REDUCING CPAP FAILURE IN EXTREMELY PRETERM INFANTS

by

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ABSTRACT

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Background: Extremely preterm infants (<29 weeks EGA) have high rates of respiratory distress syndrome (RDS). Continuous positive airway pressure (CPAP) ± intubation and surfactant administration provide a safe and effective way of treating RDS without the need for prophylactic intubation and surfactant administration. CPAP failure occurs when infants on CPAP must be subsequently intubated within the first 72 hours of life.

Local Problem: The CPAP failure rate at Parkland Hospital is elevated compared to the gold standard neonatal ICU (NICU) at Columbia University.

Methods: Quality improvement tools were applied to assess areas for improvement in the CPAP process. The baseline rates of CPAP failure at the Parkland NICU were determined through chart review. Observation of the CPAP process and interviews with NICU staff was performed.

Interventions: A CPAP failure checklist was developed and placed in each NICU room. Quarterly training led by a respiratory therapist was provided to NICU staff. CPAP audits were updated, and a visual display of the proper CPAP setup was placed in each NICU pod.

Results: There was no significant change in the CPAP failure rate from 2015 to 2017. However, there was a reduction in the variation in the CPAP failure rate from 2015 to 2017. There was no change seen in the secondary outcome of the bronchopulmonary dysplasia rate but there was a significant decrease in the total ventilator days. During this time frame, there was also an increase in the number of infants arriving to the NICU on CPAP.

Conclusion: Our interventions were not successful in lowering the CPAP failure rate. However, our interventions did have a measurable effect in lowering the variability of the failure rate. The decrease in the total ventilator days and increase in the number of infants being managed solely on CPAP indicates a culture shift in the NICU.

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CHAPTER 1
INTRODUCTION

Problem Description

Extremely preterm infants (≤ 29 weeks estimated gestational age) face a variety of medical issues in the period immediately following birth that can limit their survivability and severely impact their long-term health. The transition period immediately following the birth of a neonate has been termed the "Golden Hour" in acknowledgement of the importance of this small window in affecting the future health and wellbeing of the neonate. Of the issues that infants face in this time frame, respiratory distress syndrome (RDS) is one of the most prevalent and important issues. If left untreated, RDS can prove to be rapidly fatal to extremely preterm infants. Currently, the two most widely used treatments for RDS are mechanical ventilation/intubation and CPAP (continuous positive airway pressure).

At Parkland Hospital, preterm infants are initially trialed on continuous positive airway pressure immediately after birth. CPAP is a non-invasive method of providing respiratory support to the preterm infants who might otherwise have to be intubated. The benefits of CPAP derive directly from the fact that it does not involve intubation which is associated with long term morbidity in preterm neonates. However, infants on CPAP can undergo respiratory decompensation and have to be subsequently intubated for a variety of reasons. We call this CPAP failure. At the beginning of this project, we defined CPAP failure as intubation > 1 hour in the first 72 hours of life of any infant that entered the neonatal ICU on CPAP. In 2017, the definition was revised to include any duration of intubation with the first 72 hours of life of any infant that entered the neonatal ICU on CPAP. For the reasons stated above, there is good reason to believe that preventing CPAP failure in these infants would be beneficial for them in the long run.

Available Knowledge

Historically, endotracheal intubation and mechanical ventilation was the treatment of choice in preterm infants with RDS. Intubation and mechanical ventilation provides aggressive respiratory support and allows precise management of the various respiratory functions in a preterm neonate. In addition, endotracheal intubation allows easy administration of surfactant, one of the best medications available for treating respiratory distress syndrome. This is because for surfactant to be effective, it has to be administered directly to the lungs, something which is not possible with CPAP. However, one of the most common complications arising from mechanical ventilation is bronchopulmonary dysplasia.

Bronchopulmonary dysplasia is defined as the need for respiratory support or mechanical ventilation at 36 weeks corrected gestational age [1]. At this age, infants should have undergone enough lung development to have respiratory self-sufficiency. The need for continued oxygen support at 36 weeks of age indicates insufficient lung development or chronic damage to the developing lung. One of the factors associated with bronchopulmonary dysplasia is mechanical ventilation. In animal models, mechanical ventilation has been shown to increase the level of pro-inflammatory cytokines in the lung parenchyma [2]. In addition, mechanical ventilation can lead to over-inflation of the lungs as well as long term oxygen toxicity. As a result, this can cause scarring of the lung tissue which can cause continued supplemental oxygen dependency later on in life as well as repeat hospital visits.

