine day 3, µmol/L	40.6 [34.3-64.7] (22)	43.1 [34.5-60.6] (18)	0.849
BUN day 1, mmol/L***	6.1 [4.5-7.5] (25)	4.8 [4.0-6.4] (12)	0.381
without implausible value		4.7 [3.9-5.7] (11)	0.175
BUN day 3, mmol/L***	7.7 [4.7-9.2] (22)	3.4 [2.7-4.3] (14)	0.001
without patient with implausible value		(13)	0.002
Cardiotonic/inotropic support, n/N (%)	24/27 (88.9)	25/26 (96.2)	0.610

Note. Continuous variables: Median [IQR] (number of patients with data), compared with Mann-Whitney U test; categorical variables: compared with Fisher's exact test; *RD 15.4 percentage points (95% CI -3.1 to 34.3); Evaluable: IAP recorded on days 1 and 3; **RD 18.5 percentage points (95% CI 3.2 to 36.7); Twenty-one comparison-cohort patients without a recorded vital status were classified as survivors (discharge date recorded, no date of death); ***One comparison-cohort day-1 value of 210 mmol/L awaits source verification; results are shown with and without it

recorded date of death were classified as survivors. Because there were no deaths in the comparison cohort, standard logistic regression for in-hospital mortality failed to converge (complete separation), and Firth's penalized regression was also used for this outcome. One markedly high day-1 BUN value (210 mmol/L in patient c_20) was retained as recorded; BUN results are therefore reported with and without this value. A sensitivity analysis excluded the patient operated on at 210 days of age. Analyses were performed in Python 3.13 using pandas, SciPy, and NumPy; Firth's penalized regression and the cluster-robust variance estimator were implemented from their published formulas.

Ethics Approval

The study has been approved by the Ethical Committee of the UMC approval protocol #8/2023/ΠΕ of 17 November 2023, assigned number 2023/01-032; monitoring and re-approval protocol #8/2024/ΠΕ of 03 September 2024, assigned number 2023/01-032. Board affiliation: UMC. Institutional Review Board statement: The Ethical Committee of the UMC (web: <https://umc.org.kz/en/?ethics-commission=post-2>, accessed on 25 August 2026). Written informed consent was obtained from parents or guardians in the prospective cohort. For the retrospective review of comparison-cohort records, verbal

consent was obtained from parents or guardians by telephone, using the contact number recorded in the medical record.

RESULTS

Fifty-seven patients were included: 27 in the study group and 30 in the comparison group. Baseline demographic and diagnostic characteristics are summarized in **Table 1**.

The two cohorts were similar with respect to gestational age, birth weight, sex distribution, prematurity, and age at first operation. Gastroschisis was the predominant diagnosis in both cohorts (63.0% study, 70.0% control), with omphalocele present at a similar frequency in each (37.0% vs. 30.0%). Closure strategy did not differ significantly between cohorts, though a numerically higher proportion of comparison-cohort patients underwent primary fascial closure (80.0% vs. 59.3%), with the remainder undergoing staged closure with a silo. Because staged closure is generally chosen when viscerobdominal disproportion is greater, this difference is clinically relevant and is considered in the interpretation of the IAP findings below. Taken together, **Table 2** supports reasonable comparability between cohorts on measured baseline characteristics, although defect size, bowel condition and associated anomalies could not be compared.

Table 3. Abdominal compartment syndrome under the primary and alternative definitions, and Firth's penalized logistic regression

