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Outcomes of Airway Management in Micrognathia and Retrognathia Patients Born at Fetal versus Nonfetal Centers

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Abstract
Objectives: There is a paucity of evidence to guide the perinatal management of difficult airways in fetuses with micrognathia. We aimed to (1) develop a postnatal grading system based on the extent of airway intervention required at birth to assess the severity of micrognathic airways and (2) compare trends in airway management and outcomes by location of birth [nonfetal center (NFC), defined as a hospital with or without an NICU and no fetal team, versus fetal center (FC), defined as a hospital with an NICU and fetal team]. ***Methods:*** We retrospectively reviewed the prenatal and postnatal records of all neonates diagnosed with micrognathia from January 2010 to April 2018 at a quaternary children's hospital. We developed a novel grading scale, the Micrognathia Grading Scale (MGS), to grade the extent of airway intervention at birth from 0 (no airway intervention) to 4 (requirement of EXIT or advanced airway instrumentation for airway securement). ***Results:*** We identified 118 patients with micrognathia. Eighty-nine percent (105/118) were eligible for grading using the MGS. When the MGS was applied, the airway grades were as follows: grade 0 (30%), grade 1 (10%), grade 2 (9%), grade 3 (48%), and grade 4 (4%). A quarter of micrognathic patients with grade 0–2 airways had postnatal hospital readmissions for airway obstruction after birth, of which all were born at NFC. Over 40% of patients with grade 3–4 micrognathic airways required airway intervention within 24 h of birth. Overall, NFC patients had a readmission rate of (27%) for airway obstruction after birth compared to FC patients (17%). ***Conclusions:*** Due to the high incidence of grade 3–4 airways on the MGS in micrognathic patients, fetuses with prenatal findings suggestive of micrognathia should be referred to a comprehensive fetal care center capable of handling complex neonatal airways. For grade 0–2 airways, infants frequently had postnatal complications necessitating airway intervention; early referral to a multidisciplinary team for both prenatal and postnatal airway management is recommended.

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Introduction

Micrognathia is a rare congenital abnormality characterized by an underdeveloped mandible [1]. Micrognathia can also be associated with retrognathia, which is another rare congenital anomaly defined as an "abnormal [posterior] position of the mandible" [2, 3]. The management of a micrognathic airway at birth can be challenging, especially in those with a concomitant diagnosis of Pierre Robin Sequence (PRS): a syndrome that includes micrognathia, glossoptosis (defined as a posteriorly displaced tongue), and a wide cleft palate [2, 4]. Airway management in patients with PRS is even more challenging with the additional high risk of extrinsic upper airway obstruction [4, 5].

Currently, prenatal diagnosis of micrognathia and retrognathia is conducted by fetal ultrasound. When the fetal ultrasound demonstrates concerning features of upper airway obstruction (related to their craniofacial abnormalities and tongue position), such as polyhydramnios, lack of signal in the airway, and an inability to visualize swallowing [6, 7], a third-trimester fetal MRI is recommended [8]. Fetal MRI will further delineate the airway, contributing to delivery planning [9].

The most common options for delivery of neonates with prenatally diagnosed severe micrognathia (causing significant airway obstruction) are cesarean sections with the otolaryngology (ENT) team on standby for airway management or an EXIT (ex utero intrapartum treatment)-to-airway [7]. An EXIT-to-airway procedure utilizes placental support for stabilization of the neonate's airway via a common progression of laryngoscopy, bronchoscopy, retrograde intubation, and/or tracheostomy, with retrograde intubation and/or tracheostomy as the last resort [4, 7, 10]. Currently, the suggested indication for the EXIT-to-airway procedure in fetal micrognathia is a jaw index >23 or evidence and/or sequelae of upper airway obstruction on prenatal imaging [4, 7, 10]. The fetal jaw index is calculated by dividing the anteroposterior mandibular diameter by the biparietal index and multiplying by 100, with concern for micrognathia with an index <23 or less than the fifth percentile [11]. However, the EXIT-to-airway is a resource-intensive procedure (involving the fetal team and advanced airway team: including ENT, pediatric surgery, and pediatric anesthesia on standby) with risks to the mother greater than the routine caesarian section, and, therefore, an EXIT should be reserved for appropriate cases, in which an EXIT is not an under- or over-triaged response to a patient's specific micrognathic findings.

