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The influence of side-lying position on oropharyngeal swallow function in at-risk infants: An exploratory study

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The influence of side-lying position on oropharyngeal swallow function in at-risk infants: An exploratory study

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Explanation of Format and Composite Abstract

Speech-Language Pathologists (SLP) are the primary healthcare providers responsible for the evaluation and treatment of infant feeding and swallowing disorders. At-risk infants, such as those born prematurely or with certain medical conditions, are more prone to swallowing impairments (i.e., dysphagia). Dysphagia in at-risk infants can have severe consequences such as chronic respiratory symptoms, pneumonia, progressive lung disease, undernutrition, and death. Therefore, it is important to have methods of examining an infant's swallow functioning that are both safe and accurate. A leading method of evaluating infant swallowing is the Modified Barium Swallow Study (MBS). The works contained within this dissertation document include three research studies conducted on topics related to speech-language pathology (SLP) practices in assessing and treating infants who are at-risk for swallowing and feeding disorders (i.e., dysphagia). Specifically, these three studies investigated aspects of best-practices for the Modified Barium Swallow Study.

The first study, entitled *A Preliminary Investigation of the Effect of Fluoroscopic Rate on NICU Swallow Ratings and Recommendations,* investigated how reducing fluoroscopic pulse rate, in an effort to reduce radiation dose, effects SLP assessment of swallow parameters and feeding recommendations for infants in the Neonatal Intensive Care Unit (NICU). Segments of previously recorded infant MBS were rated on five swallow parameters. The ratings were compared between MBS rated at 30 frames per second (fps) and at 15 fps. Reducing frame rate resulted in differences in some, but not all, swallow parameter ratings. Feeding recommendations were different between MBS rated at 30fps vs 15fps. The results of this first study support the continued use of 30 pulses per second during MBS conducted for infants in the NICU, although further investigation on a larger scale is warranted.

The second study explored SLP experiences and perceptions regarding the use of side-lying position during infant MBS. Entitled *Speech-Language Pathologists' Perspectives on Side-Lying Position to Improve Swallow Performance during MBS,* this qualitative study aimed to contribute greater understanding of the current practices by SLPs in the use of side-lying position during infant MBS. Qualitative data was collected through six semi-structured interviews of hospital SLPs. Interviews were transcribed, coded via initial coding and a consensus coding approach, and analyzed to develop themes. Results of this study were that while SLPs acknowledge the importance of MBS replicating an infants' typical feeding, some SLPs who consistently use side-lying position during feeding do not conduct MBS in side-lying position. This inconsistency in practice results from the SLPs' perceived barriers, including lack of experience, concern for interdisciplinary conflict, need for MBS protocols, and lack of research investigating the impact of side-lying position on infant swallow function and safety. SLPs report the need for additional research that investigates whether side-lying position alters, possibly improving, airway protection during swallowing for at-risk infants.

The third study, *The Influence of Side-lying Position on Oropharyngeal Swallow Function in At-risk Infants: An exploratory study,* examined the effect of side-lying position on infant swallow physiology, including airway invasion, swallow initiation, and suck-swallow-breathe coordination. Infant MBS recordings were retrospectively examined in matched-pairs comparing nine at-risk infants swallowing with the same liquid consistency, bottle, and nipple in both an upright/cradled position and a side-lying position. Swallow parameters were measured independently and through a consensus coding approach. Side-lying position reduced severity of airway invasion during the swallow for some, but not all, medically complex infants. Bolus location at the time of swallow initiation was overall higher, representing decreased risk of airway invasion, when at-risk infants were fed in side-lying position compared to cradled position. Infants fed in side-lying position demonstrated, on average, fewer swallows per breaths compared to when they are fed in cradled position. The results of this third study suggest that side-lying position should be considered as a viable strategy to improve swallow safety in at-risk infants who exhibit oropharyngeal dysphagia. Additional investigation with larger, randomized controlled methods would further inform the effect of side-lying position on infant swallow function.

Part I: A Preliminary Investigation of the Effect of Fluoroscopic Rate on NICU Swallow Ratings and Recommendations

Abstract

PURPOSE: Reducing fluoroscopic pulse rate is one method of reducing radiologic dose during modified barium swallow studies (MBS). The purpose of this preliminary investigation was to determine the effect of changing fluoroscopic pulse rate from 30 pulses per second (pps) to 15 pps during NICU MBS. Does this reduction alter SLP ratings of infant swallow parameters and the subsequent feeding recommendations based on those parameter ratings?

METHODS: Segments of previously recorded infant MBS were rated by experienced SLPs on five swallow parameters: sucks-per-swallow, timing of swallow initiation, nasopharyngeal regurgitation, pharyngeal residue, and penetration/aspiration. The ratings were compared descriptively and statistically between MBS rated at 30 frames per second (fps) and at 15 fps (simulating 30 and 15 pps, respectively). Swallow parameter ratings were then used to develop infant feeding recommendations. Feeding recommendations were compared between videos rated at 30 fps and 15 fps.

RESULTS: Initiation of pharyngeal swallow was rated as more severely impaired for 30 fps than for 15 fps. There was no statistically significant difference between 30 fps and 15 fps on the remaining measures, including airway invasion scores. However, airway invasion scores were found to be different in 11 out of 30 (36.67%) swallowing trials. Feeding recommendations were different between MBS rated at 30fps vs 15fps.

CONCLUSION: These results support the continued use of 30 pulses per second during MBS conducted for infants in the NICU, although further investigation on a larger scale is warranted.

Introduction

Infants in the Neonatal Intensive Care Unit (NICU) are at high risk for dysphagia because of prematurity and other comorbidities, such as bronchopulmonary dysplasia and interventricular hemorrhage. The consequences of dysphagia for these medically complex infants can be severe, including long term feeding difficulties, poor weight gain, respiratory illnesses, and even death (de Benedictis et al., 2009; Gewolb & Vice, 2007; Jadcherla, 2019; Lefton-Greif et al., 2006; Mizuno et al., 2007; Sheikh et al., 2001; Taniguchi & Moyer, 1994). Therefore, it is important to have methods of examining an infant's swallow functioning that are both safe and accurate (i.e., sensitive to incidences of dysphagia). A Modified Barium Swallow Study (MBS) evaluates multiple components of the swallow including timing, residue, and airway invasion (i.e., penetration with or without aspiration). However, this method of assessment requires radiation exposure, similar to other medical uses of radiologic imaging.

