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ORIGINAL ARTICLE

Multidisciplinary perinatal management of the compromised airway on placental support: lessons learned

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ABSTRACT

Objective The aims of this study were to review fetal and maternal outcomes after management of the compromised perinatal airway via operation on placental support or *ex utero* intrapartum treatment and to discuss implications for future management of these complex and rare cases.

Methods We have presented a retrospective case series of 12 neonates requiring airway management on placental support at a single tertiary care, academic center.

Results One mother experienced significant blood loss. Operative recovery times were unremarkable. Eight neonates required airway management due to mass obstruction, two for removal of an endotracheal balloon for fetoscopic treatment of congenital diaphragmatic hernia, one for laryngeal atresia, and one for severe retrognathia. One of our series is an unusual case of management on placental support after vaginal delivery. Another child would have ideally been managed on placental support, but an extremely short umbilical cord prevented this. Even though the airway was secured in all 12 cases, five neonates died in the perinatal period.

Conclusions These procedures have a risk for substantial maternal blood loss. Despite excellent rates of success securing the neonatal airway, children who require management on placental support still have high mortality. A formalized multidisciplinary approach at our institution has enhanced preparedness for these cases. © 2013 John Wiley & Sons, Ltd.

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INTRODUCTION

Advances in prenatal imaging with ultrasound and fetal magnetic resonance imaging (MRI) have allowed the identification of fetuses at high risk of airway compromise. Consequently, rather than an unexpected emergency, the appropriate medical disciplines can be present and prepared to secure an airway while the baby is supported by the placental circulation. *Ex utero* intrapartum treatment (EXIT) typically involves delivering the head and shoulders of the infant through a hysterotomy, maintaining uterine relaxation and intrauterine fluid volume and temperature, and establishing an airway via orotracheal intubation or tracheotomy. In rare instances, the infant may undergo surgery to remove the obstructing mass while still on placental support.[1,2]

Although multiple reports had been published concerning the management of the neonatal airway while on placental circulation,[3–5] the term 'EXIT' was first coined by surgeons performing and relieving *in utero* tracheal occlusion for congenital diaphragmatic hernia (CDH).[6] At that time, clips were applied to the fetal trachea following neck dissection to prevent pulmonary fluid egress in an attempt to improve fetal lung volume prior to birth. Historically, that was the most common indication for EXIT.[6–8] Recently, however, CDH is increasingly being managed by fetal endoscopic tracheal occlusion, and the majority of these cases do not require an EXIT procedure in order to reverse the occlusion.[9] Therefore, the most common current indication for an EXIT procedure is the management of the neonatal airway in the presence of an obstructing mass or in the setting of congenital high airway obstruction, one example of which is laryngeal atresia. Variations from the original EXIT technique have been described, such as maintaining fetal–placental circulation while removing the entire fetus from the

uterus at delivery.[3,10] This is alternatively referred to as operation on placental support.

The need to secure an airway at birth secondary to tracheal occlusion or an obstructing mass is rare, and thus, few large series have been reported.[7,11,12] This is the second series from our institution, the first being a small series of six patients published 15 years ago.[13] Since that series, we have established a formal multidisciplinary perinatal airway management team at the University of Toronto. This has allowed for better planning of the deliveries for these complex patients. In this report, we compare our outcomes since the establishment of the multidisciplinary team with those in our previous report.

MATERIALS AND METHODS

Approval for this project was granted by the Mount Sinai Hospital (protocol number 10-0285-C) and Hospital for Sick Children (protocol number 1000022163) Research Ethics Boards. Mothers are referred to our center if prenatal imaging demonstrates a fetus with a neck mass or other airway anomalies. Institutional databases were searched for such mothers who presented between January 1999 and April 2012. Twelve infants who required a procedure on placental support were identified. All procedures were performed in the labor and delivery unit at Mount Sinai Hospital with staff from The Hospital for Sick Children's Department of Otolaryngology – Head and Neck Surgery, Mount Sinai Hospital Fetal Medicine Unit, and Mount Sinai Hospital Departments of Anesthesia and Neonatology in attendance. At our institution, we use clamps rather than staplers for hemostasis at the hysterotomy site. In general, we feel that this controls blood loss well, avoids the use of an expensive stapler, and makes closing the hysterotomy easier.

