**Using Electrical Impedance Tomography to Evaluate the Effect of Positioning in Neonates with Congenital Diaphragmatic Hernias**

Primary Investigator: Dr Judith Hough

Co-investigator: Dr Luke Jardine

Honours student: Abby McCullagh

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1. **Introduction**

Congenital diaphragmatic hernia (CDH) is a condition requiring immediate medical and multidisciplinary management, including physiotherapy. Positioning is a commonly used physiotherapy technique supported by the literature. However, the extent of its improvement on the respiratory system is unknown due to the limitations of the measuring equipment. Current measuring tools lack the ability to detect regional changes in the lungs. Electrical impedance tomography (EIT) has shown to be safe and effective in other areas of the healthcare system but has not been used for infants with CDH. This study will use EIT to assess the effectiveness of positioning in infants with CDH.

1. **Background**

Each year, 120 babies are born with CDH; a condition in which during gestation a hole is formed in the diaphragm causing invasion of abdominal organs into the thoracic cavity (*CDH Diagnosis* 2023). As a result, these babies have significant gastrointestinal, neurological and in particular cardiorespiratory compromise due to the compression of the heart and lungs resulting in tissue hypoplasia(Van Den Hout et al., 2009).

Due to the compression on the lungs, there is less branching of bronchi and alveoli, surfactant, and delayed epithelium maturity leading to less surface area for gas exchange (Tiwari et al., 2022). The herniations usually occurs on one side, however, can occur bilaterally. As a result of this, there is uneven ventilation distribution between the lungs indicated by a V/Q mismatch (Xu et al., 2021). Consequently, the infant has decreased oxygen in the blood requiring immediate intervention.

These patients require surgery to correct the defect. However, positioning is used to improve oxygenation both pre and post operatively. Effects of positioning have been reported in similar populations with respiratory distress such as prematurity and ventilated infants (Balaguer et al., 2013; Cheraghi et al., 2020; Gouna et al., 2013).

Measuring the effect of positioning is commonly performed through auscultation, oxygenation index, arterial blood gas (ABGs), oxygen saturations and chest wall observation and palpation (Gong et al., 2015; Horn-Oudshoorn et al., 2022). These measures evaluate the global oxygenation rather than regional areas of the lungs. The literature has described these measures as delayed, inaccurate and generalized (Davies et al., 2019). These measures lack the ability to detect where ventilation distributes regionally and often require invasive needling (ABGs). Other commonly used equipment exposes infants to harmful radiation, invasive procedures, lack either temporal or special high resolution or cannot be applied at the bed side (Davies et al., 2019).

EIT is a measuring tool that is non-invasive, bedside-friendly, and can continuously provide data on the distribution of ventilation (Martins et al., 2019). A belt is positioned around the chest and whilst the patient breaths spontaneously or assisted, the impedance of electrical signals are monitored and documented using specialised software (Gaertner et al., 2023). The data presents in both a visual and numerical representation particularly highlighting regions in the lungs air has travelled to (Martins et al., 2019).

EIT has been shown to be a validated tool in measuring regional lung volumes. Positioning has been shown to be an effective intervention in neonates with respiratory compromise but the extent of its effectiveness in infants with CDH is unknown. As such this study will use EIT to measure and track the distribution of ventilation in infants with CDH placed in different positions.

Through investigating the practicality and applicability of EIT in this specific population, a thorough understanding of the impact positioning has on infants with CDH can be achieved. This will generate a more individualised treatment plan depending on the infants’ specific impairments; decreasing duration of stay and creating a more cost-effective environment and procedures to improve the health care of infants with CDH.

* 1. ***Hypothesis:***

EIT will show changes in the pattern of ventilation distribution with position changes in infants with CDH.

1. **Aims**

To evaluate the effect of positioning on the regional distribution of ventilation in the dependant and non-dependant lungs of infants with CDH

1. **Study Design**

This will be a cohort study to allow relevant patterns of data to be collected.

1. **Methods** 
   1. ***Participants***

Participants will be approached for the study once diagnosis has been made. All participants will be in the Neonatal intensive care unit (NICU) of the Mater Mothers hospital, Brisbane.

The inclusion criteria allow for the largest number of participants available to be involved. The exclusion criteria, ensures that co-morbidities will not interfere with the accuracy of the data and that infant care will remain the priority.