The medical care team, including the radiologist and Speech-Language Pathologist (SLP), strive to reduce the amount of radiation to as low as reasonably achievable (ALARA) while still gathering the salient diagnostic information from the procedure. This principle of ALARA is particularly important in the NICU population given the frequent number of radiologic procedures many infants undergo (Hersh, et al., 2016; Thompson et al., 2018). One way to reduce radiation exposure during MBS is to reduce the number of radiologic pulses that are used per second, from 30 pulses per second (pps) to 15 pps, or even lower (Cohen et al., 2007; Bonilha et al., 2013; Gelgano et al., 2019). However, reducing pulse rate could diminish the quality, and therefore accuracy, of the swallow image (Bonilha, et al., 2013; Cohen, 2009; Lefton-Greif et al., 2018; Mulheren, Azola, & Gonzalez-Fernandez., 2018). Currently, there is not a consistent standard of care specific to fluoroscopic pulse rate during the MBS for NICU infants.

Previous literature on recommended pulse rate during MBS is not only limited, but yields varying results, as some studies recommend continuing to use 30 pps for accurate evaluation of the swallow, while others conclude that reducing pulse rate to 15 pps does not compromise the quality of the assessment. Cohen (2009) studying the pediatric population, though not NICU infants, found penetration events often occurred in only a single frame, which suggests that eliminating every other frame may result in missed information. Bonilha and colleagues (2013) reported that reducing pulse rate in the adult MBS from 30 pps to 15 pps resulted in differences in some, but not all, swallow parameters. They also investigated the effect of these pps differences on swallow recommendations and found that the diet and therapy plans were different for all subjects (patients) when the fluoroscopic rate was decreased. A subsequent study examining the impact of pulse rate in the adult population reported that several swallow parameters, but again, not all were significantly different when measured at 30 pps versus 15 pps (Mulheren et al., 2018). This study did not examine the effect of pulse rate on swallow recommendations. Layly et al. (2019) found that when pulse rate was reduced from 30 pps to 15 pps during pediatric MBS, there was a high reliability between the two pulse rates, with only a few incidences of differences in Penetration Aspiration Scale scores (Rosenbek et al., 1996). Unfortunately, the Layly group did not examine the influence of pulse rate on feeding or swallowing recommendations. To date, the existing literature indicates that reducing pulse rate from 30 pps to 15 pps may negatively impact the accuracy when measuring certain swallow parameters and possibly alter the recommendations made from those measurements. However, there are no studies that address this question for the infant in the NICU undergoing an MBS.

While accurate diagnostic information is important in any circumstance, assessment of swallow function and safety is paramount in the fragile NICU population given the potential ramifications of dysphagia (e.g., feeding-related bradycardia and oxygen desaturation, stress during feeding, prolonged transition to oral feeds, chronic respiratory symptoms, pneumonia, progressive lung disease, undernutrition, etc.) (de Benedictis et al., 2009; Gewolb & Vice, 2007; Jadcherla, 2019; Lefton-Greif et al., 2006; Mizuno et al., 2007; Sheikh et al., 2001; Taniguchi & Moyer, 1994). However, there is a lack of literature on the effect of pulse rate on MBS findings overall, and specifically on MBS for NICU infants. Empirical evidence is needed to determine if reducing radiation exposure by decreasing pulse rate is appropriate, or if doing so alters the accuracy of the images, thus jeopardizing the health of medically complex infants. The following investigation emulates the seminal work in the adult population of Bonilha and colleagues (2013), modified for a NICU population.

Purpose and Hypotheses

This preliminary research addresses two questions, adapted from Bonilha et al. (2013): 1) Does changing pulse rate from 30 pps to 15 pps affect SLP ratings of infant swallow parameters on the MBS? 2). Do SLP feeding recommendations made from swallow parameters rated at 30 pps differ from those made from swallow parameters rated at 15 pps?

The hypotheses were that a lower pulse rate would result in differences in swallow parameter ratings of NICU MBS, and that those differences would impact feeding recommendations for NICU infants.

Methods

This study was approved by the Institutional Review Boards at both James Madison University and Virginia Commonwealth University Health. Part 1, addressing research question 1, examined the effect of changing pulse rate from 30 pps to 15 pps on SLP ratings of infant swallow parameters, while Part 2, targeting question 2, investigated the feeding recommendations made based on Part 1 parameter ratings to determine if they varied based on pulse rate. For the purposes of this study, changes in pulses per second (pps) were represented by adjusting the frames per second (fps) of the previously recorded MBS. While these two entities are closely related, they are not the same, as pulses per second refers to the number of x-ray beam pulses delivered during fluoroscopy, whereas frames per second refers to the number of images displayed (Mulheren et al., 2018).

Participants

Four NICU MBS were collected retrospectively via convenience sampling from Virginia Commonwealth University Health (VCUH). Criteria for inclusion was the presence of dysphagia, with or without aspiration, as recorded in the medical record by the SLP conducting the study and confirmed by the primary investigator. All patients were born prematurely (Mean gestational age at birth = 28 weeks, SD = 4.08) and were between 38-41 weeks post-menstrual age at the time of MBS (M = 39, SD = 1.41). All patients were considered medically complex, as they had two or more medical diagnoses at the time of examination. Patient demographics are presented in Table 1.

Standard MBS Procedures at VCUH

The MBS is completed by a speech-language pathologist (SLP) and a pediatric radiologist following the VCUH MBS guidelines for infants. Trials are administered starting with thin liquids (VARIBAR® Thin Liquid barium sulfate powder mixed with sterile water per manufacturer instructions) via the slowest available flow of each infant's typical bottle system (Arvedson et al., 2020; Patel et al., 2016). Subsequent bolus presentations and compensatory interventions (e.g., change in liquid consistencies/viscosity, change in nipple flow rates, etc.) are determined as clinically indicated based on the infant's response to the initial swallowing trial, per the discretion of the evaluating speech-pathologist (SLP) and radiologist (Arvedson et al., 2020; Fishbein et al., 2013; Patel et al., 2016; Sitton et al., 2011; Suterwala et al., 2017). All MBS are conducted using fluoroscopy at 30 pulses per second and are recorded at 30 frames per second (fps) on a high resolution TIMS recording system (TIMS Medical Video Platform™, Foresight Imaging, LLC). For all MBS included in this study, the infant was positioned in a reclined upright (i.e., cradled) position in a Tumble Forms 2 Delux Floor Sitter (Patterson Medical/Performance Health).