Definition	Technique, n/N (%)	Comparison, n/N (%)	RD, pp (95% CI)	p-value
A. Primary: IAH + ≥ 2 domains	5/26 (19.2)	1/26 (3.8)	15.4 (-3.1 to 34.3)	0.191
B. IAH + ≥ 1 domain (consensus-style)	7/26 (26.9)	4/26 (15.4)	11.5 (-10.9 to 32.8)	0.499
C. IAP > 10 mmHg on ≥ 2 of days 1, 3, 7 + ≥ 1 domain	7/26 (26.9)	6/30 (20.0)	6.9 (-14.9 to 28.8)	0.752
D. IAH alone	8/26 (30.8)	4/26 (15.4)	15.4 (-7.7 to 36.7)	0.324
E. IAH + all 3 domains	0/26 (0.0)	0/26 (0.0)	0.0 (-12.9 to 12.9)	1.000
A, all patients (non-evaluable counted as no ACS)	5/27 (18.5)	1/30 (3.3)	15.2 (-1.7 to 33.6)	0.091
A, excluding patient operated on at 210 days	5/25 (20.0)	1/26 (3.8)	16.2 (-2.6 to 35.5)	0.099
Components among evaluable patients				
IAH	8/26	4/26		0.324
Renal domain	1/26	9/26		0.011
Respiratory domain	14/26	9/26		0.264
Hemodynamic domain	23/26	25/26		0.610
Firth OR for ACS (primary definition)			OR (95% CI)	
Unadjusted (26 vs. 26)			4.35 (0.63-29.98)	
Adjusted for gestational age (26 vs. 22)			3.70 (0.52-26.06)	
Firth OR for in-hospital death			OR (95% CI)	
Unadjusted (27 vs. 30)			14.91 (0.75-298.05)	
Adjusted for gestational age (27 vs. 26)			12.63 (0.76-210.93)	

Note. IAH (daily mean IAP > 10 mmHg on postoperative days 1 and 3); RD (technique minus comparison) in percentage points with Newcombe hybrid score 95% CI; p-values from Fisher's exact test, except ORs (Wald test from Firth's penalized logistic regression); Definition C uses patients with IAP on at least two of the three days; Domain components missing because of absent measurements were counted as not met; creatinine on both days was available for 22 technique and 14 comparison patients, the PIP/FiO₂ ratio for 20 and 7, and pCO₂ for 23 and 25; There were no deaths in the comparison cohort, so the odds ratios for in-hospital death are very imprecise; the Wald test is conservative in this situation, which explains why the Firth p-value is larger than the Fisher exact p-value (0.019)

ACS occurred in 5 of 26 evaluable technique-cohort patients (19.2%) compared with 1 of 26 evaluable comparison-cohort patients (3.8%) (risk difference 15.4 percentage points, 95% CI -3.1 to 34.3); this difference did not reach statistical significance ($p = 0.191$). One technique-cohort patient died on postoperative day 2, before the day-3 measurement, and four comparison-cohort patients had no day-1 IAP, so these patients could not be evaluated. In-hospital mortality followed a similar pattern (5/27, 18.5% vs. 0/30, 0%; risk difference 18.5 percentage points, 95% CI 3.2 to 36.7; $p = 0.019$), though 21 comparison-cohort patients without a recorded vital status were classified as survivors on the basis of a recorded discharge date and no recorded date of death. Proposed technique-group patients had significantly higher IAP on postoperative day 7 (median 8.6 vs. 7.0 mmHg, $p < 0.001$) and higher BUN on postoperative day 3 (median 7.7 vs. 3.4 mmol/L, $p = 0.001$; $p = 0.002$ without the implausible value). Postoperative day of first stool passage was earlier and feeding initiation timing trended later in the comparison group but did not reach statistical significance (stool: $p = 0.357$; feeding: $p = 0.087$). Postoperative day 1 and day 3 IAP and creatinine at both timepoints did not differ significantly between groups. Urine output was higher in the technique cohort on day 1 (median 4.8 vs. 2.0 mL/kg/h, $p < 0.001$) and day 3 ($p = 0.026$), and day-3 pCO₂ was higher (44.7 vs. 35.6 mmHg, $p = 0.011$).

As the ACS events were rare (6 events), standard maximum-likelihood logistic regression was unstable, and Firth's penalized regression was used. In the unadjusted model, the GJI technique group had roughly 4.4 times the odds of ACS relative to the non-GJI group (odds ratio [OR] 4.35, 95% CI 0.63-29.98), and this estimate changed only modestly after adjusting for gestational age (OR 3.70, 95% CI 0.52-26.06). Neither the unadjusted nor the adjusted estimate reached statistical significance, and the CIs are wide, consistent with the small number of events; they are compatible with no difference as well as with a substantially higher frequency of ACS in the technique cohort.