Table 1. Cormack-Lehane grading system

Grading system	Airway findings
Grade 1	A full view of the glottis
Grade 2a	Only part of the cords are visible
Grade 2b	Only the arytenoids or very posterior origin of the cords are visible
Grade 3	Only the epiglottis is visible
Grade 4	No glottis structure is visible

Patients with micrognathia are at an increased risk for perinatal and postnatal airway complications, and the highest risk of an airway complication in neonates with micrognathia is within the first 24 h of life [6]. Successful airway management results in less or no perinatal hypoxemia, which can result if a baby is born with significant unrelieved airway obstruction. Furthermore, it is unknown if postnatal outcomes differ between patients with micrognathia and retrognathia born at fetal centers (FCs) versus nonfetal centers (NFCs).

In this study, we had the following primary aims: (1) develop a grading system to assess the severity of micrognathic airways and (2) compare postnatal outcomes in micrognathia patients by the location of birth (NFC vs. FC). The secondary aims of the study were to (1) describe the severity (using the jaw index) and grade of airways in prenatally and postnatally diagnosed micrognathic patients and determine if airway intervention by ENT is needed perinatally and (2) compare trends in airway management by delivery type (cesarean section vs. vaginal delivery) as well as by location (NFC vs. FC). We hypothesized that micrognathic patients with high grades of airway severity would have an increased rate of airway-related complications when delivered at NFC versus FC.

Materials and Methods

Setting

Children's Hospital Colorado is a quaternary pediatric referral center with a dedicated fetal care center that services Colorado and the adjacent 7 states of North Dakota, SD, western Nebraska, Kansas, NM, Wyoming, and Montana. This study was approved by the Colorado Multi-Institutional Review Board (COMIRB) with a waiver of informed consent.

Study Design

We performed a retrospective review of the Children's Hospital Neonatal Database at Children's Hospital Colorado between Janu-

Table 2. MGS of airway management after birth

Grading system	Airway management	Corresponding Cormack-Lehane score	Recommended algorithm choice
Grade 0	Airway is easily secured	N/A	No airway specialist (ENT) required at birth
Grade 1	Traditional intubation with direct laryngoscopy	CL1, CL2	No airway specialist (ENT) required at birth
Grade 2	Patient can be intubated via glidescope, mask-ventilated±use of the nasal trumpet; No advanced instrumentation needed	CL3	No airway specialist (ENT) required at birth
Grade 3	Patient has an unstable airway and requires advanced instrumentation for airway securement by ENT or anesthesia (institution dependent)	CL3, CL4	Recommend ENT standby
Grade 4	Surgical intervention and/or advanced instrumentation is required for airway securement (including tracheostomy)	N/A	Recommend EXIT procedure

N/A, not applicable; MGS, Micrognathia Grading Scale.

ary 2010 and April 2018. We included all patients with micrognathia or retrognathia identified by diagnosis code who were born at the Colorado Fetal Care Center or UC Health University of Colorado Hospital as well as all out-born neonates who were transferred to Children's Hospital Colorado with a diagnosis of micrognathia or retrognathia. We excluded neonates who underwent an EXIT-to-airway procedure for reasons other than retrognathia or micrognathia. The electronic medical record was interrogated, and clinically relevant prenatal and postnatal demographic and clinical variables were selected and analyzed.

A novel grading system for severity of airway management was developed by our multidisciplinary research team including pediatric surgery, pediatric ENT, and pediatric radiology. The Micrognathia Grading Scale (MGS) was developed by modifying the current Cormack-Lehane grading system which describes airway anatomy seen at intubation (Table 1) to include the type of airway intervention required as demonstrated in Table 2 [9]. The MGS was developed by reviewing each patient's postnatal charts retrospectively to evaluate how the airway was managed and correlated the grade of airway management with the Cormack-Lehane scores assigned to each patient by the ENT or anesthesia team. Grade 0 airways were considered airways that were secure at birth and achieved adequate oxygenation levels on room air or nasal cannula alone; patients with grade 0 airway did not require intubation or intervention. Grade 1 airways underwent traditional intubation with direct laryngoscopy. Grade 2 airways required intubation similar to grade 1 airways. The distinction between grade 1 and grade 2 airways is that grade 2 airways were not able to be secured with intubation with conventional means, and these patients required an addition of video laryngoscopy, mask ventilation, and/or nasal trumpet. Grade 3 airways were considered unstable, and they were insufficient for ventilation and oxygenation without advanced instrumentation. Finally, grade 4 airways received an EXIT or advanced surgical instrumentation for airway securement (including tracheostomy).