Question 1: Does changing pulse rate from 30 pps to 15 pps affect SLP ratings of infant swallow parameters on the MBS?

Employing the methods outlined by Mulheren et al. (2018) and Bonilha et al. (2013), each 30 fps (representing 30 pps) MBS video recording was converted to AVI format, duplicated, and transformed to simulate 15 fps (representing 15 pps) by removing every other frame using VirtualDub software (version 10.1.4). MBS recordings were then segmented into individual swallowing trials by liquid consistency and type of bottle and nipple, so that each individual video clip included swallows from one infant, with only one combination of consistency and modality (bottle and nipple type) (e.g., thin liquid via Dr. Brown preemie nipple). This resulted in a total of 32 video segments from the 4 full MBS. Table 2 outlines the break-down of each MBS into video segments. The number of video segments (each of one infant feeding from one bottle with one liquid consistency) varies for each MBS because the number of specific consistencies/modalities offered differed for each infant. Change in consistency and modality (bottle and nipple type) are based on the clinical judgement of the performing SLP and radiologist, based on the infant's performance, as described in the VCUH MBS procedures above (Arvedson et al., 2020; Fishbein et al., 2013; Patel et al., 2016; Sitton et al., 2011; Suterwala et al., 2017).

Examiners for Question 1

Two Speech-Language Pathologists each with at least 10 years of experience completing MBS for infants in the NICU served as expert examiners for research question 1. Examiners were trained by the primary researcher on scoring guidelines for swallow parameters using the definitions as provided in Table 3. The five swallow parameters assessed for this study were: number of sucks-per-swallow, presence of nasopharyngeal backflow, location of the bolus at the time of swallow initiation, amount of pharyngeal residue, and penetration-aspiration scores (PAS) (Gosa, 2015). Neither examiner was involved in the administration or interpretation of the original MBS to avoid bias that could occur from recognizing MBS.

Examiner training, inter-examiner reliability, and intra-examiner reliability were assessed using additional MBS images that were not included in analysis. The examiners scored these additional video segments at the same frame rates (both examiners scoring an individual video segment at 30 or 15 fps). After training, examiners demonstrated good-to-excellent scores on the interclass correlation coefficient on the five parameters (Table 4).

<u>Rating Swallow Parameters</u>

Each video segment (consisting of one infant swallowing one consistency via one modality) was randomly assigned to an examiner at either 30 fps or 15 fps, with examiners blinded to frame rate and participant information (Table 5). This was done to minimize any bias caused by examiners recalling previously rated images (Mulheren et al., 2018). Similarly, video segments were provided to examiners in random order. No time limit was placed for the completion of ratings of the videos, and examiners were allowed to review video segments as many times as needed, in slow motion, and frame-by-frame. Examiners completed ratings of the five swallow parameters (number of sucks-per-swallow, presence of nasopharyngeal backflow, location of the bolus at the time of swallow initiation, amount of pharyngeal residue, and penetration-aspiration scores) for each MBS video segment. Of note, the penetration-aspiration scale (PAS) used by the examiners to rate swallows was transformed into an ordinal scale of airway invasion with 3-levels: a score of 1 indicating no airway invasion, a score of 2 indicating airway invasion that did not pass below the true vocal folds (penetration), and a score of 3 indicating airway invasion that passed below the vocal folds (aspiration). This reorganization of the PAS scale was done given the categorical nature of the original PAS scale, and the need for an ordinal outcome measure to represent the severity of airway invasion (Steele & Grace-Martin, 2017). The 3-level airway invasion scale used in this study is different from the 3-level PAS scale proposed by Steele and Grace-Martin. This adjustment was made to mirror airway invasion scales previously used in infant swallow analysis, (McGratten et al., 2020; Newman et al., 2001; Suterwala et al., 2017) and taking into consideration findings indicating that laryngeal penetration is clinically significant in the pediatric population (Duncan et al., 2018; Friedman & Frazier, 2000; Gosa et al., 2017).

Analysis

Of the 32 video segments from the 4 MBS, thirty (30) video segments were included in analysis. Two (2) video segments, each consisting of one infant, one consistency, and one modality, did not capture any swallows given the infant's inability to extract liquid from that consistency/modality and were therefore not included in analysis for Question1. Swallow parameter ratings were analyzed for each video segment as matched-pairs, with each segment rated at both 30 fps and 15 fps. Differences in swallow ratings were compared both descriptively and statistically. For statistical analysis, a dependent measures t-test was performed on number of sucks-per-swallow. Location of bolus at the time of swallow initiation, amount of residue, PAS scale, and nasopharyngeal backflow were compared using Wilcoxon signed-rank tests. The a priori alpha level was set at .05 (Fishbein et al., 2012; Mulheren et al., 2017; Thoyer et al., 2012).

Question 2: Do SLP feeding recommendations made from swallow parameters rated at 30 fps differ from those made from swallow parameters rated at 15 fps?

To answer the second research question, parameter ratings were recombined into the original full MBS studies, so that the ratings of entire NICU MBS could be reviewed in totality. Since each of the four MBS were rated at both 30 fps and 15 fps, this produced a total of eight sets of full MBS results (four MBS reviewed at 30 fps and those same four MBS reviewed at 15 fps).

Examiners for Question 2

Methods for research question 2 employed two new examiners that were SLPs with at least 10 years of experience in level IV NICUs. Examiners reviewed the MBS results of swallow parameter ratings from question 1 and provided feeding recommendations based solely on those findings. Question 2 examiners did not review any MBS images, and frame rate information and infant history were not disclosed. This was done to reduce extraneous variables. MBS results were randomly organized, making sure that pairs (original MBS rated at 30 fps and corresponding MBS rated at 15 fps) were separated to avoid examiners recognizing the order of consistency/modality. Of note, examiners for question 2 were recruited from two differing NICUs than where the infants' MBS assessment occurred to minimize the influence of institution-specific NICU practices on feeding recommendations. Both examiners were instructed to make recommendations based on the treatment principle of providing the safest and least restrictive treatment option (Arvedson & Brodsky, 2002; Elichar et al., 1987). As with the methods for the first question, neither examiner for question 2 was involved in the administration or interpretation of the original MBS to avoid bias that could occur from recognizing MBS.