Under every alternative definition that identified any cases, ACS was more frequent in the technique cohort, and no difference was statistically significant (**Table 3**); no patient in either cohort met all three domains (definition E). With the consensus-style definition (IAH with at least one domain), ACS occurred in 7 of 26 (26.9%) and 4 of 26 (15.4%) patients. The hemodynamic domain was met by almost all patients (23 of 26 and 25 of 26 evaluable patients), so in practice ACS classification depended on IAH together with the renal or respiratory domain. The renal domain was met more often in the comparison cohort (9 vs. 1 patient; $p = 0.011$), reflecting lower day-1 urine output, and the respiratory domain more often in the technique cohort (14 vs. 9). Renal and respiratory components were less often evaluable in the comparison cohort: creatinine on both days was available for 14 comparison and 22 technique patients, and the PIP/FiO₂ ratio of 7 and 20.

The group $\times$ time interaction for IAP was statistically significant ($p = 0.018$) (**Table 4**), indicating that the day 1-to-3 trajectory of IAP diverged between cohorts – consistent with the higher day-7 IAP observed in the GJI technique cohort in **Table 2**, the IAP in this cohort declined more slowly over the early postoperative course than in the comparison cohort. Group $\times$ time interactions for creatinine, pCO₂, and PIP/FiO₂ ratio did not reach statistical significance, though the creatinine interaction ($p = 0.092$) approached the threshold. The GJI technique cohort also had a significantly higher PIP/FiO₂ ratio on postoperative day 1 (difference +0.10, $p = 0.033$), and because the cohort $\times$ day interaction was not significant, this difference did not change significantly between day 1 and day 3 – that is, the GJI technique cohort's respiratory support requirement relative to oxygenation was higher at the start of the early postoperative period, rather than worsening or improving faster than in the comparison cohort over time; however, the ratio could be computed for only 7 comparison-cohort patients.

Table 4. Group × time interaction (repeated measures, day 1→3)

Variable	Patients (technique/ comparison)	Cohort difference on day 1 [95% CI]	p-value*	Cohort × day interaction [95% CI]	p-value**
IAP, mmHg	26/26	-1.10 [-2.56; 0.36]	0.137	+1.83 [0.32; 3.33]	0.018
Creatinine, μmol/L	22/14	+10.95 [-8.83; 30.72]	0.269	-11.25 [-24.42; 1.93]	0.092
pCO ₂ , mmHg	23/25	-12.24 [-29.41; 4.93]	0.158	+4.00 [-2.28; 10.28]	0.207
PIP/FiO ₂ ratio	20/7	+0.10 [0.01; 0.20]	0.033	-0.06 [-0.17; 0.06]	0.330

Note. Linear regression with cohort, day and cohort × day terms; standard errors clustered by patient; Patients with values on both days contributed; A positive interaction means the variable rose more, or fell less, in the technique cohort between day 1 and day 3; *Difference between cohorts on postoperative day 1; **Difference between cohorts in the change from day 1 to day 3 (group × time interaction); p-values from two-sided Wald tests with cluster-robust standard errors

Table 5. In-hospital deaths in the technique cohort

Characteristics	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Diagnosis	Omphalocele	Gastroschisis	Gastroschisis	Omphalocele	Omphalocele
Defect closure	primary	staged	staged	staged	staged
Gestational age (weeks)	39	37	36	35	39
Birth weight (g)	1880	2818	2360	2850	2580
Days from first operation to death	22	22	32	2	9
IAP day 1 (mmHg)	9.9	15.3	14.6	11.6	9.7
IAP day 3 (mmHg)	7.4	11.1	9.8	-	4.3
IAP day 7 (mmHg)	7.1	9.9	6.7	-	-
ACS – Primary definition	No – 1 domain	Yes – 2 domains	No – 1 domain	Not evaluable – died before day 3	No – no IAH, 2 domains
Death cause	Multiple congenital anomalies, trisomy 18	Sepsis	Sepsis	Multiple congenital anomalies	Abdominal compartment syndrome