There have been several studies that have compared the outcomes of respiratory support using CPAP vs mechanical ventilation in preterm neonates [1,3,4]. Although the data from these studies is admittedly somewhat mixed, all of the studies have found that CPAP is at the very least no worse of a respiratory mode than mechanical ventilation in terms of long-term outcomes. In

addition, out of these studies, there was modest support that use of CPAP resulted in less bronchopulmonary dysplasia and death at 36 weeks of age in preterm neonates [1]. In addition, infants treated on CPAP were shown to require less subsequent mechanical ventilation and corticosteroid therapy compared to infants treated with mechanical ventilation at birth[4]. The American Academy of Pediatrics issued a level 1 recommendation in 2017 that CPAP immediately after birth with subsequent selective surfactant administration may be used as an alternative to routine intubation with surfactant administration [4].

There have also been a number of studies examining CPAP failure over the years. Unfortunately, although individual studies have found certain factors that are correlated with CPAP failure including early gestational age, lack of antenatal corticosteroid administration and severity of RDS on chest x-ray, none of these factors have enough sensitivity or specificity to accurately predict which infants will fail[5]. In light of this, there is increasing consensus among the neonatologist community that all preterm infants be trialed on CPAP immediately after birth. The CPAP setup used at Parkland Hospital is based on the model originally developed at Columbia University which is widely considered the gold standard. This is based on a pivotal study where it was shown that incidence of chronic lung disease in preterm infants at Columbia University Neonatal ICU was significantly lower than 7 other comparable centers in the surrounding region. Some of the features of the Columbia model include use of a water seal to provide positive pressure (bubble CPAP), maintenance of all preterm infants on CPAP with intubation and surfactant administration only when signs of impaired oxygenation or ventilation are present ($FiO_2 > 60\%$, $pH < 7.2$, $pCO_2 > 65$ mm Hg), use of appropriate size nasal prongs, a hat and chin straps and frequent suctioning and repositioning of the infant.

The CPAP failure rate is usually highly variable depending on the center. In one of the

studies published by Columbia University on their own neonatal population for infants with birth weights less than 1250g, the CPAP failure rate was 24% [6]. At the start of the project in 2015, the failure rate for extremely preterm infants at Parkland NICU in the years of 2014 and 2015 was approximately 45%. Although these two populations are not directly comparable, over 70% of the infants in the Parkland population were under 1250g. In addition, infants over 1250g have lower rates of CPAP failure so the CPAP failure rate at Parkland NICU would have been even higher if the >1250g group had been excluded.

Rationale

There a variety of reasons why infants can fail CPAP and not all of them have been elucidated. One popular theory is that there is a subset of infants that absolutely need surfactant administration in order to maintain adequate oxygenation/ventilation and are destined to fail CPAP otherwise. Clinical prediction models are currently being developed to determine this subset of infants and there is hope that if these infants are able to receive surfactant in a timely manner (through methods other than prolonged intubation), these infants would be able to remain on CPAP. Non-optimal respiratory support from the CPAP circuit is another reason why infants could fail CPAP. This can be caused by improper CPAP setups such as inappropriate sized nasal prongs, failure to use auxiliary tools such as chin straps or from blockages in the infant's respiratory pathway such as excessive nasal/oral secretions. Finally, medical complications can arise which would necessitate switching from CPAP to another respiratory support mode. Some of the complications of CPAP include pneumothorax and nasal breakdown. These complications are preventable to a large extent and reducing the incidence of these complications would also likely reduce CPAP failure.

In developing our interventions, we worked under the assumption that the cause of CPAP failure in each infant was multifactorial. Since not all causes of CPAP failure are yet known or readily observable, we chose to focus on optimizing the CPAP setup as well as targeting a select prenatal population with surfactant using less invasive methods.

Specific Aims

The aim of my project was to reduce the rate of CPAP failure at the Parkland NICU by 25% by December 2017. To carry this out, several goals were set. The first goal was to collect more information about the CPAP process at Parkland. This would be done through a variety of quality improvement methods including process mapping, fishbone diagrams, pareto charts and data analysis. Through these methods, we wanted to clarify the characteristics of the extremely preterm infants at Parkland that were failing CPAP. In addition, we would look for areas where quality improvement implementations could be performed. The second goal was to develop quality improvement packages to target areas of deficiency according to the data gathered as well as the rationale described above.

All parts on the project were carried out at either the Parkland labor and delivery (L&D) rooms, 3rd floor operating rooms or the NICU. The main groups involved in the project were the neonatologists, respiratory therapists, the nurse practitioners and the nurses. The goals of the project are squarely in line with Parkland's standard of excellence. They will help the NICU to provide care which meets high standards of service and performance.