Feeding Recommendations

Examiners provided recommendations for liquid consistency (thin, slightly thick, or nectar thick), bottle type, nipple flow, and feeding strategies (i.e., side-lying position, pacing, time limits, etc.). Examiners could only choose one recommendation for consistency (e.g., thin liquid vs nectar thick liquid, etc.) and one for modality (e.g., Dr. Brown bottle with preemie nipple, Nuk slow flow nipple, etc.) but could provide multiple feeding strategy recommendations. After the examiners prepared recommendations independently, consensus coding of recommendations occurred where any discrepancies appeared. Examiners had the opportunity to discuss the rational underlying recommendations in order to establish finalized recommendations. There were no instances where the examiners did not come to an agreement after discussion. Final consensus recommendations were compared between sets of matched pairs, examining any differences between SLP feeding recommendations for each infant when the MBS was rated at 30 fps versus 15 fps.

Results

Question 1: Does changing pulse rate from 30 pps to 15 pps, as represented by frames per second, affect SLP ratings of infant swallow parameters on the MBS?

Differences in Swallow Parameters

Across all consistencies/modalities, judgement of location of the bolus at the time of pharyngeal swallow initiation was most influenced by frame rate, and was found to be statistically significantly different ($Z = 49.00$, $p = .024$). Number of sucks-per-swallow ($t = .629$, $p = .534$), amount of pharyngeal residue ($Z = 40.00$, $p = .197$), and nasopharyngeal backflow ($Z = 1.00$, $p = .317$) ratings were not significantly different between 30 fps and 15 fps.

Difference in Level of Airway Invasion (PAS scores)

Of the total 30 video clips (see table 5 for detailed breakdown of number of clips in each of the four full MBS), approximately one third of swallow trials (11 out of 30 swallow video segments) had differences in ratings of airway invasion when judged at 30 fps compared to 15 fps (table 6). Percentages of differences in airway invasion ratings were similar between thin and thickened liquids (38.10% different airway invasion scores on trials of thin liquids; 33.34% different airway invasion scores on trials of thickened liquids). Differences in the judgements of the 3-level ordinal airway invasion scale were not statistically significant in this sample ($Z = 30.00$, $p = .317$). All four MBS studies had differences in level of airway invasion scores (penetration/aspiration) when judged at 30 fps compared to 15 fps.

Question 2: Do SLP feeding recommendations made from swallow parameters rated at 30 fps differ from those made from swallow parameters rated at 15 fps?

Feeding recommendations were provided via consensus coding with the goal of providing the safest and least restrictive diet (i.e., preventing aspiration while allowing for developmentally appropriate, normal swallowing) (Arvedson & Brodsky, 2002). Results of consensus coding from the two experienced NICU SLP examiners revealed that all four infants would have differing recommendations for bottle and/or nipple flow if their assessment of swallowing impairment was judged solely on swallow ratings from a 30 fps versus 15 fps MBS (Table 7). Two of the four infants were recommended to use a therapeutic bottle (Bionix) when the MBS was judged at 30 fps, but not when judged at 15 fps.

Half (2/4) of the infants were given different recommendations for thickening (i.e., adding rice or oatmeal cereal to formula). One infant would have the feeding recommendation of NPO, or speech-only feeds (depending on other factors including physician preference, tolerance of aspiration, standard of practice in different NICUs) when the MBS was judged at 30 fps, but was recommended to feed without restrictions when the recommendations were made from the 15 fps MBS. Tables 8 and 9 reveal PAS scores and the differences in feeding recommendations, respectively, for this specific MBS when rated at 30 versus 15 fps.

Additional differences in recommendations of MBS at 30 fps versus 15 fps were noted. These included time limits on feeding sessions, such as restricting to 10 minutes given concern for aspiration with fatigue in one MBS judged at 30 fps but not at 15 fps;

positioning changes (one instance of recommendation for upright position vs side-lying position, related to need for thickener); and recommendation for strict external pacing every 3-5 sucks rather than pacing as needed.

All but one of the infants were recommended to have a repeat MBS in two weeks. The expert NICU SLPs did not feel the results of the exception MBS, when judged at 15 fps, warranted a repeat study since there were safe options for upgrading as clinically appropriate. This same MBS judged at 30 fps required a repeat MBS to safely reassess readiness for diet upgrade given the restrictive feeding recommendations. When all recommendations were combined (4 studies x 6 recommendations), 54% (13/24) of feeding recommendations were different between 30 fps and simulated 15 fps.

Discussion

Modified Barium Swallow Studies (MBS) are used to quantify the presence and nature of dysphagia, and to provide safe feeding recommendations for infants in the NICU (Arvedson & Brodsky, 2002; Arvedson et al., 2020; Logemann, 1986; 1998). Misdiagnosed or undetected dysphagia, in particular the consequences of aspiration, may further complicate their stability (de Benedictis et al., 2009; Gewolb & Vice, 2007; Jadcherla, 2019; Lefton-Greif et al., 2006; Mizuno et al., 2007; Sheikh et al., 2001; Taniguchi & Moyer, 1994). Therefore, empirical evidence is critical to inform practice standards for instrumental assessment of swallowing via MBS to ensure these fragile infants receive the safest feeding recommendations.

The principle of ALARA (As Low As Reasonably Achievable) states that all unnecessary radiation should be eliminated given it's associated risks. Medically complex infants in the NICU often undergo a high number of radiologic procedures, which can result in high cumulative radiologic dosing (Hersh, et al., 2016; Thompson et al., 2018). In addition, radiation dose received during MBS is known to be highest in infants under 1 year and patients with increased severity of dysphagia (Bonilha et al., 2013b; Weir et al., 2007). Younger infants have also been found to be more sensitive to the carcinogenic effects of radiation (Suleiman, 2004; Weir et al., 2007). Therefore, the need to reduce radiation exposure is of high importance to the medical teams caring for this population. There are several ways to reduce radiation dose during MBS, one of which is to reduce the number of fluoroscopic pulses provided per second (Gelgano et al., 2019; Hiorns, 2006; Peladeau-Pigeon & Steele, 2015; Thompson et al., 2018). However, previous research suggests that this method of radiation dose reduction may decrease the sensitivity of the MBS results to certain components of dysphagia (Bonilha et al., 2013; Cohen 2007; Lefton-Greif et al., 2018; Peladeau-Pigeon & Steele, 2013; Peladeau-Pigeon & Steele, 2015). To date, little research has been done to assess the best fluoroscopic pulse rate during MBS on NICU infants.