Note. All five patients received cardiotoxic or inotropic support; No deaths were recorded in the comparison cohort (0/30), including 21 patients classified as survivors on the basis of a recorded discharge date and no recorded date of death

Day-7 IAP was available for 22 technique-cohort patients; one had died. Part of the day-7 difference reflects closure type. Patients with staged closure had higher day-7 IAP in both cohorts (median 10.1 and 9.4 mmHg), because definitive closure took place a median of 7 days after silo placement, and staged patients made up a larger share of the technique cohort. Among patients with primary closure, day-7 IAP was 7.8 mmHg (n = 13) vs. 7.0 mmHg (n = 24; p = 0.002), a difference of less than 1 mmHg and below the IAH threshold. The higher day-3 BUN in the technique cohort occurred with higher urine output and similar creatinine, a pattern more consistent with a higher nitrogen load or catabolism than with reduced glomerular filtration. BUN was available for only 12 (day 1) and 14 (day 3) comparison-cohort patients, so this comparison is uncertain.

In-Hospital Deaths

Five technique-cohort patients died in hospital (18.5%, 95% CI 8.2-36.7), 2 to 32 days after the first operation (median 22 days) (Table 5). One of them met the primary ACS definition, and one died on day 2, before ACS could be assessed. Two deaths were attributed to sepsis, two to multiple congenital anomalies (one with trisomy 18), and one to ACS. The patient who met the primary ACS definition died of sepsis, whereas the patient whose death was attributed to ACS did not meet the study IAH criterion (daily mean IAP 9.7 and 4.3 mmHg on day 1 and day 3) although two organ-dysfunction domains were present. No deaths were recorded in the comparison cohort (0/30; 95% CI 0-11.4%), including 21 patients classified as survivors on the basis of discharge documentation.

All five patients received cardiotoxic or inotropic support. No deaths were recorded in the comparison cohort (0/30), including 21 patients classified as survivors on the basis of a recorded discharge date and no recorded date of death.

Exploratory NGAL/Cystatin C Sub-Analysis

Among the 13 GJI technique-cohort patients with available biomarker data (3 with ACS, 10 without), median NGAL was numerically higher in patients who developed ACS than in those who did not on postoperative day 3 (151.6 vs. 67.4 ng/mL) but not on day 5 (44.0 vs. 94.1 ng/mL); neither difference reached statistical significance (day 3 p = 0.69; day 5 p = 0.48). Cystatin C did not differ meaningfully by ACS status at either timepoint (day 3: 1.5 vs. 1.7 mg/L, p = 0.73; day 5: 1.7 vs. 1.6 mg/L, p = 0.91). Neither biomarker changed significantly from day 3 to day 5 within patients (NGAL, n = 12, p = 0.622; cystatin C, n = 11, p = 0.320). Spearman correlations between day-3 biomarker levels and conventional renal markers were positive but did not reach significance (NGAL vs. creatinine: p = 0.49, p = 0.106; cystatin C vs. creatinine: p = 0.52, p = 0.102; cystatin C vs. BUN: p = 0.50, p = 0.117; NGAL vs. BUN: p = 0.13, p = 0.681). Given the small subgroup size (n = 13, only 3 with ACS) and absence of a comparison-group comparator, these results should be regarded as preliminary and hypothesis-generating rather than evidence for or against the clinical utility of either biomarker in this population; the analysis is too small to support conclusions about either marker.

Sensitivity Analysis

Excluding the patient operated on at 210 days of age, ACS occurred in 5 of 25 (20.0%) vs. 1 of 26 (3.8%) evaluable patients (risk difference 16.2 percentage points, 95% CI -2.6 to 35.5; p = 0.099); the IAP group × time interaction (p = 0.018) and the day-7 IAP difference (p = 0.001) were unchanged. Counting patients who could not be evaluated as not having ACS, as in the previous version of this analysis, gave 5 of 27 vs. 1 of 30 (p = 0.091).

