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Conversion to Open Repair During Thoracoscopic Repair of Congenital Diaphragmatic Hernia in Neonates: Risk Factors and Countermeasures

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Abstract: There are currently no general guidelines on the selection criteria for thoracoscopic repair (TR) of congenital diaphragmatic hernia (CDH) in neonates, and some patients who are not suitable for the thoracoscopic approach have to be converted to open repair (OR) after undergoing initial thoracoscopy. The aim of this study was to evaluate factors associated with conversion to OR during TR of neonatal cases of CDH and to explore countermeasures against conversion. Medical records of neonates who underwent thoracoscopy for Bochdalek-type CDH at a tertiary center from January 2013 to July 2019 were retrospectively reviewed. We defined two groups: the T group included neonates undergoing complete TR and the TO group included neonates requiring conversion to OR during TR. Thoracoscopy was performed in 58 neonates, with 48 in T group and 10 in TO group. The conversion rate was 17.2%. The proportion of patients with diaphragmatic defect size greater than 6 cm x 5 cm was significantly higher in the TO group than in the T group (30% vs. 2.08%; $p = 0.014$). The rate of patch use was significantly higher in the TO group compared to the T group (30% vs. 4.17%; $p = 0.032$). There was no statistically significant difference between the two groups in terms of stomach herniation or liver herniation. The postoperative recurrence rate was 17.78% in the T group and 0% in the TO group ($p = 0.39$). Defect size greater than 6 cm x 5 cm and patch use were associated with higher conversion rate, while stomach herniation and liver herniation were not. Patients who require conversion but are not actually converted to open repair may have a higher risk of postoperative recurrence.

Keywords: Congenital Diaphragmatic Hernia, Thoracoscopy, Conversion to Open Surgery, Neonate

1. Introduction

Congenital diaphragmatic hernia (CDH) is characterized by a congenital defect in the diaphragm that allows herniation of abdominal viscera into the thoracic cavity leading to abnormal lung development, with an incidence of about 1 in 3000 live births [1]. Bochdalek hernia presenting as a postero-lateral defect is the most common type (70%-75%) [2].

The increasing popularity of minimally invasive surgery (MIS) has led to its use in some complex pediatric surgical conditions such as CDH. Silen etal introduced the first thoracoscopic CDH repair in an adolescent in 1995 [3]. Becmeur etal described the thoracoscopic treatment for CDH in an infant aged 8.3 months in 2001 [4]. In 2003, Liem initially reported the feasibility of performing thoracoscopic repair (TR) of CDH in neonates [5]. Since then, TR of CDH in neonates has been increasingly used in many medical centres.

The reported advantages of TR may include less damage, shorter postoperative mechanical ventilation and hospitalization, improved cosmetic results and decreased thoracic deformity [6, 7]. However, a randomized controlled study showed a significant increase in intraoperative hypercapnia and acidosis during TR of neonatal CDH [8]. In addition, some studies have reported that MIS for CDH is associated with a higher recurrence rate compared to open surgery [9, 10]. Although it is controversial whether the benefits of TR of CDH outweigh the potential risks, thoracoscopy is an option for CDH repair. A survey of International Pediatric Endosurgery Group (IPEG)

members revealed that 89% of participants performed thoracoscopic CDH repair and 40% used this approach routinely [11]. Nevertheless, because of the failure to identify which patients should not be approached thoracoscopically, some neonates with CDH have to be converted to open repair (OR) after undergoing initial thoracoscopy, which can result in increased incisions, prolonged operative time and anesthetic duration, as well as additional physiologic stress and trauma. The incidence of conversion varies considerably in recent studies, ranging from 7.4% to 31% [12-17].

The purpose of this study was to identify risk factors related to conversion to OR during TR of neonatal CDH and then to explore specific countermeasures for conversion.

2. Methods

2.1. Patients

The study was approved by the Medical Research Ethics Committee of Anhui Provincial Children's Hospital. We retrospectively analyzed the medical records of neonatal patients who underwent thoracoscopy for Bochdalek-type CDH at our institution between January 2013 and July 2019. Two groups were defined based on whether the TR was successful or not: the T group consisted of neonates with complete TR and the TO group consisted of neonates who required conversion to OR during the TR.