RESULTS

Our series consists of 12 infants, six boys and six girls, who were identified antenatally as potentially having airway compromise. Eight of the infants had obstructing neck masses (three lymphatic malformations, four teratomas, and one venous malformation). One had complete laryngeal atresia, one had severe retrognathia, and two had a tracheal occlusion balloon *in situ*, which had been inserted 8 weeks previously for treatment of CDH. All abnormalities were initially identified on antenatal ultrasound, and fetal MRI was performed in eight cases (Table 1). Patients were grouped into quartiles to indicate when in the series they were born (first quartile is earliest).

Airway management and morbidity

We follow a standard algorithm of airway management. Oral intubation is attempted initially. Failing that, we attempted rigid bronchoscopy, followed by tracheotomy if necessary. The airway was secured via an oral route in seven cases. Tracheotomy was necessary in four cases because of the inability to visualize the larynx (Table 2). In the fifth case (case 11), direct laryngoscopy confirmed the laryngeal atresia, and then tracheotomy was performed. In all cases of tracheotomy, the baby was completely removed from the uterine cavity and placed on an adjacent sterile stand to give better access for airway management. There were no other criteria for doing so, and this was essentially due to surgeon preference.

The child with severe retrognathia (case 12) deserves special discussion regarding the tracheotomy procedure. This child had been identified antenatally as having severe retrognathia, and an EXIT with tracheotomy was planned. Once the hysterotomy had been performed, it became evident that the umbilical cord was too short to allow the baby to be maneuvered into an appropriate position for tracheotomy. Direct laryngoscopy was performed without successful visualization of the larynx. Accordingly, the decision was made to cut the cord and perform an emergent tracheotomy off placental support.

Generally, babies who required tracheotomy did poorly, whereas those who were intubated orally did well (Table 2). Of the patients with neck masses, all but one who required a tracheotomy died despite the airway being secured successfully. One died from complications of prematurity (case 3), one died because the thoracic component of a massive teratoma resulted in severe pulmonary hypoplasia (case 4), and one went into asystole after the airway was secured and the cord was clamped, resulting in anoxic injury and subsequent withdrawal of care 2 months later (case 5). Conversely, most neonates who were intubated orally survived with no long-term complications.

Exceptions to the aforementioned generalizations are worth noting. The infants with CDH, despite being expeditiously orally intubated, both succumbed to overwhelming pulmonary hypertension, one at 6 weeks of age and after 2 weeks on extracorporeal membrane oxygenation and the other at 2 days of life (cases 7 and 10, respectively). Another exception, the infant with laryngeal atresia, necessarily underwent tracheotomy in the delivery suite and has done well from a physical standpoint with 12 years of follow-up, although he has demonstrated prolonged aversion to oral intake, which he is gradually overcoming.

Delivery and anesthetic characteristics

Procedures lasted between 30 and 65 min, with times on placental support ranging from 2 to 37 min (Table 3). Mothers tended to stay postoperatively for 4 days, which is typical of patients after a cesarean section (CS) at our institution. At our institution, we prefer uterine clamps, rather than staplers, for hemostasis at the site of hysterotomy, and average blood loss was 883 mL. Only one mother had a significant fall in her hematocrit and required a transfusion of two units (case 6). Early in our series, one neonate was delivered vaginally, and tracheotomy was performed while on placental support (case 11). This was due to parental wishes expressed during prepartum discussion regarding the extent of measures to be taken for their newborn. Given that our goal was to evaluate the safety of hysterotomy carried out for a procedure on placental support, this case is not included in Table 3. Furthermore, because case 12 was essentially a normal CS without an intervention on placental support, we have also excluded this case from Table 3.