Statistical Analysis

Demographic and outcomes data are presented as means and standard deviations for continuous variables and frequencies and percentages for categorical variables. Continuous variables were tested for group differences using a Student's t test, and χ^2 testing was utilized for categorical variables. A significance level of $p \leq 0.05$ was used. The analysis was conducted using R version 3.6.1 software (R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/).

For analysis, we divided patients into 2 groups: those who underwent vaginal delivery and those who underwent cesarean section. A secondary sub-analysis was also conducted to compare patients by location of birth, NFC versus a FC. Both groups were compared based on the grade of airway intervention. We also compared postnatal outcomes between patients born at NFCs versus FCs.

Results

Demographics

Overall, 118 patients were admitted to our NICU, either immediately after birth or in a separate hospital admission after birth, with a diagnosis of micrognathia and/or retrognathia during the study period. There were inadequate data in the charts of 14 patients, and as a result, airway grading was not feasible on those patients. A total of 82 patients were born at NFC and 36 were born at FC. Of the patients who were prenatally diagnosed, the average gestational age at diagnosis was approximately 28 weeks. At birth, the average gestational age of all study patients was 37 weeks. Approximately, 40 percent of study patients had PRS on clinical diagnosis. Demographics are shown in Table 3.

Grade of Airway Intervention

We used the MGS to evaluate the severity of airways. Patients with grade 0 airways underwent vaginal delivery

Table 3. Comorbidities affecting airway management in micrognathia patients

Demographics	$N = 118$
Gender, female	60 (50.8%)
Gestational age at birth, median	38.0 [31.0, 41.0]
Comorbidities, *n* (%)	
Pierre Robbin syndrome	48 (40.7)
Laryngomalacia	26 (22.0)
Tracheomalacia	25 (21.2)
Choanal atresia	5 (4.3)
Congenital diaphragmatic hernia	4 (3.4)

Table 4. Comparison of airway management by delivery type and location of delivery

Grade of airway	Mode of delivery, $p = 0.61$		Location of birth, $p = 0.08$	
	C-section, $n = 51$ (%)	vaginal delivery, $n = 67$ (%)	NFC, $n = 82$ (%)	FC, $n = 36$ (%)
Grade 0	11 (21.6)	21 (31.3)	25 (30.5)	7 (19.4)
Grade 1	4 (7.8)	6 (9.0)	5 (6.1)	5 (13.9)
Grade 2	3 (5.9)	6 (9.0)	8 (9.8)	1 (2.8)
Grade 3	22 (43.1)	28 (41.8)	35 (42.7)	15 (41.7)
Grade 4	3 (5.9)	1 (1.5)	1 (1.2)	3 (8.3)

Advanced airway intervention includes fiberoptic intubation, nasopharyngeal airway, supraglottic airway, and tracheostomy. EXIT, ex utero intrapartum treatment; OSH, outside hospital; NFC, nonfetal center hospitals; FC, fetal center.

Table 5. Comparison of outcomes by FC versus NFC

Complications	NFC, $n = 82$ (%)	FC, $n = 36$ (%)	*p* value
Readmission for airway obstruction	21 (26.6)	5 (17.2)	0.2277
NICU length of stay, mean, SD	30.8 (32.0)	35.4 (33.5)	<0.0001
Death	6 (7.3)	7 (19.4)	0.0630
Encephalopathy	9 (11.0)	4 (11.1)	1.0000
Hypoxia	42 (51.2)	15 (41.7)	0.4243
Failure to thrive	57 (69.5)	18 (50.0)	0.0377

NFC, nonfetal center hospitals; FC, fetal center; SD, standard deviation.

or cesarean sections (31 vs. 22%). Forty-three percent of patients who underwent vaginal delivery required neonatal airway intervention for grade 3 or 4 airways on the MGS, and the majority of these patients did not have a known prenatal diagnosis of micrognathia. These results are demonstrated in Table 4.