2.2. Selection Criteria for Thoracoscopic CDH Repair in Neonates

Patients considered for TR met the following criteria preoperatively: (1) weight beyond 2000g; (2) able to maintain stable respiration under conventional mechanical ventilation, no need for high frequency oscillation ventilation or extracorporeal membrane oxygenation; (3) pH value of arterial blood gas analysis between 7.35 and 7.45; (4) stable hemodynamic function, including capillary filling time less than 3 seconds, urine output more than 2ml/kg/h, lactate below 3mmol/L; (5) no severe congenital heart defects or pulmonary anomalies.

2.3. TR Technique

Thoracoscopic surgery was performed in the operating room. The patient was placed in the lateral decubitus position with the affected side elevated, and three trocars were used. The first 5-mm trocar was placed below the tip of the scapula in the fourth intercostal space for the thoracoscope. Carbon dioxide insufflation was initiated and maintained at a pressure of 4 mmHg in the thoracic cavity. Under direct vision, a second 3-mm trocar was placed in the anterior axillary line in the fourth intercostal space and a third 3-mm trocar was inserted at the midpoint of the line between the scapula tip and the spine. The herniated organs were reduced into the abdominal cavity using thoracoscopic instruments. Insufflation pressure was increased up to 6 mmHg if reduction of herniated contents was difficult. After reduction, the hernia defect was repaired using non-absorbable interrupted sutures (2-0/Ethicon). If the diaphragmatic defect is not large, closure of the two diaphragmatic rims was performed directly. A polyesther patch was required with interrupted stitches if the direct closure of defect was under tension or impossible. In absence of the diaphragm rim, pericostal sutures were performed. A chest drain was placed.

2.4. Data Collection and Statistical Analysis

Demographics and main preoperative variables including sex, birth weight, incidence of prenatal diagnosis, defect side, use of preoperative ventilation support, associated cardiac malformations, pulmonary hypertension and bidirectional or right-to-left shunt through patent ductus arteriosus (PDA) were recorded. Operative repair data were collected, including day of life at repair, liver or stomach herniation, hernia sac, defect size, patch repair and duration of surgery. Postoperative recovery data were ventilator days, time to start oral feeding, length of stay and mortality after surgery. Postoperative complication involving pneumothorax, pleural effusion, bowel obstruction, and recurrence were reviewed.

The diaphragmatic defect size was measured using open forceps as a length standard after the reduction of abdominal viscera during thoracoscopy. The maximum transverse diameter of defect was measured in the coronal plane, with the maximum anteroposterior diameter of defect measured in the sagittal plane. The size of the defect was recorded by these two diameters. In this study, diaphragmatic defects were classified as small to moderate defects (between 2x2cm and 6cmx5cm) and large defects (greater than 6cmx5cm) based on defect size.

Statistical analysis was performed using IBM SPSS Statistics software (version 22.0). Continuous variables with normal distribution were reported as mean ± standard deviation and compared using *t*-test. Continuous variables with skewed distribution were represented as median (25th - 75th percentiles) and analyzed using Mann-Whitney *U* test. Categorical variables were presented as number and percent and compared using Pearson's Chi-square test or Fisher's exact test. A p-value less than of 0.05 was considered statistically significance.

3. Results

3.1. Patients with Conversion

From January 2013 to July 2019, 58 neonates underwent attempted thoracoscopic CDH repair. All newborns were full-term with mean birth weight 3117.88 ± 446.21 g. 48 of 58 (82.8%) patients underwent complete thoracoscopic repair, including 46 primary repair and 2 patch repairs. Conversion to OR occurred in 10 of 58 (17.2%) patients.