Women were reviewed in the antenatal period by the anesthesia team to evaluate the mother's airway for intubation

Table 1 **Maternal and prenatal characteristics**

Case	Temporal quartile	Maternal age, gravidity, and parity	Karyotype	Gestational age at diagnosis (weeks)	Fetal imaging results	Amniotic fluid
1	2nd	26 G1 P0	Normal	24	8×7×7 cm left neck mass with significant airway compression and mandibular distortion	Normal
2	1st	39 G3 P2	No data	34	6×5×4 cm neck mass descending to mediastinum with airway compression	Polyhydramnios
3	2nd	21 G2 P0	No data	14	10×9×9 cm cystic oropharyngeal mass	Polyhydramnios (amnioreduction at 28 weeks)
4	2nd	32 G3 P2	Normal	18	12×7×5 cm cervical mass extending to upper mediastinum and causing hyperextension of the head. Rapid growth with some involution seen by 36 weeks	Polyhydramnios (amnioreduction at 28 weeks)
5	1st	38 G5 P3	Normal	21	9×6×11 cm mass with intrathoracic extension and mediastinal shift	Polyhydramnios
6	3rd	32 G2 P0	Declined	18	5×5×5 cm right neck with infiltrative extension into the right thorax	Normal
7	4th	23 G1 P0	Normal	19	Left CDH. LHR 0.81, o/e LHR 27%	Normal
8	3rd	33 G2 P1	Declined	41	11×7×6 cm left lateral neck mass, macrosomia, and head deflexed	Normal
9	4th	33 G2 P1	Normal	18	10×10×9 cm left cystic and solid neck mass with patent trachea and oropharynx	Normal
10	4th	30 G1 P0	Normal	22	Left CDH. LHR 0.9, o/e LHR 27%	Polyhydramnios
11	1st	22 G2 P1	No data	20	Complete laryngeal atresia but normal diaphragmatic contour indicating a likely tracheoesophageal fistula	Normal
12	3rd	30 G2 P0	Normal	22	Severe retrognathia, low set ears, and intrauterine growth retardation	Polyhydramnios

Quartile indicates when in the study the case occurred, with the first quartile being earliest and the last quartile being latest.
AFP, α-fetoprotein; LHR, lung–head ratio; o/e LHR, observed-compared-to-expected lung–head ratio.

Table 2 **Fetal characteristics and postnatal outcomes**

Case	Sex	Pathology	APGAR 1 min	APGAR 5 min	Airway management	Postnatal course	Extubation/ decannulation	Long-term outcome
1	Male	Neck teratoma	2	8	Oral intubation	DOL 3 – neck dissection to remove mass	POD 6	No long-term abnormalities or complications
2	Male	Venous malformation	6	7	Oral intubation	DOL 8 – neck dissection to remove mass – Horner's syndrome postoperatively	POD 8	No long-term abnormalities or complications
3	Female	Oropharyngeal teratoma	1	2	Tracheotomy	DOL 1 – excision of oropharyngeal teratoma DOL 3 – death secondary to bronchopulmonary dysplasia	N/A	Death
4	Female	Neck and thoracic teratoma	1	0[a]	Tracheotomy	Death at delivery due to pulmonary hypoplasia	N/A	Death
5	Female	Lymphovenous malformation	4	0[a]	Tracheotomy	Cardiac arrest at 5 min after cord clamped DOL 8 – Neck dissection to remove mass	N/A	Withdrawal of care at age 2 months secondary to anoxic brain injury
6	Female	Lymphatic malformation	5	8	Oral intubation	DOL 75 – neck dissection to remove mass	DOL 1	No long-term abnormalities or complications
7	Male	CDH, endotracheal balloon occlusion × 8 weeks	2	3	Oral intubation	Balloon removed without difficulty	N/A	Severe pulmonary hypertension and withdrawal of care at age 6 weeks
8	Female	Lymphatic malformation	7	9	Oral intubation	DOL 3–5 – sclerotherapy × 3	DOL 5	No long-term abnormalities or complications
9	Male	Cervical teratoma	2	8	Oral intubation	DOL 5 – left neck dissection to remove mass	POD 5	Occupational therapy required for feeding issues related to mandibular dislocation
10	Female	CDH, endotracheal balloon occlusion × 8 weeks	1	3	Oral intubation	Balloon removed without difficulty	N/A	Severe pulmonary hypertension and withdrawal of care at DOL 2
11	Male	Complete laryngeal atresia, TEF	No data	No data	Tracheotomy	DOL 5 – TEF repair, LTR × 3	N/A	Tracheotomy dependent. Gastrostomy tube dependent × 10 years, now taking PO feeds. No other abnormalities
12	Male	Severe retrognathia, Pierre Robin sequence, unspecified syndrome	4	8	Tracheotomy	DOL 15 – TEF repair	N/A	Tracheotomy and gastrostomy tube dependent, globally delayed