Subsequently, we conducted a comparison of airway management by location of birth at NFC versus FC. As anticipated, we found that a higher percentage of patients had grade 0 airways at NFC (31 vs. 19%). Approximately, 44% of patients born at NFC had grade 3 or 4 airways at birth or at time of transfer. The percentage of grade 3 and 4 airways was comparable at NFC to FC (44 vs. 50%). There was one patient with a grade 4 airway who was born at an NFC and was transferred emergently to a FC for acute respiratory distress and unstable airway; an emergent tracheostomy was recommended for this patient. The remainder of the results is shown in Table 4.

Association between the Jaw Index on Prenatal Imaging and Postnatal Outcomes

Only 17 patients had prenatal imaging, either ultrasound or MRI, at our institution. In general, patients with higher grade airways [3, 4] were more likely to have prenatal imaging than those with lower grade airways (0–2). Among the study patients who had prenatal imaging, only three patients had a jaw index <23; of those 3, one had a grade 2 airway, one a grade 3 airway, and one a grade 4 airway. Of note, only one patient with a jaw index <23 received an EXIT-to-airway procedure. Prenatal imaging from the outside hospitals was not available for evaluation.

Postnatal Outcomes in Nonfetal Centers versus Fetal Centers

Subsequently, we compared postnatal outcomes of neonates born at NFC to those born at FC (Tables 5, 6). In our analysis, we found that the rate of readmission for airway obstruction in neonates was 27% at NFC and 17% at FC. There were also higher rates of failure to thrive (70 vs. 50%, $p = 0.037$) in the NFC group compared to the FC group.

Overall, we found that 41% (48/118) of all patients ultimately received mandibular distractions for airway management, of which only 17% (8/48) had prenatal imaging. Approximately, one-third of patients admitted at our hospital for airway obstruction after birth required mandibular distractions, and all these patients were born at NFC.

Last, we compared postnatal outcomes by grade of airway severity. We found that, overall, at FC and NFC, low-

Table 6. Correlation of grade of airway with clinical outcomes

Grade of airway	Abnormal jaw index (<23) on MRI	EXIT	Airway intervention within 24 h	Readmission for airway obstruction	Mandibular distraction	Death
Grade 0, *n* = 32 (%)	0 (0.0)	0 (0.0)	0 (0.0)	8 (25.0)	4 (12.5)	0 (0.0)
Grade 1, *n* = 10 (%)	0 (0.0)	0 (0.0)	6 (60.0)	3 (30.0)	3 (30.0)	2 (20.0)
Grade 2, *n* = 9 (%)	1 (11.1)	0 (0.0)	2 (22.2)	2 (22.2)	5 (55.6)	1 (11.1)
Grade 3, *n* = 50 (%)	1 (11.1)	0 (0.0)	20 (40.8)	7 (14.3)	33 (67.3)	4 (8.2)
Grade 4, *n* = 4 (%)	1 (25)	3 (75.0)	4 (100.0)	00 (0.0)	2 (50.0)	2 (50.0)

grade airways (0–2) had high rates of readmission for airway obstruction ranging from 22 to 30%. There were also elevated rates of hypoxia and failure to thrive in lower grade airways. The mortality rate was highest in higher grade airways [3–5].

Discussion

Currently, there is limited literature on the management of patients presenting with micrognathia and retrognathia at birth. In a recent survey of craniofacial surgeons, there was noted heterogeneity in the surgical management of the airways of patients with micrognathia and PRS among providers [12]. Present studies recommend consideration of cesarean section and an EXIT-to-airway procedure for airway management of severely micrognathic patients [4]. The EXIT-to-airway procedure may be necessary in severe cases of micrognathia; however, there is limited literature on the efficacy of prenatal indices such as the fetal jaw index and polyhydramnios in predicting the severity of airway obstruction at birth and ultimate need for an EXIT-to-airway procedure [7]. In our study, we found that only one patient out of three with abnormal jaw indices (<23) required an EXIT-to-airway procedure. The grading of airway in patients with micrognathia should not solely consist of the jaw index as it does not necessarily predict the requirement for perinatal intervention. Our findings emphasize the need for additional objective prenatal imaging measures to evaluate the severity of airway obstruction.