CHAPTER 2
METHODS

Context

As the safety net hospital for Dallas County, Parkland has one of the busiest obstetric services in the country. As a result, the Parkland Neonatal ICU sees large volumes of preterm infants with the ICU totaling over ninety beds with an average of 1,100 to 1,200 infants admitted annually. This high patient volume translates into a large sample size to test the effectiveness of various interventions. In addition, due to the nature of the patient population at Parkland, the women that come to Parkland for childbirth are usually from lower-income households. This means that the infants born at Parkland have been exposed to the various conditions that are potentially more prevalent among women in lower income households e.g. gestational diabetes or pre-eclampsia. As such, the neonatal population at Parkland could have significant differences from those at a private institution.

On the other hand, Parkland Hospital is also closely affiliated with the UT Southwestern academic center. As an academic institution, this allows the introduction of current standards of care more rapidly. In addition, the physicians at Parkland Hospital rotate through other medical center affiliated hospitals such as Children's Medical Center and Dallas Presbyterian Hospital. Each of these institutions has their own policies and practices, some of which differ from those at Parkland.

Interventions

To achieve our first goal of collecting more information about the CPAP process at Parkland Hospital, we implemented used several quality improvement tools. Process mapping was performed of CPAP usage in the delivery room and in the neonatal ICU. This was done by

observing resuscitation efforts in the delivery room and the CPAP setup process in the neonatal ICU. For expert opinion on the CPAP process at Parkland, nurses and respiratory therapists were interviewed. The information collected was used to create a fishbone diagram of various causes of CPAP failure. Finally, review of existing data was performed to establish baseline characteristics of the infants that fail CPAP. In addition, compliance data with CPAP setup was analyzed to create a pareto chart.

Our first round of interventions was targeted towards education. To this end, we developed a checklist for CPAP failure. The intention of the checklist was to provide a source of information that providers could refer to during cases of CPAP failure. Included on the checklist were items for proper CPAP setup such as usage of chin straps and appropriate size nasal prongs, items for adjusting CPAP settings such as FiO2 and PEEP and other steps including suctioning and repositioning the infant. The respiratory therapists also provided regular training sessions for the nurses on proper CPAP setup and usage. A Delphi survey was also developed to try to achieve consensus among providers on acceptable CPAP settings, but this tool has not yet been implemented.

Our second round of interventions focused on introducing the use of LISA (less invasive surfactant administration) to provide surfactant to a select group of infants. LISA involves using a thin catheter inserted past the larynx into the trachea to provide surfactant rapidly to the infant. Infants eligible to receive LISA were those that were on CPAP at the time of the intervention but had been experiencing increasing PEEP and FiO2 requirements (CPAP level of 7, FiO2 $\geq$ 30%). A protocol and flow diagram were developed for LISA usage.

Measures

Our primary measure was the CPAP failure rate. This was defined as the percent of infants that experienced intubation > 1 hour in the first 72 hours of life out of all infants that entered the neonatal ICU on CPAP. We chose CPAP failure rate as our primary measure since it was the most closely tied to our aim. The failure rate was determined through chart review of all extremely preterm infants that entered the NICU on CPAP. Since any intubation event is distinctly recorded in the chart, we have high confidence in the reliability of our measured rate.

Our secondary measures included incidence of bronchopulmonary dysplasia, incidence of pneumothorax, length of hospital stay, number of ventilator days and self-reported nursing compliance with proper CPAP setup. These measures were obtained through a combination of chart review and nursing surveys. Bronchopulmonary dysplasia was defined as the need for respiratory support or mechanical ventilation at 36 weeks corrected gestational age. Pneumothorax was diagnosed radiologically and clinically by chest x-ray and clinical respiratory deterioration.

Analysis

Quality improvement software was used to generate run charts for the primary and secondary measures. This allowed us to see trends in the CPAP failure rate along with secondary outcome measures over time. It also allowed us to observe the effects of our interventions based on the time they were implemented. Upper and lower bounds were generated to determine the magnitude of effect of the interventions.

Comparison of the Parkland outcome measures with that of Vermont Oxford Network was done qualitatively. Both data sets were plotted on line graphs and both trend lines were assessed together.

A pareto chart was also used to analyze the CPAP self-reported nursing compliance with CPAP setup. The chart allowed us to determine the top areas where compliance was an issue.

Ethical Considerations

There are no ethical considerations present for this project.