DOL, day of life; N/A, not applicable; POD, post-op day; TEF, tracheoesophageal fistula; CDH, congenital diaphragmatic hernia; LTR, laryngotracheal reconstruction; PO, per os.
[a]Patient was actively being resuscitated.

Table 3 Summary of the placental bypass procedures

Case	Gestational age at delivery (weeks + days)	Total procedure time (min)	Time on placental support (min)	Drop in Hb (g/L)	Drop in Hct	EBL (mL)	Hospital stay (days)
1	38 + 1	31	2	39	0.09	800	4
2	37 + 5	nd	8	5	0.01	1000	nd
3	28 + 5	nd	15	20	0.06	550	5
4	34 + 1	64	37	4	0.01	700	4
5	37	60	17	nd	nd	1200	4
6	38 + 3	30	7	74	0.22	nd	4
7	36 + 3	40	8	31	0.09	800	4
8	41 + 2	31	2	29	0.09	800	3
9	36 + 6	11	7	28	0.08	1200	5
10	37	65	14	43	0.12	900	3

Hb, hemoglobin; Hct, hematocrit; EBL, estimated blood loss; nd, not documented.

and prepare for a delivery under a nonconventional anesthetic modality (general anesthesia). Induction was typically with a modified rapid sequence induction using sodium pentothal or propofol, succinylcholine, and a narcotic. The volatile anesthetic used was either desflurane or sevoflurane at supra-anesthetic concentrations until the umbilical cord was clamped. Table 4 summarizes relevant anesthetic data.

COMMENT

We have presented a case series of 12 infants who received airway management in the perinatal period, 11 while on placental support, and one for whom it was planned but was not possible because of a very short umbilical cord. When combined with six cases previously reported from our center,[13] this represents one of the largest series of head and neck abnormalities requiring perinatal airway intervention.

Otolaryngologic airway concerns and perinatal outcome

Although formal statistical analysis is precluded by the small sample size, the children in our series follow a bimodal distribution with regard to outcome. They tend either to do well with no long-term sequelae or to expire in the perinatal period. Five babies in the current series and two from the previous series died in the perinatal or neonatal period. Of these, four were related to the effect of the lesion on the lungs (pulmonary hypoplasia, pulmonary hypertension, or pulmonary hemorrhage[13]). In the other three, mortality was a result of concomitant cardiopulmonary comorbidities (cardiac arrest, bronchopulmonary dysplasia of prematurity, and single cardiac ventricle[13]). All of these babies died despite an airway being secured at the time of birth. Although we feel that comorbidities were most responsible for death in these cases, we cannot exclude the possibility that the additional stress of surgically managing the airway itself played a role. Unfortunately, our recorded data of fetal heart rate and blood gases are incomplete and cannot support or detract from this assertion. Rescue of these patients depends not only on overcoming the airway obstruction but also on fetal comorbidities and possible complications attendant to the procedure. All three of these points should be raised in prenatal counseling.

Babies who could be intubated orally tended to do well, whereas those who required tracheotomy did poorly. A similar trend has been seen in other series.[11] The need for a tracheotomy may be indicative of a larger mass, and thus, this may not be surprising. Large masses that extend into the thorax can cause pulmonary hypoplasia or profuse bleeding during intubation attempts. Large tumors can also significantly alter fetal cardiovascular physiology leading to cardiomyopathy,

Table 4 Anesthetic summary for *ex utero* intrapartum treatment procedures

Parameter	Summary
Type of anesthesia administered	6 GA + regional
	4 GA only
Type of volatile anesthetic used	4 Desflurane
	6 Sevoflurane
Maximum MAC used for uterine relaxation – mean (SD)	1.8 (4)
Time in operating room – mean (SD) minutes	110 (31)
Time from uterine incision until cord clamp – mean (SD) minutes	16 (9)
Extra monitors	2 cases – invasive arterial blood pressure monitor

GA, general anesthesia: regional, spinal, or epidural anesthesia; MAC, minimum alveolar gas concentration to inhibit 50% of population moving to surgical stimulation; SD, standard deviation.

valve abnormalities, and even hydrops.[14] Alternatively, increased time on placental support itself may lead to worse outcome. Additionally, we performed our tracheotomy procedures with the neonate fully delivered, which may deliver less reliable placental support than partial delivery.