There were 10 conversions in group TO: one to thoracotomy and nine to conventional subcostal laparotomy. All the conversions were left-sided CDH. One case was converted to thoracotomy due to removal of an associated congenital cystic adenomatoid malformation found intraoperatively. Among the 9 patients converted to laparotomy, one was converted due to the need to repair the ileum damaged during reduction; three were due to a large

defect and the need for a patch closure, one required conversion owing to failure of reduction of the herniated left lobe of the liver and stomach and the remaining four cases were converted because of inability to reduce extremely dilated bowel in the thoracic cavity.

3.2. Preoperative Data

Table 1 shows patients' demographics and main preoperative data, there were no significant differences for all these variables between the T group and the TO group.

3.3. Operative Data

Table 2 compares operative data between the T and TO group. As is shown in Table 2, two variables were significantly different between the two groups. The percentage of cases with defect size larger than 6cm x 5 cm in the TO group was significantly higher than that in the T group (30% vs. 2.08%; p = 0.014). The rate of patch use in the TO group was significantly higher compared to the T group (30% vs. 4.17%; p = 0.032). The age at repair was similar between the two groups. No statistically significant association between stomach or liver herniation and conversion was identified. The presence or absence of a hernia sac was not significantly different between the two groups.

3.4. Postoperative Data

Postoperative data are summarized in Table 3. There were 4 (8.33%) deaths in the T group and 1 (10%) death in the TO group. Postoperative ventilation duration, the initiation of oral feeding after surgery, and the postoperative hospital stay were also similar in the two groups of surviving patients. These outcomes may depend more on pulmonary hypoplasia and management strategy than just surgical approach and conversion, so they were not statistically compared.

3.5. Postoperative Complications

Table 4 illustrates the postoperative complications of the two groups. The median follow-up period was not significantly different between the two groups.

Regarding postoperative recurrence, one death with evidence of recurrence in group T was included in the recurrence count; while the rest of the dead patients were excluded from the statistics on recurrence. There were 8 recurrences (8/45, 17.8%) in the T group, including 7 primary repairs and 1 patch repair; while there was no recurrence in the TO group. The difference in recurrence rate between the two groups was not statistically significant (p = 0.39). Of these recurrences, one experienced a second recurrence; except for one case that ultimately died without reoperation, the other seven cases were cured after further thoracoscopic or open surgery.

There were no significant differences between the two groups in terms of other postoperative complications including bowel obstruction, pneumothorax, and pleural effusion.

Table 1. *Demographics and preoperative data.*

	T group (thoracoscopic) (n=48)	**TO group (thoracoscopic → open) (n=10)**	***P*-value**
Gender			
Male	28 (58.33%)	6 (60%)	1.0
Female	20 (41.67%)	4 (40%)	
Birth weight (g)	3132.86±453.75	3055±429.99	0.625
Time at diagnosis			
Prenatal	13 (27.08%)	2 (20%)	0.945
Postnatal	35 (72.92%)	8 (80%)	
Structural heart disease (ASD, VSD)	23 (47.92%)	5 (50%)	1.0
Pulmonary hypertension	24 (50%)	5 (50%)	1.0
Defect side			
Left	41 (85.42%)	10 (100%)	0.451
Right	7 (14.58%)	0 (0%)	
Preoperative ventilator support	20 (41.67%)	5 (50%)	0.894
Bidirectional PDA or R/L shunt (at admission)	8 (16.67%)	3 (30%)	0.593

Table 2. *Operative data.*

	T group (n=48)	**TO group (n=10)**	***P*-value**
Day of life at repair (days)	4 (2-7)	3 (2-4)	0.493
Liver herniation	3 (6.25%)	1 (10%)	0.541
Stomach herniation	6 (12.5%)	3 (30%)	0.363
Hernia sac			
Present	15 (31.25%)	2 (20%)	0.742
Absent	33 (68.75%)	8 (80%)	
Defect size (cm)			0.014
Small to moderate (2x2—6x5)	47 (97.92%)	7 (70%)	
Large (>6x5)	1 (2.08%)	3 (30%)	
Type of repair			0.032
Primary	46 (95.83%)	7 (70%)	
Patch	2 (4.17%)	3 (30%)	