CHAPTER 3
RESULTS

Data from before our interventions were implemented was collected and analyzed to provide more information about the extremely preterm infants at Parkland that underwent CPAP treatment. Data for infants between 23 to 29 weeks estimated gestational age from the years of 2014 – 2016 was sorted by CPAP failure and CPAP success. The infants in the CPAP failures group were then sorted by several criteria including estimated gestation age, birth weight, time of arrival to intubation. The infants in the CPAP failures group also had additional data collected including FiO2 before intubation, PEEP level before intubation, blood gases and antenatal steroid administration to the infant's mother. As expected, infants that had earlier gestational ages and lower birth weights had higher rates of CPAP failure. Data from those two stratifications are shown in graphs 1 and 2. Breakdown of infants by time of arrival to intubation showed that a majority of infants that arrived in the NICU on CPAP experienced failure within the first four hours with the rate of CPAP failure being highest within the first hour of arrival. There was a relatively low incidence of CPAP failure after an infant had been maintained on CPAP for greater than 24 hours. These results are shown in Figure 3.

The CPAP failure rate showed significant variability from quarter to quarter before and after our first round of interventions. The average CPAP failure rate between the years of 2014 – 2017 was approximately 45%. The upper and lower control limits were at 95% and 1% respectively. Between those years, the failure rate ranged between 80% to 8%. At the beginning of 2017, the CPAP failure definition was changed from intubation for greater than 1 hour to any intubation duration at all. This makes it hard for any direct comparison to be made for the rates before and after the year of 2017. However, before the change in CPAP definitions the average CPAP failure rates for the years of 2015 and 2016 were 29% and 33% respectively.

The incidence of bronchopulmonary dysplasia, a secondary outcome measure, did not show significant change before and after the intervention. From the years of 2014 - 2016, the incidence of bronchopulmonary dysplasia among extremely preterm infants was approximately 37%. For the year of 2017, the incidence of BPD stayed roughly the same at 38%. However, a marked decrease in total ventilation days was observed between 2015 and 2017. The average number of ventilator days per month was approximately 140 in 2015. This rate dropped to an average of 75 days in 2016 and 22 in 2017 respectively.

One significant contextual change of note was the Parkland hospital transition in fall 2015. As with any transition between hospitals, there was a learning curve for adjusting to the equipment and infrastructure in the new hospital. This may have affected the CPAP failure rate during that year.

Data on the primary and secondary process measures are still pending for 2018 as a whole. Since LISA was implemented in 2018, data on the intervention is still being processed.

CHAPTER 4
DISCUSSION

Summary

After review of the data, there does not appear to have been a statistically significant decrease in the CPAP failure rate after our first round of interventions. A large part of this can be attributed to the significant variability in CPAP failure rates from quarter to quarter. Because of this, the upper and lower control limits were placed at percentages that were incredibly hard to attain. However, it is worth noting that there appeared be a downtrend in the CPAP failure rates in the years of 2015 and 2016 where the average CPAP failure rates in those years were substantially lower than 2014 (29% and 33% vs 54%). The definition change of CPAP in 2017 towards more inclusive criteria for CPAP failures caused more infants to be included CPAP failures. This likely had some responsibility for the increase in the CPAP failure rate that year. However, other factors may also have contributed to the increase in failure rate.

Our secondary process outcomes were also mixed. There was no change in the rate of bronchopulmonary dysplasia among extremely preterm infants. However, a substantial decrease in the number of ventilator days was seen from 2015 to 2017. These results are in line with our primary process measure. Without a significant decrease in the CPAP failure rate, it would have been unusual for the incidence of BPD to decrease. The decrease in ventilator days shows that our intervention could have still had a potential impact, just not at the level of the CPAP failure rate or BPD incidence.

Interpretation

There are a number of reasons why our first round of interventions could have failed to

have a significant difference in reducing the CPAP failure rate. Our initial project rationale hypothesized that the cause of CPAP failure was multimodal and therefore our intervention might have targeted a reason for CPAP failure that was not as prominent as we believed. In addition, even though the CPAP model at Parkland is based on the model developed at Columbia University which has lower CPAP failure rates, many of the CPAP interventions proposed by Columbia University are based on clinical experience and not on research evidence. Therefore, the best practice model proposed by Columbia University could be specific to their site and not as easily generalizable. Our second round of interventions (less invasive surfactant administration) targets a different area of CPAP failure. Data for this intervention is still being collected and it remains to be seen what impact this will have on the CPAP failure rate.