* + 1. *Inclusion Criteria*
* Age less than or equal to 12 months
* CDH diagnosis
* Parents/ guardians given informed consent.
  + 1. *Exclusion Criteria*
* Infants with associated anomalies that would directly affect postnatal outcome.
* Infants with associated disease or conditions compromising the cardiorespiratory system other than CDH.
* Infants with fragile skin conditions at risk of skin breakdown from the EIT belt.

1. **Measurement Procedures** 
   1. ***EIT***

The Sentec LuMon electrical impedance tomography monitor will be used to assess the ventilation distribution. EIT belt will be placed around the chest at nipple level. Measurements will be taken continuously. Any ventilatory changes made will be documented. The EIT belt exerts an electrical current and the resultant voltages are measured, enabling calculation of, end expiratory lung volumes (EELV; measuring relative impedance of electrical currents at the end of expiration), amplitude values (change in aeration per pixel between the end expiratory and end inspiratory lung impedance), overall aerated lung volumes (Aer%; as indicator of overall lung volume), aeration homogeneity ratio (AHR; as indicator of aeration similarity between lungs), coefficient of ventilation (CV; as indicator of ventilation homogeneity), the centre of ventilation (CoV; as representation of aeration in the horizontal and vertical planes) and the dependant and non-dependant silent spaces (SSGD, SSNGD;as indicators atelectasis and overdistension in regions of the lungs) (Gaertner et al., 2023).

* 1. ***Lung Ultrasound***

Lung ultrasound (LUS) has been stated in the literature to be clinimetrically sensitive to the spatial and temporal changes in lung volumes. LUS will be used in conjunction with EIT to assess ventilation distribution and lung function. LUS cannot be used in isolation as it can detect consolidations and fluids in the chest wall but cannot quantify regional lung volumes (Gaertner, 2023). Clinicians with experience in lung and heart ultrasonography will perform the measurements. The standard NICU equipment and a 10-MHz linear prone will be used parallel or perpendicular to the ribs. The measurements will be taken in designated position for 2 minutes. Three lung areas will be measured limited by the fifth intercostal space and the anterior and posterior axillary lines on both sides.

* 1. ***Physiological Parameters***

To assess cardiac involvement, pre- and post-ductal oxygen saturations will be performed along with transcutaneous oxygenation and arterial blood gas analysis (already measured for medical advisement). Other values taken from the bed or ventilator monitor include, heart rate, positive end expiratory pressure, tidal volume, frequency, fraction of inspired air, end tidal carbon dioxide, respiratory rate and blood pressure. These values will be monitored throughout the study and used to evaluate the infant’s improvement.

1. **Study Procedure** 
   1. ***Recruitment***

All parents/ guardians of infants with CDH admitted to the Mater Mothers Hospital will be approached by a research team member and provided with an information and consent form. The parents will have 48 hours to make an informed decision to participate in the project and provide consent.

* 1. ***Deidentification***

Once consent is obtained and forms scanned and secured, deidentification of patient information will occur in which original forms will be secured off site.

* 1. ***Preoperative Assessment***

Patients will be medically assessed and managed to stabilize their condition prior to surgery. During this time, patient demographics will be taken including gestational age and weight, gender, side of herniation, presence of liver herniation, presence of pulmonary hypertension, mode of ventilation, ventilator settings, APGAR score, umbilical artery pH, level of sedation and lung to head ratio. LUS and EIT will be performed for pre-operative assessment.

**7.4 *Surgical intervention***

Once the infant is stabilized the infant will go to theatre for surgical intervention and the EIT belt will be placed on the infant again.

***7.5 Measurements:***

EIT belt will be left on the infant and data will be continuously measured. Data will be analysed after routine position changes immediately, at 30 minutes, 1 hour, 2 hours and 6 hours. This will be done pre and post operation and after extubation. The belt will be removed for LUS measurements that will be performed during routine changes with time and position documented.

1. **Removal of participants**

Removal of the participants may occur any time during the study. Reasons for removal of participants may include:

* + Parent request
  + Suspicion of adverse event
  + Infants condition worsening
  + Adverse reaction to study
  + Other co-morbidities found resulting in exclusion to the study.