The fact that babies who required tracheotomy did poorly suggests that those babies who most need EXIT in the setting of head and neck masses are those with the worst outcome. The decision to proceed with EXIT is necessarily made before the newborn is given a trial of spontaneous ventilation without intervention. Although such decisions are a result of multidisciplinary review, they are subjective and based on the collective experience. Consequently, it is impossible to know which neonates who underwent EXIT to secure the airway truly required it and who would have been able to breathe adequately without intervention. One approach to this problem is the newly described tracheoesophageal displacement index, an objective method that has been proposed to try and predict neonates that require intervention on placental support.[15] The future of this field will benefit from studies correlating outcomes with prenatal imaging characteristics to better indicate when to proceed with EXIT.[16]

Two patients in our series with CDH underwent EXIT to remove fetoscopically placed tracheal balloons after percutaneous puncture attempts failed. Both succumbed to overwhelming pulmonary hypertension. Even with tracheal occlusion, infants born with a similar degree of pulmonary hypoplasia to that seen in our patients have a mortality rate of approximately 50%.[17] Additionally, animal studies demonstrate that relief of tracheal occlusion performed weeks before delivery allows better development of type II pneumocytes, whereas relief at the time of delivery leads to decreased number of these pneumocytes.[18] Accordingly, neonates such as those in our series who have their tracheal balloons removed at delivery might have a worse prognosis compared with neonates whose balloons were removed fetoscopically or by ultrasound-guided percutaneous needle puncture prior to delivery.

Maternal–fetal considerations

The maternal characteristics in our series were varied. There were no trends in terms of maternal age or parity, bearing in mind the small sample size. As expected, karyotypes, when performed, were normal. Isolated head and neck malformations such as those presented here are not associated with chromosomal abnormalities. There was a high incidence of polyhydramnios (50% of cases with neck masses). Polyhydramnios is common in the setting of large head and neck masses and arises from the inability of the fetus to swallow amniotic fluid.[19] Fetuses with polyhydramnios tended to do worse than those without in this and our previous series. This is likely because polyhydramnios is reflective of a larger, more internally disruptive mass, with greater potential for cardiopulmonary effects. Polyhydramnios has been associated with a higher level of complications during delivery and a greater need for neonatal intensive care unit care after delivery.[20] Thus, the presence of polyhydramnios should alert the perinatal airway management team of a potentially higher risk of complications.

In cases 3 and 4, delivery was premature and unplanned. Accordingly, the perinatal airway management team was assembled on an urgent, rather than planned, schedule. Even though both babies died in the neonatal period, we do not feel that the urgent nature of these deliveries affected the neonatal outcomes. In case 3, the extreme prematurity resulted in bronchopulmonary dysplasia that ultimately caused the demise of the patient. In case 4, demise was secondary to pulmonary hypoplasia caused by the effect of the mass. Neither case was the result of poor team coordination or failure to secure the airway.

In the current and previous series from our institutions, there were no maternal complications; however, one mother in this series did suffer significant blood loss and required a transfusion. Given the caveat of small sample size, this 10% rate of significant blood loss is higher than would be expected from standard CS cases. Overall, average blood loss and hospital stay were not significantly different from regular CS cases at our institution or from those in previously published series.[7] Although there were no short-term complications, we did not collect long-term data or information on subsequent pregnancies. Future work may define the risks of subsequent pregnancies in women who have had EXIT.