There is reason to believe that our first round of interventions did have an impact on the culture at the Parkland NICU. This is reflected in the decreased number of ventilator days from 2015 – 2017. Some of the main factors that affect the number of ventilator days are the number of infants that are able to be maintained solely on CPAP as well as how quickly the NICU team feels comfortable transitioning from mechanical ventilation back to CPAP. Since the CPAP failure rate did not show significant change, the decrease in the number of ventilator days likely reflects a shift in the attitude of the Parkland NICU staff towards CPAP. In addition, since the use of CPAP is associated with lower costs than with mechanical ventilation, the reduction in mechanical ventilation days also provides a cost benefit for Parkland.

Overall, our results are fairly consistent with what has been observed in other quality improvement projects targeting CPAP failure in the neonatal ICU. Those projects found that the culture at the NICU could be adjusted over a minimum period of several years. However, in those projects, they were unsuccessful in reducing the rate of CPAP failure and the incidence of BPD.

Limitations

One of the limitations of our project is related to the CPAP setup that Parkland uses. There are a number of ways to apply facial CPAP and the bubble CPAP setup is only one of many. If another institution elects to use a different setup, some of the specifics of our intervention including CPAP equipment and CPAP settings may not be applicable.

In addition, the CPAP failure is not the only quality improvement project being performed at the Parkland NICU. There are multiple other projects going on concurrently including projects to decrease delivery room intubation and infant nasal breakdown. Some of these other quality improvement projects have interventions that overlap with our project and which also could have had an effect on our process measures. This makes it harder to attribute specific changes in our quality measures to our own interventions.

Conclusions

Our project focused on implementing a quality improvement solution to address one of the most common problems faced in the neonatal ICU: CPAP failure in the treatment of respiratory distress syndrome. As CPAP increasingly becomes a primary mode of treating RDS, CPAP failure has become an issue that NICU's all across of the country will have to deal with. Our project highlights some of the difficulties every NICU will face in combating CPAP failure including the lack of consensus among the scientific community on the causes of CPAP failure and on the best mode of administering CPAP. This speaks to the importance of quality improvement interventions to be based on solid research findings and that interventions based on expert opinion alone may not always be effective, especially when transferred across institutions.

However, out of the changes that we have seen as a result of the project including less ventilator days overall, these changes are likely to be sustainable long term. This is because there is reason to believe that there is a general culture shift among the Parkland NICU staff and increased awareness of the importance of maintaining extremely preterm infants on CPAP. In addition, the project is still ongoing and with our new round of interventions using less invasive surfactant administration, there is hope that we will begin to see long term decreases in the CPAP failure rate.