Caregivers may verbally withdraw and will be given a withdrawal consent form in which they will choose whether the current data already taken can be used. Opting to remove their child from the study will not alter care given to the infant.

1. **Safety reporting** 
   1. ***Adverse Events***

Adverse events during this study are likely to be due to the nature of CDH and it’s invasive and aggressive medical treatment rather than the procedure of this study.

* 1. ***EIT***

Potential risks hypothesized with the use of EIT are an allergic reaction to the gel application or skin breakdown from the belt. However, this has not been found or documented in any of the literature analysed.

* 1. ***Positioning***

Possible risks associated with position changes and/ or particular positions can include oxygen desaturation. In the case of desaturations (mentioned in one study) the patient will be taken out of the position and medical treatment will be available.

1. **Data analysis**

EIT data will be analysed using the technology and software provided with the equipment. The measurements taken will be compared and analysed for all patients. Four different regions of the lungs (ventral, mid-ventral, mid-dorsal and dorsal) will be analysed to allow for a thorough investigation of ventilation distribution.

* 1. ***Sample size***

The Mater Mothers Hospital receives on average, 30 CDH patients per year. As such, over a 4-month period, we expect a sample size of at least 10-20 infants.

1. **Statistics Procedure**

Results will be presented as mean and standard deviation (SD) for the demographic and baseline clinical data. Generalised estimating equations will be used to determine differences and interactions between positions for each dependent variable. A p-value of < 0.05 will be considered statistically significant.  All statistical analyses will be performed using SPSS (v26.0, Lead Technologies, Inc., Chicago, IL, USA).

1. **Ethical Considerations** 
   1. ***Vulnerable Subject Group***

To undertake this study, it is essential that the research be done on the vulnerable population of neonates with CDH. As such, extreme care will be taken during measurements of the infant and will come secondary to the infants medical and respiratory needs. Prior to approaching the primary caregivers, the neonatologist will confirm suitability and the safety of each participant for the study. Consent may be withdrawn at any time and withdrawal will not compromise care given to the infant. Additionally, any member of the neonates’ care team may present concern for their continuing in the study. If it is deemed to be in the best interest of the infant to be removed from the study, this will be done.

* 1. ***Consent***

Potential participants will be identified daily through the NCCU/ maternity ward database. Those meeting the specified criteria will be provided with an information and consent form. Caregivers will have the ability to choose to consent, deny or ask questions without the consequence of altered care to their baby. They will only be approached if they’re not in significant distress (recovered from delivery) and deemed competent to provide informed consent. It will be explicitly communicated to the caregivers that if consent is withdrawn it will not affect the care given to the infant or any relationship with the hospital or its staff. If the withdrawal is made after completion of the study procedures, caregivers will be asked if data already taken can be used and if additional outcome data can be collected.

* 1. ***Confidentiality***

Standard confidentiality policies for regular medical records and patient information will be followed. All data will be stored as re-identifiable information with no reference to a participant’s personal information in any publication or presentation. All original files will be stored in a locked cabinet in a locked room with additional password protection. Data stored after publication will be determined by the Mater Misericordiae Limited Research Governance Office or by editorial policy.

* 1. ***Equipment Risk***

All infants will be closely monitored throughout the study by experienced health professionals. The care provided will be standardised respiratory support delivered from regular medical staff and will always take priority to the study. The anticipated risks of the study are low as the regular standardised therapy for all infants with CDH will be followed and EIT has shown to be safe for the patient.

* + 1. *EIT*

No identifiable risks or hazards associated with the use of EIT have been documented in the literature. The equipment does not interfere with the standard care given to the infant or with any other monitoring of vitals or disease progression. The belt used for measurements will remain on the baby to limit handling. To avoid any associated tissue damage, the current is set to 5 mAmp, well below the threshold associated with potential tissue damage. The Mater HREC has previously accepted EIT as minimal risk to similar neonatal populations.

* + 1. *LUS*

Lung ultrasound has been proven in the literature as a safe and feasible equipment in the neonatal intensive care population and is routinely used.

1. **Indemnification**

No special arrangements for indemnification will be made as the participants are not exposed to additional risks.

1. **Equipment and Disposables**

The EIT equipment and software required for this study are already available.

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