Research conducted on adult populations revealed that there are differences in some, but not all, swallow parameter ratings between studies rated at 30 fps and those rated at 15 fps (Bonilha et al., 2013; Mulheren, et al., 2018). In particular, measures such as location of the bolus head at the time of the swallow and epiglottic movement were found to be rated differently at simulated 15 fps compared to 30 fps. Each of these measures are rated based on a single frame, at the moment of greatest excursion or the moment of initiation of movement. Therefore, if the frame used to score either of these measures was not present at the simulated 15 fps, because every-other frame had been removed, then the measure taken would be based on the frame before or after and therefore the parameter might be rated differently (Bonilha et al., 2013). In the present study, location of the bolus at swallow initiation was the only parameter found to be statistically significantly different between ratings measured at 15 fps versus 30 fps, likely due to the nature of measuring this parameter via a single frame (Bonilha et al., 2013). This finding has important clinician implications given location of the bolus at the time of the swallow may present increased risk for aspiration (Matsuo & Palmer, 2008). Other parameters, such as number of sucks per swallow, nasopharyngeal backflow, and pharyngeal residue are generally rated over multiple frames, and therefore less likely to be influenced by number of frames per second.

The penetration-aspiration scale (PAS scale) is a reliable measure of airway invasion in infant bottle-feeders (Gosa & Suiter, 2011; Martin-Harris et al., 2020; Rosenbeck et al., 1996). This study illustrated that the detection of aspiration and penetration, which is considered clinically significant in the pediatric population (Duncan et al., 2018; Friedman & Frazier, 2000; Gosa et al., 2017) may be compromised by reducing number of pulses per second. Of the 30 swallow trials included in analysis (across 4 MBS studies), 11 trials had different ratings of airway invasion (penetration or aspiration) when rated at only 15 fps rather than 30 fps. Percentages of differences in airway invasion ratings was consistent across liquid consistencies. These differences are likely explained by the occurrence of airway invasion over a single frame. This parallels the results of the Cohen study (2009) that found penetration events in the pediatric population can occur across just one frame, indicating that removing every other frame could result in undiagnosed penetration or aspiration events. It is important to note that other research found that tracheal aspiration was visible in infants below the vocal cords for 3 or more frames (Hiorns, 2006). However, the results of the current study found that aspiration and penetration events were similarly mis-quantified at the lower frame rate of 15 fps, indicating that lower frame rates result in reduced sensitivity to both penetration and aspiration events.

While these differences in penetration-aspiration scores were not statistically significant in this sample, a finding of different airway invasion measures in 11 out of 30 (36.67%) swallowing segments at 15 fps is certainly clinically concerning. Given the fragility of this population, detection of penetration or aspiration is critical, even if the aspiration only occurs on one swallowing trial. Layly and colleagues investigated the differences in penetration-aspiration scores across varying pulse rates in a pediatric population and emphasized the high rate of reliability in PAS scores judged at 30 pps versus 15 pps, with only a few differences found (Layly et al., 2019). While a high rate of reliability is important, it does not supersede the need for detection of impairment. If an aspiration event is missed due to reduced frame rate, the consequences could be profound (de Benedictis, 2009) even if the remainder of the swallowing trials were rated accurately (i.e., producing overall high reliability, sensitivity, and specificity of the test).

This issue of clinical significance was further elucidated by the results of Question 2 in the present study, which examined the clinical implications of changes in pulse rate. Based only on the five parameter ratings of swallowing trials, all four infants would have received different feeding recommendations if their MBS were judged at 30 fps compared to if they were judged at 15 fps. Most notably, one infant demonstrated aspiration on even the most cautious, safe bottle recommendations when judged at 30 fps, but not when judged at 15 fps. This discrepancy, a difference of only two PAS scores (each between PAS of 8 at 30 fps and PAS of 2 at 15 fps, a difference of silent aspiration at 30 fps to flash penetration at 15 fps), along with the differences in location of the bolus at swallow initiation, resulted in an extremely different set of feeding recommendations. When judged at 30 fps, the MBS ratings revealed that the infant had more severe dysphagia, resulting in a recommendation of NPO, or of once-a-day speech-only feeds with a therapeutic nipple and 10-minute time limit. In contrast, when judged at 15 fps, the MBS ratings indicated that the infant was safe to feed, with a therapeutic nipple, without limitations. If this MBS had been judged only at 15 fps, the infant would have feeding recommendations that may have increased the infant's risk of adverse consequences of dysphagia.

The primary motivation for this line investigation is the need for diagnostic accuracy while achieving ALARA. Not only does this research suggest that reducing pulse rate may compromise diagnostic accuracy, but other literature advises that alternative methods of radiation reduction may in fact outperform the reduction of radiation dose via pulse rate adjustments (Bonilha, et al., 2013b; Galgano et al., 2019; Suleiman, 2004; Thompson, et al., 2018). Galgano and colleagues found that using a higher pulse rate (30 per second) with a lower dose mode decreased overall radiation dose by 50%, and that the standardization of MBS protocol, including higher pulse rate, reduced radiation dose and did not increase fluoroscopy time (Galgano et al., 2019). Bonilha, Humphries, and colleagues also found that standardizing MBS procedures reduced radiation dose (Bonilha et al., 2013b). Further, they found that reducing pulses per second might result in the need to perform more tasks (or even repeat the MBS) given concern for decreased diagnostic accuracy, which in turn would increase fluoroscopy time and radiation dose (Bonilha et al., 2013b). Similar results were reported by other research groups, indicating that standardization, to include the use of 30 pps, not only does not increase radiation dose but may, in fact, decrease it. Finally, Henderson and colleagues examined radiation doses between lower (12.5 fps) and higher (25 fps) pulse rates (Henerson et al., 2015). They found that radiation dose and time were not significantly higher when using higher pulse rates, and that neither pulse rate exceeded recommended standard dosing from an MBS (Henderson et al., 2015; Weird et al., 2007). The current body of literature on this topic indicates that other methods of radiation reduction (i.e., standardization, reducing radiation time, etc.) may be more effective means of achieving ALARA than reducing number of pulses per second, and supports the continued use of 30 pps for MBS.

Limitations and Future Directions

There were two primary limitations of the current study: 1) small sample size, and 2) feeding recommendations based only on swallow parameter and airway invasion scores. The first limitation of this study is the small sample size of only four full MBS, given the preliminary nature of this investigation in the NICU population. Even though the four MBS were partitioned into 30 swallowing segments, this may be too small a sample (n = 30) to detect statistical significance with these measures. It is possible that if a larger number of swallowing trials (swallow video segments) were analyzed, statistically significant differences may have been found in additional swallow parameters, such as penetration-aspiration scores. Future research would benefit from a power analysis to determine appropriate sample size (and this preliminary study would assist in this effort).