FIGURES

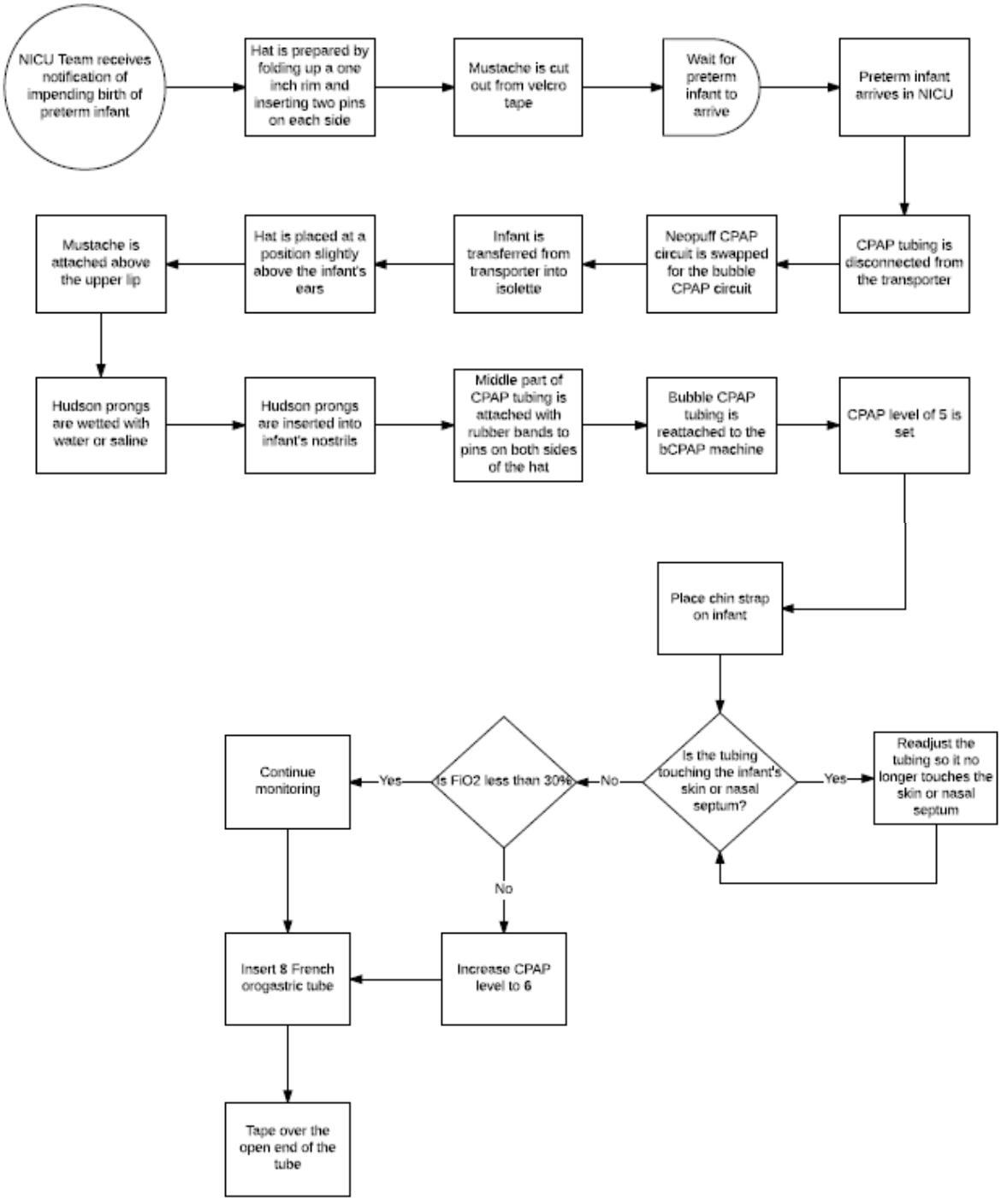

Figure 1. Process map of CPAP process in the Parkland NICU

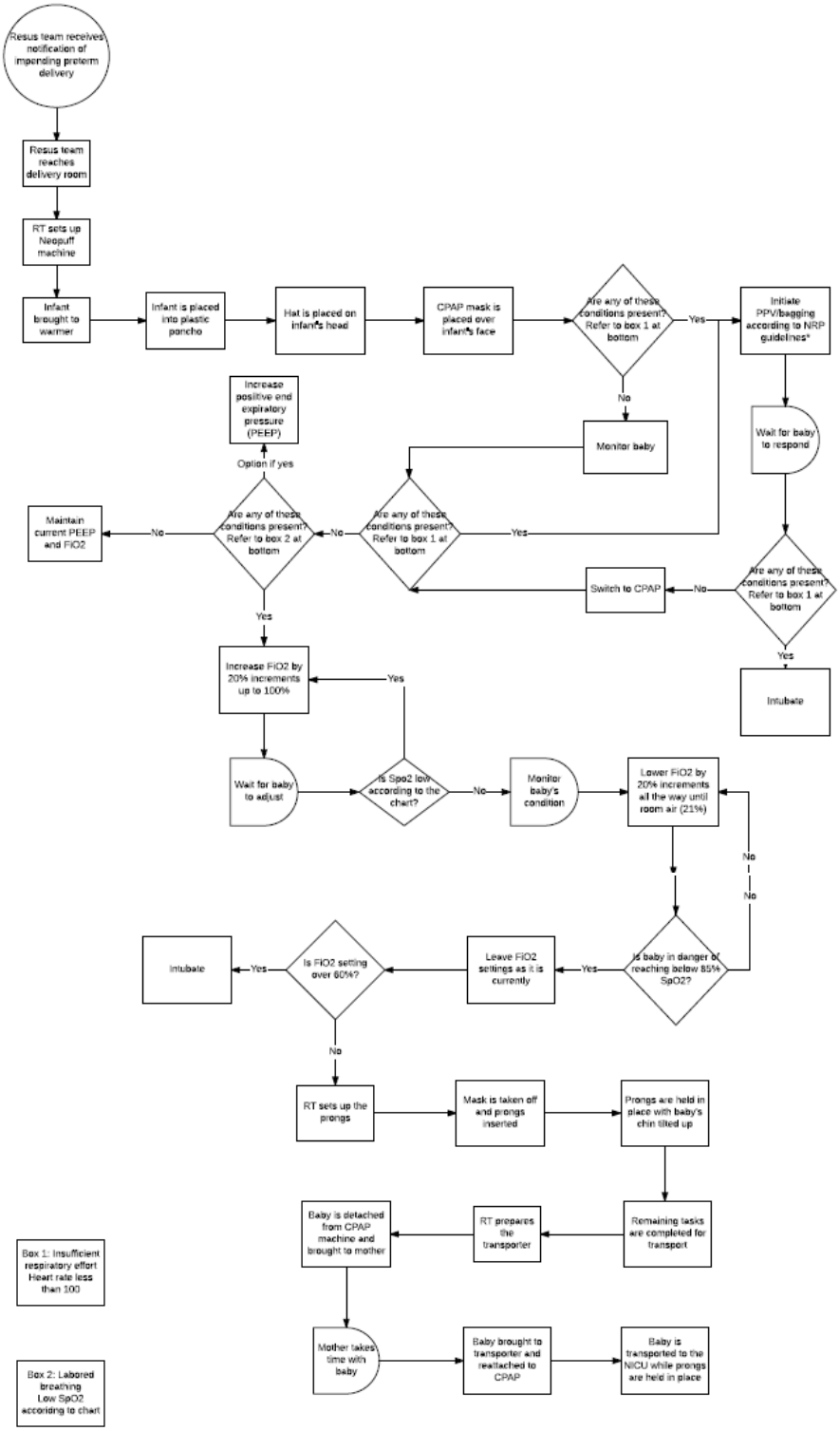

Figure 2. Process map of CPAP process