DISCUSSION

In this ambispective observational two-center cohort of 57 infants undergoing repair of ventral wall defects, the incidence of ACS was not significantly associated with GJI relative to conventional repair (5/26 vs. 1/26 evaluable patients; risk difference 15.4 percentage points, 95% CI -3.1 to 34.3; Firth OR 4.35, 95% CI 0.63-29.98), and the point estimate indicated a higher incidence in the technique cohort. This association changed little after adjustment for gestational age (adjusted OR 3.70, 95% CI 0.52-26.06), which indicates only that gestational age does not explain the cohort difference. In-hospital mortality showed a similar pattern (5/27 vs. 0/30; $p = 0.019$; Firth OR 14.91, 95% CI 0.75-298.05), with wide CIs reflecting the small number of events. The GJI technique cohort had significantly higher IAP at postoperative day 7 and significantly higher BUN at postoperative day 3; the earlier first stool passage and later initiation of feeding in the comparison group did not reach statistical significance.

The group $\times$ time interaction for IAP trajectory was statistically significant ($p = 0.018$), indicating that IAP declined more slowly in the technique cohort over the first three postoperative days, while interactions for creatinine, $p\text{CO}_2$, and PIP/FiO₂ ratio did not reach significance; the technique cohort had a significantly higher PIP/FiO₂ ratio on day 1 ($p = 0.033$), without a significant difference in its day 1–3 trend. Collectively, these results run counter to our initial hypothesis regarding an ACS risk-reduction technique and should be interpreted with caution given that this is a non-randomized, center-confounded comparison from which no causal conclusions can be drawn.

If confirmed, an ACS frequency of about one in five would be clinically important and would argue against assuming that adding post-pyloric decompression lowers ACS risk. The pressure findings also run counter to the rationale for GJI: the technique cohort started with a lower day-1 IAP but did not show the decrease seen in the comparison cohort. Several explanations are possible. The technique cohort included more staged closures, and staged patients had higher day-7 IAP in both cohorts because definitive closure took place around day 7; among patients with primary closure, the remaining difference was under 1 mmHg and of uncertain clinical significance. IAP was summarized as the mean of six daily measurements in the technique cohort. The effect of the gastrostomy and tube itself cannot be excluded or confirmed with these data. In practice, the findings support routine IAP monitoring after repair regardless of technique, and they do not justify adopting GJI to prevent ACS outside a prospective evaluation.

A central limitation shaping this interpretation is that the technique and comparison cohorts were drawn from two different centers rather than randomized within a single institution, with the technique-cohort center treating a more complex case mix as a tertiary referral unit. Since the surgical technique is confounded by treating center, disparities in ACS incidence, mortality, and gastrointestinal recovery timing may be driven by referral patterns and case-mix differences across centers rather than by the procedure used. This is consistent with earlier observations in the gastroschisis literature that outcome comparisons between closure strategies are vulnerable to treatment-selection bias, since infants with more severe intestinal compromise are disproportionately directed toward one management pathway rather than being randomly

allocated [12, 13]. Adjustment for gestational age cannot address the other differences in disease severity – such as defect size, extent of bowel compromise, associated anomalies or preoperative respiratory support, which were not available, or the differences in clinical management between the centers. A cluster-randomized or single-center randomized design would be needed to estimate a causal technique effect; the present observational design can only generate hypotheses about that effect.

Our findings on renal and respiratory trajectory should be interpreted against the pediatric-specific IAH/ACS framework rather than the adult 20 mmHg threshold: median IAP values in both cohorts remained below 15 mmHg at every timepoint but declined more slowly in the technique cohort than in the comparison cohort over the first three postoperative days (group $\times$ day interaction $p = 0.018$), a pattern consistent with the significantly higher day-7 IAP observed in the technique cohort in **Table 2**. The overall event rate for ACS (6 of 52 evaluable patients, 11.5%, using a > 10 mmHg plus ≥ 2 -domain organ dysfunction definition) is slightly above the 0.6-10% reported in critically ill children and the 8% reported in a neonatal series that required dysfunction of one or more organs, albeit measured with heterogeneous definitions across studies [16, 32]. Our two-domain requirement is stricter than the WSACS pediatric definition [15]; however, the hemodynamic domain was met by almost all patients and did not discriminate, and renal and respiratory components were less often available in the comparison cohort, so ACS may have been under-ascertained there, which would inflate the apparent difference between cohorts. The PIP/FiO₂ ratio is not a validated measure. The creatinine group $\times$ time interaction approached but did not reach significance ($p = 0.092$), and the $p\text{CO}_2$ interaction was not significant; low event counts limit power for detecting moderate effects in both cases.