Second, not providing the infants' medical history to the examiners for Question 2, in an effort to eliminate extraneous variables, may have influenced the examiners' decision making when providing feeding recommendations. These researchers do not promote making feeding recommendations based solely on PAS scores or any other swallow parameter, but rather to make them in the context of the infants medical and feeding picture as a whole. Further research should investigate how the addition of pertinent medical information about the infant affects feeding recommendations, and if it reduces or increases the importance of, or reliance on, swallow parameters in making recommendations.

Conclusions

In this preliminary investigation, the use of simulated 15 fps rather than the 30 fps typical to MBS for infants resulted in measurable differences in both SLP ratings of swallow parameters, as well as feeding recommendations based on those swallow parameter ratings. Most notably, even small, non-statistically significant differences in parameter ratings such as penetration-aspiration scores produced crucial changes to feeding recommendations, demonstrating the clinical significance of decreased test sensitivity and the importance of detection of impairment. Feeding alterations resulting from differences in swallow parameter ratings have potential consequences not only on infant health, but on the health system as a whole, as the consequences of un-identified dysphagia may increase length of hospitalization and cost of medical care. These preliminary results support the continued use of 30 pps during MBS conducted on infants in the NICU, although further investigation on a larger scale is warranted.

Table 1. *Patient demographics: gestational age (GA) at birth, post-menstrual age (PMA) at time of MBS, medical diagnoses*

Patient/MBS number	GA at birth	PMA at time of MBS	Diagnoses
1	27 weeks	41 weeks	Chronic lung disease (CLD), prolonged intubation, s/p MRSA pneumonia, slow growth trajectory
2	25 weeks	38 weeks	CLD, multiple intubations, milk protein intolerance, necrotizing enterocolitis (NEC)
3	34 weeks	38 weeks	Intrauterine growth restriction (IUGR), ventricular septal defect, monosomy 1p36 syndrome
4	26 weeks	39 weeks	Extremely low birth weight, CLD, patent ductus arteriosus (PDA), gastroesophageal reflux (GER)

Table 2. *Each MBS segmented by liquid consistency and modality (bottle/nipple type).*

Patient/MBS number	Number of video clip segments within MBS
1	10
2	6
3	7
4	9
Total:	32

Table 3. *Swallow parameter definitions and instructions for measurement, adapted from Gosa, Suiter, & Kahane, 2015*

Parameter	Definition
Number of sucks per swallow	Downward motion of mandible to mandible returning to neutral position counted as one suck. Number of sucks per swallow counted and averaged for each consistency/modality.
Collection of bolus before swallow	Location of body of bolus (posterior oral cavity-POC, base of tongue-BOT & valleculae-V, pyriform sinuses-PS) at onset of BOT propulsion. Lowest location of bolus (presenting highest risk) recorded for each consistency/modality.
Nasopharyngeal backflow	Presence or absence of bolus material entering the nasopharynx before during or after the swallow (reaches above the point of maximal soft palate contact with posterior pharyngeal wall). Recorded as "yes" for any instance within each consistency/modality.
Penetration-aspiration scale	Airway invasion recorded on scale of 1-8 from the penetration-aspiration scale (Rosenbeck, et al., 1996) to describe the level of airway compromise during the swallow. Highest level of airway compromise across all swallows was recorded for each consistency/modality.
Pharyngeal residue	Amount of pharyngeal residue after the swallow (none-N, less than trace-<T, or trace/greater than trace-T). Highest level of residue recorded for each consistency/modality.

Table 4. *Inter rater reliability by swallow parameter*

Swallow Parameter	Intraclass Correlation Coefficient	Level of Reliability
Sucks-per-swallow	98.2	Excellent
Bolus location at time of swallow	76.9	Good
PAS	84.6	Good
Residue amount	76.2	Good
Nasopharyngeal backflow	100	Excellent

(Koo & Li, 2016; Portney et al., 2000)

Table 5. *MBS video clips (each with one infant, liquid consistency, and bottle/nipple type) reviewed and swallow parameters rated by each examiner at either 30 fps or 15 fps*

MBS video clip #	SLP examiner A	SLP examiner B
1-16	Reviewed and rated at 30fps	Reviewed and rated at 15fps
17-32	Reviewed and rated at 15fps	Reviewed and rated at 30fps

Table 6. *Percentages of swallow trials with differences in level of airway invasion scores (penetration-aspiration scores) when scored at 15 fps compared to 30 fps*

	Ratio	Percentage
Total (30 video clips)	11/30	36.67%
Thin liquids	8/21	38.10%
Thickened liquids	3/9	33.34%
Half-nectar consistency	2/7	28.57
Nectar consistency	1/2	50%

Table 7. *Consistency and modality recommendations when MBS were rated at 30 fps vs 15 fps*

	Recommendations from ratings at 30 fps	Recommendations from ratings at 15 fps
MBS #1	Nectar thick liquid via Nuk slow flow	Thin liquid via Dr. Brown ultra preemie
MBS #2	Thin liquid via Dr. Brown ultra preemie	Slightly thick liquid via Dr. Brown preemie
MBS #3	Thin liquid via Bionix level 2	Thin liquid via Dr. Brown preemie
MBS #4	NPO or Thin liquid via Bionix level 1, 1x daily	Thin liquid via Dr. Brown ultra preemie

Table 8. *Level of airway invasion scores (1 = none, 2 = penetration, or 3 = aspiration) when MBS #4 was rated at 30 fps verses 15 fps with differences noted in "Thin via Dr. Brown ultra-preemie" and "Thin via bionix level 1". Penetration-Aspiration Scores (PAS) are included in parenthesis for clinician reference.*

Consistency/modality	Level of airway invasion scores when rated at 30 fps	Level of airway invasion scores when rated at 15 fps
Thin via Dr. Brown ultra-preemie	2 (PAS of 2)	2 (PAS of 2)
Thin via Dr. Brown ultra-preemie with special needs valve	3 (PAS of 8)	3 (PAS of 8)
STL via Dr. Brown level 1	3 (PAS of 8)	3 (PAS of 8)
STL via Dr. Brown preemie	3 (PAS of 8)	3 (PAS of 8)
NTL via Dr. Brown preemie	n/a (infant unable to elicit bolus)	n/a (infant unable to elicit bolus)
NTL via Dr. Brown level 1	3 (PAS of 8)	3 (PAS of 8)
Thin via Bionix level 1	1 (PAS of 1)	2 (PAS of 2)
Thin via Dr. Brown ultra-preemie	3 (PAS of 8)	2 (PAS of 4)
Thin via Bionix level 1	3 (PAS of 8)	2 (PAS of 2)