in the Parkland labor and delivery room

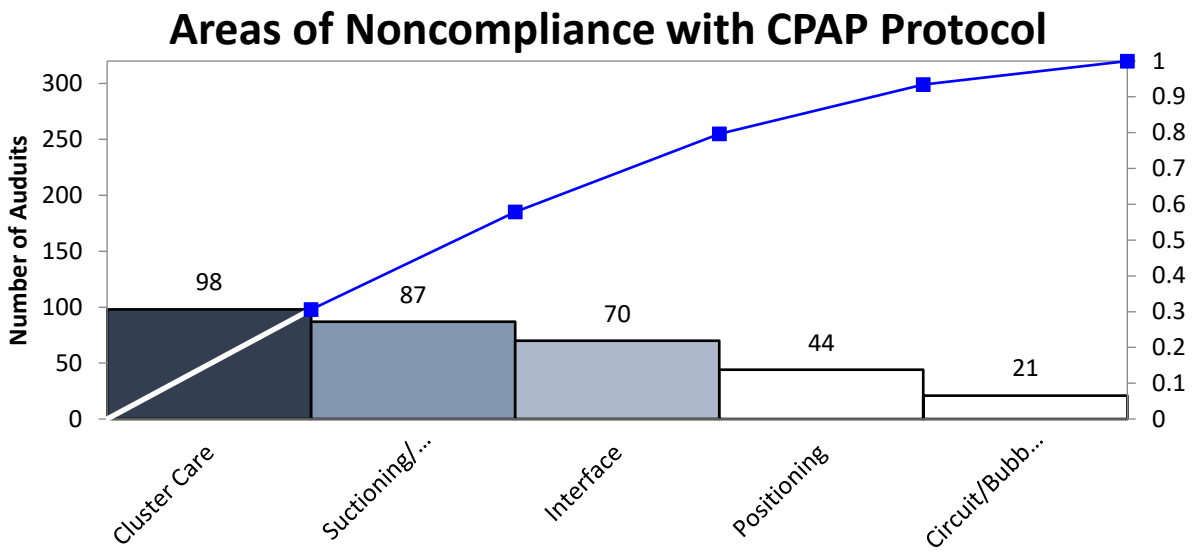

Figure 3. Pareto chart of areas of CPAP noncompliance

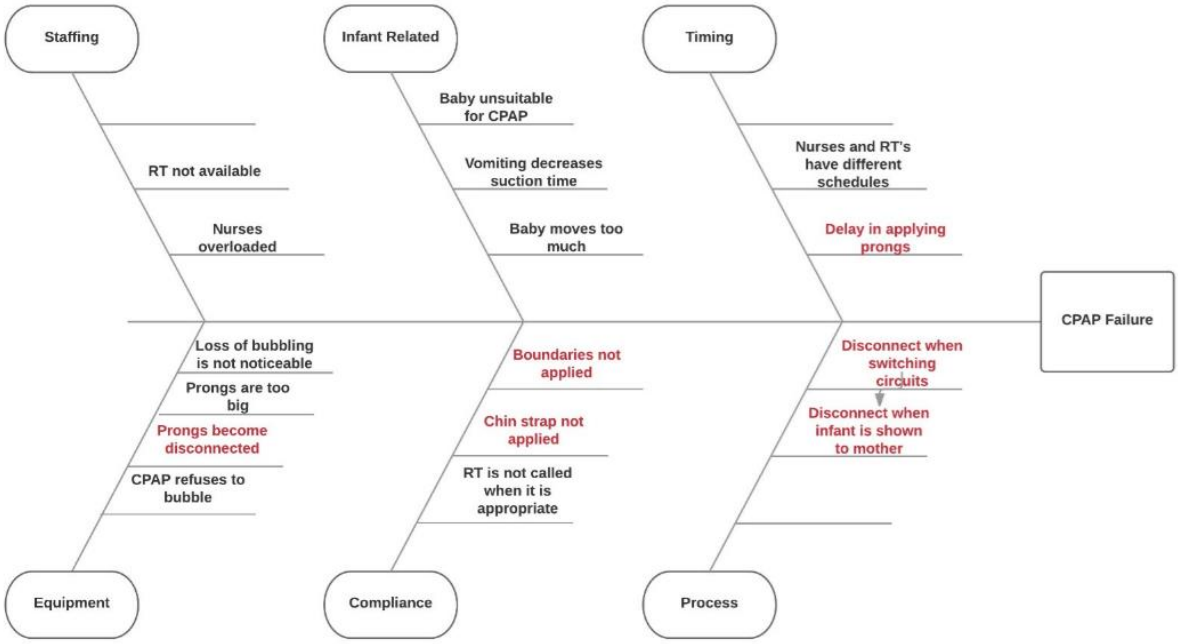