The exploratory analysis of serum NGAL and cystatin C, available in a subset of the technique cohort, was intended to test whether these early tubular-injury biomarkers would detect renal compromise before it became apparent on creatinine or diuresis. Prior work in other pediatric surgical populations – most extensively in cardiopulmonary bypass surgery – has shown that NGAL rises within hours of renal insult and that serum cystatin C can predict acute kidney injury before creatinine-based criteria are met, motivating our decision to measure both markers on postoperative days 3 and 5 [20, 21, 33, 34]. In our subgroup of 13 technique-cohort patients, neither NGAL nor cystatin C differed significantly by ACS status at either timepoint, or correlations with conventional renal markers (creatinine, BUN) were positive but did not reach significance – a pattern fully consistent with chance given the small number of ACS cases available for comparison ($n = 3$). Because these measurements were available in only half of the technique cohort and had no corresponding comparison-cohort comparator, this analysis is too small to support meaningful conclusions; a properly powered, prospective biomarker study across both cohorts would be needed to determine whether NGAL or cystatin C meaningfully improve early detection of IAP-mediated renal injury in this population. Biomarker measurement was restricted to half of the technique cohort because of cost and resource constraints.

Several additional limitations merit emphasis. The overall sample size (27 technique and 30 comparison) and the low number of ACS events limited statistical power throughout;

even with Firth's penalized regression, CIs for the cohort effect remained wide enough to be compatible with anywhere from a modest to a very large difference in risk. Because the comparison cohort was assembled retrospectively via chart review while the technique cohort was followed prospectively, data completeness differed systematically between cohorts: death status was missing for a substantial proportion of comparison-cohort patients in the source records and was classified as survival on the basis of discharge documentation, and several other variables (e.g., day-1 FiO₂, day-1 creatinine, and BUN) were more often missing in the comparison cohort as well. Although this classification is consistent with the available discharge dates, it cannot rule out unrecorded deaths and may underestimate comparison-cohort mortality; more broadly, this asymmetric completeness is an inherent limitation of the ambispective design and should be considered when interpreting any comparison between cohorts. One markedly implausible day-1 BUN value (210 mmol/L, versus a cohort range otherwise below 93 mmol/L) was retained as recorded pending verification against the source record, and BUN-based results are therefore shown with and without this value. Our organ-dysfunction composite for ACS also lacked a metabolic/acid-base domain, which is included in several published pediatric ACS definitions, potentially leading to under-ascertainment of ACS in patients whose primary manifestation was metabolic rather than renal, respiratory, or hemodynamic [16, 19]. In addition, one patient fell outside the stated diagnosis and age criteria, although excluding this patient did not change the findings; patients admitted in a critical state, who are at the highest risk of ACS, were excluded; and tube-related complications were not systematically recorded. Most fundamentally, as an ambispective observational study with treatment structurally confounded by center, this design cannot distinguish a true effect of GJI from an effect of the treating center, its case mix, or its data-collection approach; all associations reported here should be read accordingly.

In conclusion, this exploratory observational comparison did not show an association between GJI and a lower incidence of ACS; if anything, point estimates for ACS and mortality were higher in the technique cohort, a pattern that cannot be separated from the confounding effect of differing case complexity across the two contributing centers. Given the non-randomized, center-confounded design, these findings should not be interpreted as evidence for or against the comparative efficacy of this technique. They are descriptive and hypothesis-generating only. To draw conclusions about the comparative effectiveness of GJI after ventral wall defect repair, a multicenter randomized or patient-adjusted study limited to one clearly defined diagnosis, with standardized IAP monitoring, complete mortality ascertainment, systematic recording of tube-related complications, validated baseline data, and a full-scale biomarker subgroup study is needed.

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