Herein, we developed a grading system to objectively measure the severity of airways in micrognathic patients (Table 2). In our study, we identified that micrognathic and retrognathic patients have high rates of complex airways, specifically grades 3 and 4 by the MGS. A high proportion of the patients with micrognathia and retrognathia were born at NFCs. This underscores an area for quality improvement regarding prenatal diagnosis and delivery planning with pediatric ENT or pediatric surgery on standby to manage these complex airways at birth.

The MGS was developed based on postnatal airway intervention with the hope that future studies can validate the measure and incorporate prenatal imaging findings to inform the airway management algorithm. Future studies are necessary to identify additional prenatal imaging findings indicative of the severity of airway obstruction and develop a prenatal scale for the severity of airway in patients with micrognathia and airway obstruction. We propose that the prenatal imaging findings suggestive of a grade 0 or 1 airway include polyhydramnios and the lack of visible fluid column in the airway via ultrasound or MRI in the airway. For grade 0–2 patients, we suggest early referral to a Level IV NICU with a complex airway team for management of postnatal airway complications and future interventions as over 40% of patients born at NFC were admitted after discharge to our hospital for airway obstruction and required mandibular distraction to stabilize the airway long-term (Table 4).

Advanced airway expertise may not be necessary at birth for low-grade MGS patients but may be necessary for postnatal interventions such as mandibular distraction. Urgent admissions after birth for airway obstruction in our cohort could have potentially been avoided with evaluation by pediatric ENT during the index admission and close follow-up with a planned mandibular distraction. We also found that lower grade airways born at NFC had higher rates of hypoxia and failure to thrive, and that majority of patients with low-grade airways were born at NFC. Prenatal imaging findings including a jaw index <23, polyhydramnios, lack of fluid column in the airway, lack of visualized swallowing, absent stomach, and other signs of airway obstruction may be associated with higher grade airways (MGS grades 3–4). We recommend that these patients be referred to a FC prenatally for delivery as expert airway assistance by pediatric ENT or pediatric surgery will be expected for successful airway management at birth. Not all MGS grade 3–4 patients will need an EXIT-

to-airway, but most will require advanced airway intervention with ENT before their discharge to home.

There are multiple limitations to our study. First, we were limited in our ability to evaluate the effectiveness of the grading system using prenatal imaging findings as only a few patients had prenatal studies available for analysis. Second, this study was a retrospective review and only included one FC which could skew the population sample. Last, the grading system we developed is only applicable after retrospective review of the patients' charts, and some patients were missing details on postnatal airway management necessary for grading. Future goals would be to use prenatal imaging characteristics and patient characteristics to develop a prenatal grading system for severity of micrognathic airways and ultimately create an algorithm for airway management based on these findings.

We recommend consideration of the use of the MGS to objectively measure the severity of the micrognathia and resultant airway obstruction. We suggest that patients with micrognathia and retrognathia be evaluated by a multidisciplinary team for delivery planning and determining the level of anticipated airway management that will be required. We believe that the MGS can be used by FCs and pediatric hospitals to establish a standard way to evaluate the severity of micrognathia, and ultimately, the development of a prenatal tool to improve care for these patients. In the future, this grading system could be used as a quality measure to objectively compare outcomes between FCs, determine the most appropriate delivery plan of care for airway management, and optimize resource utilization.

Statement of Ethics

Our research complies with the guidelines for human studies and was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. Approval for this study was provided by the Colorado Multi-Institutional Review Board (COMIRB/IRB is 19-0792) with a waiver of written consent from patients and their families.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Study conception and design: Niti Shahi, Peggy Kelley, and Ahmed Marwan. Data acquisition: Niti Shahi, Ryan Phillips, and Maxene Meier. Analysis and data interpretation: Niti Shahi, Ryan Phillips, Mariana Meyers, Theresa Grover, Henry Galan, Michael Zaretsky, Peggy Kelley, and Ahmed Marwan. Drafting of the manuscript: Niti Shahi, Ryan Phillips, Mariana Meyers, Theresa Grover, Henry Galan, Michael Zaretsky, Peggy Kelley, and Ahmed Marwan. Critical revision: Niti Shahi, Ryan Phillips, Mariana Meyers, Theresa Grover, Henry Galan, Michael Zaretsky, Peggy Kelley, and Ahmed Marwan.

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