Figure 4. Fishbone diagram of areas of CPAP failure

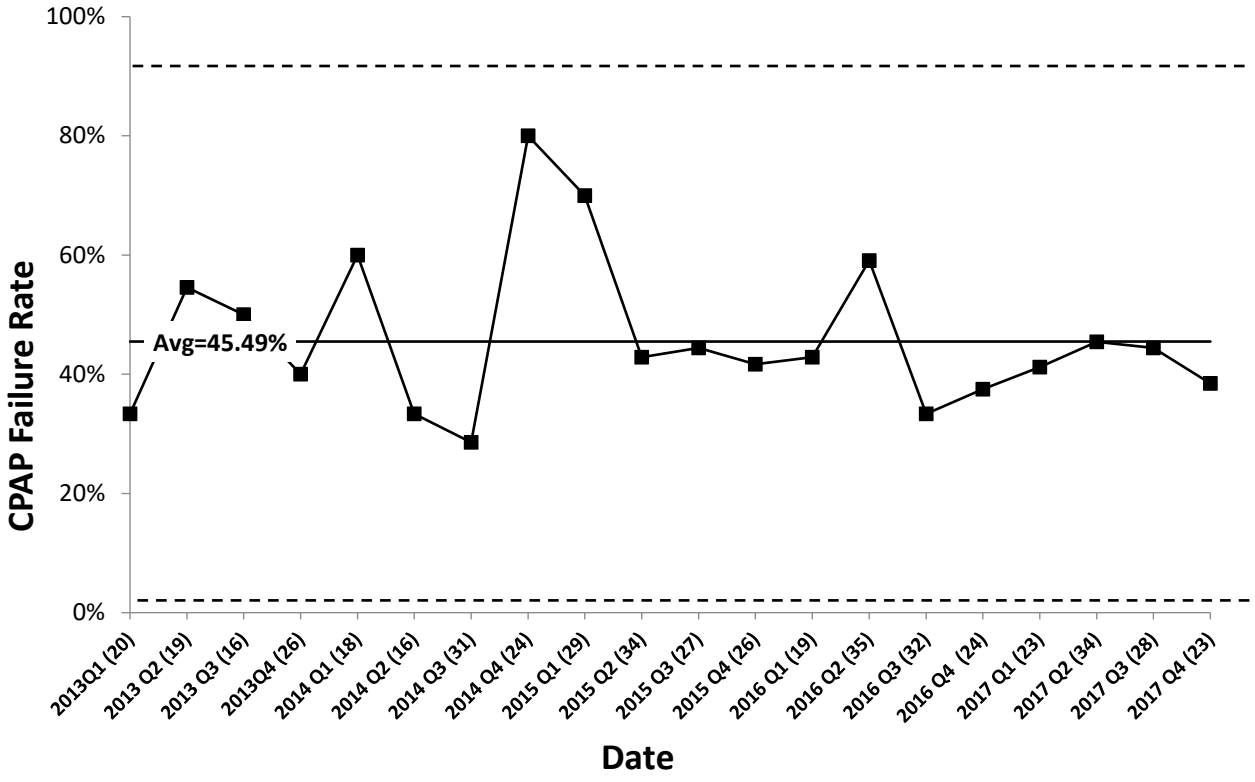

Figure 5. Run diagram of the CPAP failure rate

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