Table 3. *Postoperative data.*

	T group	TO group
Mortality	4/48 (8.33%)	1/10 (10%)
Postoperative ventilator days for survivors	4.07 (2.87-5.71)	4.71 (2.47-10.06)
Postoperative days until oral feeding initiation for survivors	9 (7- 15)	9 (8-21)
Postoperative length of stay for survivors (days)	18.16±8.62	22.44±11.11

Table 4. *Complications.*

	T group	TO group	*P*-value
Pneumothorax	2/45 (4.44%)	0/9 (0%)	1.0
Pleural effusion	5/45 (11.11%)	1/9 (11.11%)	1.0
Small bowel obstruction	1/44 (2.27%)	0/9 (0%)	1.0
Recurrence	8/45 (17.78%)	0/9 (0%)	0.392
Follow-up duration (months)	47.5 (27-71.75)	60.5 (39-71.25)	0.41

4. Discussion

At present, there are no general guidelines for selection criteria for TR of CDH in neonates, and the indications for TR vary greatly among pediatric surgical institutions. Thus, some neonates who are not suitable for thoracoscopic repair will have to undergo conversion if thoracoscopy is performed. Several factors have been described in the literature to be associated with conversion, including herniation of the stomach in the thorax, intraoperative visceral injury, inability to reduce the herniated organs, cardiopulmonary instability, large defect size, need for a patch and preoperative OI >3.0 [12-18]. However, most of them are proposed on the basis of experience, and only a very few of them are concluded by statistical analysis. Moreover, to our knowledge, there have been few articles in recent years that provide a comprehensive summary of specific preventive measures for conversion. Therefore, in the present study, we compared patients undergoing complete TR with those who required conversion to OR, aiming to explore risk factors that may be related to conversion and thus identify concrete measures to tackle conversion.

A large defect size is thought to be correlated with the severity of CDH. Although it has been previously mentioned that larger diaphragmatic defects have a higher likelihood of requiring a conversion, the specific defect size that can predict conversion is currently unknown. In this study, we objectively measured the actual defect size during surgery to accurately evaluate the extent of the diaphragmatic defect. Further, we sought to find a specific defect size that could be identified as the cut-off point for conversion in order to select candidates for TR. Based on our findings, there was a clear association between larger defect size greater than 6 cm x 5 cm and higher conversion rate. In addition, the need for patch repair is also a factor related to conversion. Patch use is, to some extent, a surrogate for large defect size. For large diaphragmatic defects or when the residual native diaphragmatic tissue is insufficient, patch repair to close the diaphragmatic defect is essential to ensure a tension-free repair.

Some studies have shown that larger defect size and MIS approach are associated with higher recurrence rates [19, 20]. Accordingly, for CDH with larger defect size and the need for patch repair, given technical difficulties, longer operative time and the associated adverse effects of prolonged anesthesia, and especially the high recurrence rate, open surgery can be preferred for those institutions that have limited experience in TR or that currently have a policy of voluntarily converting the patients requiring patch repair to open surgery. Furthermore, if larger defect size and therefore patch use can be predicted preoperatively, then open surgery can be chosen directly so as to avoid the disadvantages of thoracoscopy followed by conversion. However, it is previously difficult to predict the size of the diaphragmatic defect and the potential need for patch closure before surgery. Fortunately, several recent studies have proposed the usefulness of preoperative ultrasound evaluation in providing surgeons with anatomical information to determine surgical approach and repair method of neonatal CDH. Hattori et al. confirmed the consistency between preoperative ultrasound measurements and surgical findings in terms of diaphragmatic defect size, existence or loss of diaphragm rim, and hernial contents [21]. Hosokawa et al. demonstrated that postnatal ultrasound-measured defect size was larger in neonates undergoing open surgery than in those undergoing thoracoscopic operation; likewise, neonates who underwent patch repair had greater measured defect size compared to those who underwent primary repair [22]. Although these studies included small numbers of cases and further studies with a larger cohort are needed, they still give us a clue that preoperative ultrasound assessment can be expected to play a role in selecting optimal candidates for thoracoscopic CDH repair, thereby reducing the conversion rate.