Table 9. *Expert team-based (consensus) recommendations of MBS #4 (same MBS as presented in Table 8) when recommendations were made from swallow parameters rated at 30 fps versus 15 fps.*

Recommendations when swallow parameters were rated at 30 fps	Recommendations when swallow parameters were rated at 15 fps
NPO or "Speech-only" feeds If medical team deciding to try "speech-only feeds (1x daily): -thin liquid via Bionix level 1 nipple -external regulation every 3-5 sucks -10-minute time limit -repeat MBS in 2 weeks	Bottle feed per infant cues -thin liquid via Dr. Brown ultra-preemie nipple -external regulation every 3-5 sucks -20-30 minute time limit -repeat MBS in 2 weeks

**Speech-only feeds indicates that no one will feed the infant orally except for the SLP who will provide one therapeutic feeding trial max per day. At the two NICUS where the expert examiners practiced, this is considered a cautious alternative to making an infant NPO when there is assumed aspiration risk on all consistencies/modalities.*

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Part II: Speech-Language Pathologists' Perspectives on Side-Lying Position to Improve Swallow Performance during MBS

Abstract

PURPOSE: The purpose of this qualitative investigation was to report current practices of hospital-based SLPs related to infant modified barium swallow studies (MBS), to determine whether or not SLPs use side-lying position during MBS, to examine possible differences in the use of positioning, and to explore SLPs' perceptions and experiences in this practice. Research questions guiding this inquiry were: What is the current practice of hospital-based pediatric SLPs in regard to the use of side-lying position during infant MBS? What is the experience of the hospital-based SLP in their use of side-lying position during MBS? What are the barriers or benefits to using side-lying position during MBS, as perceived by the SLP?

METHOD: Qualitative data was collected through six semi-structured interviews of SLPs currently practicing in level 3 or 4 NICUs with at least two years of experience working in a hospital setting. Interviews were transcribed, coded via initial coding and a consensus coding approach, and analyzed to develop themes.

RESULTS: Three themes emerged from the analysis of the coded interviews: 1) variations in practice patterns, 2) factors influencing clinical practice, and 3) items that SLPs identified as needs to facilitate change in their clinical practice.

CONCLUSION: While SLPs acknowledge the importance of MBS replicating an infants' typical feeding, some SLPs who consistently use side-lying position during feeding do not conduct MBS in side-lying position. This inconsistency in practice results from the SLPs' perceived barriers, including lack of experience, concern for interdisciplinary conflict, need for MBS protocols, and lack of research investigating the impact of side-

lying position on infant swallow function and safety. SLPs report the need for additional research that investigates whether side-lying position alters, possibly improving airway protection during swallowing for at-risk infants.

Introduction

Speech-Language Pathologists (SLP) are the primary healthcare providers for evaluating and treating infants with suspected dysphagia (ASHA, 2016; Ross, 2008) Instrumental assessment via fluoroscopy, the modified barium swallow study (MBS), is integral to diagnosing dysphagia and recommending feeding interventions, and is typically completed by an SLP and pediatric radiologist. Although a side-lying position has been noted by SLPs as a best practice for feeding in many neonatal intensive care units (NICU), (Ross, 2013; Shaker, 2019; Thoyer et al., 2012), infant MBS have traditionally been completed in the upright, or cradled, position. As more literature encourages clinicians to replicate an infant's "typical" feeding position during the MBS, position adjustments during MBS are becoming more common (Arvedson et al., 2020). However, there is a dearth of research on infant positioning during MBS, and what is available often follows an adult model of upright positioning despite the common use of side-lying position as a reported clinical feeding strategy in the NICU (Logemann, 1998; Uhm et al, 2013; Zerilli et al., 1989).

The incongruity between use of side-lying position during feeds, and completing MBS in an upright, or cradled, position, presents several challenges including generalizability of study results, caregiver buy-in, and medical team acceptance of the results of the study. That is, if aspiration was observed in upright position, there may be disputes as to whether or not the infant is also aspirating in side-lying position. Although use of side-lying position during MBS appears to be gaining popularity among clinicians, there is currently no standard practice for when and how to implement it in the hospital setting and no research exploring its use, barriers, and benefits. Thus, the purpose of this qualitative investigation was to bring to light current practices of Speech-Language Pathologists in regard to NICU MBS, to assess the consistency of practice patterns in the use of positioning, and to explore SLPs' perceptions and experiences in this practice. Specific research questions guiding this inquiry were: What is the current practice of hospital-based pediatric SLPs in regard to the use of side-lying position during infant MBS? What is the experience of the hospital-based SLP in their use of side-lying position during MBS? What are the barriers or benefits to using side-lying position during MBS, as perceived by the SLP?

Methods

This study was reviewed and approved by the James Madison University Institutional Review Board for human subjects research (protocol ID 20-1057).

Data Collection

Qualitative data was collected through the use of semi-structured interviews with six SLPs who work at six unique Level-III to IV Neonatal Intensive Care Units (NICU). A purposive-convenience sampling technique (Creswell & Plano Clark, 2011) was employed. Inclusion criteria for SLPs that were interviewed was as follows:

1. holding current and active license to practice as a Speech-Language Pathologist
2. currently practicing at least part-time in a Level III-IV NICU
3. have at least two years working in a hospital setting (preferably NICU)
4. have the desire and ability to participate in a 30-minute phone interview.

Data was collected via 30-minute, semi-structured interviews, following the question protocol detailed in Table 1. Given the qualitative nature of this study, which reflects a constructivist world view, the participants were encouraged to provide additional information and follow personal lines of thought not initially outlined. Further, given the emic positioning of the primary researcher as outlined in the positioning statement in Appendix A, clarifying questions were presented as opportunities arose in the discussion. All interviews were digitally recorded and later transcribed verbatim.

Data Analysis

Qualitative data was analyzed according to a grounded theory approach. Grounded theory, first developed by Glaser and Strauss (1967), is a systematic method of developing theory through rigorous collection of and analysis of data (Charmaz & Belgrave, 2012). This study follows in the tradition of a constructivist approach to grounded theory, in which emphasis is placed on social construction and developing an understanding of how participants construct meaning in their lives (Charmaz, 2007). In this particular study, grounded theory was implemented to build an understanding of how Speech-Language Pathologists view their current practice and construct meaning of their clinical decision making in regard to a very specific component of clinical practice - the use of side-lying during modified barium swallow studies.