Anesthetic considerations

The intraoperative goals of the anesthesiologist are to maintain the fetal–placental circulation, which requires adequate uterine relaxation, prevention of breathing until the airway is secured, and maintenance of uterine perfusion pressure. The usual routine of regional anesthesia for cesarean delivery does not prevent myometrial contraction following uterine incision; therefore, these patients are anesthetized under general anesthesia and maintained on high concentrations of volatile anesthetics to keep the uterine myometrium relaxed and to maintain the uteroplacental perfusion until the airway is secured. Intraoperative blood loss is increased under general anesthesia, so it is important to prepare patients appropriately for fluid resuscitation and potential blood transfusion. Another goal of maternal care during this period is maintaining normal acid–base balance, often requiring serial blood gas monitoring during the case to allow adjustment of positive pressure ventilation. Lastly, all anesthetic agents except for nondepolarizing muscle relaxants cross the placenta and may provide some element of fetal anesthesia; however, it may not be adequate for the stimulation of a surgical airway procedure. If needed, paralytic and analgesic medications can be given directly to the fetus via the umbilical cord. To date, we have not had to use this approach. The unique characteristics of anesthesia required for prolonged placental support of the fetus mandate that an anesthesiologist familiar with these procedures be involved.[21]

Synthesis and the multidisciplinary approach

Since our initial report of our experience with procedures on placental support,[13] we have endeavored to improve our efficiency and preparedness with respect to these cases. Improvements and increased use of prenatal MRI and ultrasound have helped in the identification of these

patients.Furthermore, we have made efforts to formalize our multidisciplinary airway team and protocol.

The multidisciplinary perinatal airway team at the University of Toronto is a collaborative effort led by members from the Department of Otolaryngology – Head and Neck Surgery and the Maternal–Fetal Medicine Unit. Members from the Departments of Anaesthesia, Neonatology, Critical Care, and Paediatric Surgery are also involved. A standardized set of procedures outlining which team members should be present, what equipment is needed, and an airway management algorithm has been developed. Cases are discussed at multidisciplinary conferences, and our goal is to have a controlled delivery with all the key team members present. Appropriate equipment to manage the perinatal airway including laryngoscopes, bronchoscopes, telescopes, endotracheal tubes, and a tracheotomy set is open and available at the time of delivery.

The rare situation resulting from an abnormally short umbilical cord in a syndromic patient demonstrates how an unexpected event can pose a challenge even when all appropriate planning and preparation steps have taken place. To us, this highlights the importance of multidisciplinary rehearsal and contingency planning. In anticipation of technically challenging cases, such as the removal of the tracheal balloon, we have performed simulations in the surgical skills laboratory in order to ensure that all members of the team were familiar with the flow of events, the necessary equipment, and the contingency plans. Furthermore, post-delivery conferences and debriefing sessions allow for continued improvement in coordination and technique.

Given the caveat of small sample size, it appears that despite our enhanced preparedness for neonatal airway cases in this series compared with our previous one, the perinatal outcomes have not necessarily improved. The most likely explanation for this is that the failure to secure an airway was not a cause for mortality in either series. Furthermore, as we have become more proactive in identifying potential EXIT candidates, we have become more aggressive in determining who will undergo EXIT. The fetuses in our current series demonstrate larger and more severe pathologies than those in the previous one. Future areas of improvement for the team include increased use of simulation, standardization of prepartum workup, and involvement of representatives of the nursing team in the planning conferences.

Although the majority of these patients do well, the risk of fetal morbidity or mortality remains high. Large neck masses that prevent oral intubation and lead to polyhydramnios seem to pose the greatest danger. We noticed a potential increased risk of maternal blood loss. Multidisciplinary team preparation and collaboration are crucial elements for a successful procedure on placental support and to achieve an optimal outcome for both mother and child.

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WHAT'S ALREADY KNOWN ABOUT THIS TOPIC?

- The approach to infants with potentially compromised airways requires multidisciplinary planning. Various centers have published their experience with compromised neonatal airway and proposed algorithms regarding its management. Here, we compare our outcomes before and after the institution of a formal multidisciplinary airway management team at the University of Toronto.

WHAT DOES THIS STUDY ADD?

- This is the first paper to examine fetal outcomes before and after the institution of an airway protocol for the infants at risk.

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