In present series, 40% of conversions are caused by the severely dilated small intestine and colon that cannot be pushed back into the abdominal cavity. This is mainly due to the fact that not every child is routinely intubated and mechanically ventilated after birth or after admission to hospital. Our results indicate that in some cases without preoperative intubation the herniated intestine is so dilated even with the placement of gastric tube that reduction is impossible during thoracoscopic surgery and conversion to laparotomy is indispensable. Tracheal intubation and gastric tube placement immediately after birth can help neonates with

CDH achieve the optimal preoperative status by reducing gas entry into the gastrointestinal tract and improving oxygenation and respiratory conditions [6]. Accordingly, it is essential that neonatal CDH cases are routinely intubated and mechanically ventilated immediately after birth. Moreover, placement of the anal tube has also been mentioned as a method of bowel decompression [23]. These strategies can facilitate the decrease in conversion as a result of severe intestinal dilatation.

In our study, there was one converted case because of intestinal injury during reduction, and other reports have mentioned conversion resulting from intraoperative injury of herniated viscera, such as bleeding from short gastric vessels and spleen hemorrhage [13]. With advances in surgical techniques and increased experience, this situation will improve. In addition, Inoue et al. reported that the application of an endoscopic surgical spacer SECUREA™ could be effective in preventing injury of herniated viscera during organ reduction and repair of hernia orifice of thoracoscopic surgery for CDH [24].

The absence of stomach herniation in the thoracic cavity by radiograph was once considered an anatomic selection criteria for neonatal thoracoscopic CDH repair in one study [18]. In a retrospective study, the intrathoracic position of the stomach at X-ray was also described as one of risk factors for failure of thoracoscopic primary repair [12]. However, in our study, the presence of stomach or liver herniation in the thoracic cavity did not differ significantly between the T and TO groups, suggesting that stomach herniation or liver herniation may not be an inhibitory factor for TR of CDH in neonates. Additionally, there was no case of conversion to OR due to intraoperative cardiopulmonary instability during TR in our series, which may indicate the importance of preoperative selection criteria for TR.

There was a huge difference in the postoperative recurrence rate between the T and TO groups (17.8% vs. 0%), and it was not statistically different simply because of the small sample size. In addition, the higher recurrence rate in the T group suggests that we may have missed some factors that should have warned us that a conversion was needed. This indicates that if some patients who require conversion are not in fact converted to OR, it may lead to a higher recurrence rate. Therefore, it is advisable for the surgeon to convert to open surgery when needed, rather than going on with a difficult thoracoscopy.

There were several limitations in this study. Firstly, it is a retrospective study. Secondly, the number of patients presented in this single-center study was relatively small, despite no flaws in terms of case selection bias and different skill levels. Thus, a large prospective multi-center study is necessary to assess the validity of using these factors as preoperative selection criteria in order to increase chances for successful TR of CDH in neonates.

5. Conclusions

In conclusion, the present series suggests that diaphragmatic defect size greater than 6cm x 5 cm and patch repair were correlated with conversion to OR during TR of CDH in the neonatal period. No statistically significant association between stomach herniation or liver herniation and conversion was identified. Measures to prevent unnecessary conversion may include strict selection criteria for TR, immediate postnatal tracheal intubation and mechanical ventilation, preoperative ultrasound measurement of defect size as a reference for surgical approach, a spacer to protect herniated viscera during reduction and improved surgical techniques. Moreover, it is worth noting that there is a possibility of an increased recurrence rate if those cases requiring conversion are not actually converted.

Consequently, on the one hand, in view of the drawbacks caused by unnecessary conversion, pediatric surgeons should make every effort preoperatively to anticipate which patients are at higher risk for conversion and take utmost measures for preventable conversions. On the other hand, patients who have already undergone thoracoscopy should be converted if conversion is needed to avoid an increased risk of postoperative recurrence.

Conflict of Interest

The authors declare that they have no conflict of interest.

Abbreviations

CDH: congenital diaphragmatic hernia
MIS: minimally invasive surgery
OR: open repair
PDA: patent ductus arteriosus
TR: thoracoscopic repair

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