The process of coding in grounded theory allows for the capturing of the language and perspectives of the participants in order to develop an emergent theory (Charmaz, 2014). This process is complex and multi-layered. Data was entered into NVivo to assist with data management and coding. Interview transcripts were read and re-read thoroughly by the primary researcher and one additional researcher. The interviews were initially coded by the researchers independently, then were compared and differences resolved using a consensus approach (Braun and Clark, 2006). Once coding was completed, researchers developed initial themes based on codes and code categories, which were then reviewed, refined, and named with the help of a third researcher who is the faculty advisor for this project and who has extensive experience in qualitative research. Finally, member check-in was utilized to assess the themes and theories that emerged to ensure a grounding in the lived experience of the SLPs who were interviewed (Merriam & Tisdell, 2016).

Findings and Emergent Themes

Three broad themes emerged from the analysis of the coded interviews—variations in practice patterns, factors influencing clinical practice, and items that SLPs identified as needs to facilitate change in their clinical practice (Table 1).

Variations in Practice Patterns

The broad theme of variations in practice patterns can be further broken down into sub-themes of incongruities in practice, and incongruities in perception of practice. One of the most frequently coded items was the idea of instrumental assessment replicating a typical feed. "MBS should replicate feeding" was coded 21 times across multiple interview questions, and was mentioned by all six SLPs. This sentiment is echoed in the literature (Arvedson et al., 2020). However, while all six SLPs stated that they frequently recommended side-lying position for infants during feeding, only one SLP reported using side-lying consistently during MBS, as part of a standard protocol. Two of the six SLPs had never completed an MBS all or partially in side-lying position. This difference in practice patterns between the use of side-lying position clinically versus during MBS is in direct contrast to the idea that the MBS should replicate feeding. If most infants are being fed in a side-lying position clinically, but most MBS are being conducted in an upright/cradled position only, then there is a chiasm between diagnostic protocols and clinical practices.

The second sub-theme that emerged was the presence of differences in SLPs' perceptions of using side-lying during MBS. When asked how radiologists and other health care providers responded to the use of side-lying position during MBS, SLPs responded that they had no difficulties nor received any negative feedback, and that they had not experienced barriers to implementing different positions during MBS. However, when probed later in the interview session, 23 different barriers were stated, coded a total of 87 times, and mentioned by all six SLPs. Potential barriers to using side-lying position during MBS fell into two categories—interdisciplinary issues and SLP perceived barriers. SLPs reporting no experienced barriers, but later listing a broad array of potential barriers, suggests an uncertainty in SLPs' perceptions relative to the feasibility of using side-lying position during an MBS.

Factors Influencing Clinical Practice

Within this broader theme, two primary categories emerged: benefits and barriers. Interestingly, all coded benefits were infant driven (benefits to the infant), including physiologic benefits, likely improved swallow function, and mimicking a typical feeding. In contrast, only one coded barrier had to do with the infant—concern for increased radiation exposure if assessing the infant in both upright and side-lying position. All other barriers fell into additional categories related to either concern for interdisciplinary issues (i.e., "push-back" from radiologists) or SLP concerns (i.e., diminishing productivity). Additional sub-categories included lack of research, lack of education and experience, lack of protocol, and lack of "buy in".

What SLPs Indicated as Needed

The third overarching theme that emerged revolved around the needs of SLPs if they were to change their clinical practice such that MBS positioning would replicate positioning during feeding. The most prominent sub-theme that evolved was the need for further research and evidence. The code “objective data” was frequently used (9 times), as was the code “direct comparison”, referencing the need to directly compare infant swallow function in upright versus side-lying position. In particular, these SLPs stated the need for research directly comparing the incidence of penetration and aspiration in upright versus side-lying position, for at-risk infants. They stated that this information would help with provider and parent buy-in and would guide their practice both clinically and during instrumental assessment. Additionally, ideas of interdisciplinary collaboration permeated the responses, as did the need for protocols and further education of SLPs, providers, nurses, radiologists, and infants’ parents (Table 2).

Summary and Justification for Additional Quantitative Investigation

The collective perspectives, based on clinical experiences, revealed in this study emphasize the need for more research on the effect of side-lying position on infant feeding and swallowing outcomes. While SLPs are regularly using side-lying position during infant feeding, they do not consistently use this position during MBS. These SLPs expressed the need for quantitative research assessing the potential influence of position on infant swallow function. If improvements can be empirically documented, this will advance provider acceptance and promote evidence-based practice. While there were a variety of specific research needs articulated, the most dominant codes related to future research were those surrounding topics of "aspiration", "airway protection", and "safety" during the swallow. The voices of respondents in this qualitative study lend merit to the importance of further investigation – a quantitative study addressing the question: does side-lying position improve swallow safety for at-risk infants?

Table 1. *Semi-structured interview questions.*

Semi-structured Interview Questions	
1	Do you use side-lying as a positioning strategy during feeding sessions?
2	Do you recommend it for NICU patients? If yes, how often?
3	Tell me about the typical NICU MBS protocol used in your professional practice setting.
4	Has there been a specific time in your clinical practice that you either used or observed side-lying positioning in an MBS? Why was side-lying used?
5	(If yes for #4) How did the MBS radiologists and radiology technician respond to using side-lying position?
6	In your professional experience, how side-lying position is used clinically in the NICU?
7	What is your stance on the use of side-lying positioning during MBS?
8	Have you ever had nurses, physicians, or other health care professionals question the use of using side-lying either clinically or during an MBS? Tell me about it.
9	What information about the use of side-lying position in MBSS would be helpful to your clinical practice? What research would you like to see completed?
10	From your experience, please share your thoughts on barriers/benefits you perceive of using side-lying during MBS.
11	(Simulated parent ed) Imagine I was a parent that had an infant in the NICU on whom you had completed an MBSS and for whom you were recommending side-lying position. How would you educate me on the results and recommendations from your study?

Table 2. *Sub-themes and sample codes for the third broad theme of "What SLPs indicate as needed". Note that not all codes are included in this table.*

Sub-theme	Sample codes
Additional research	Direct comparison of swallow function by position Using the same bottle and consistency in both positions Compare outcomes Research needed to implement evidence-based practice No or limited research on this topic Need for evidence to support clinical practice
Education/training/experience	Lack of experience of SLP/RN/radiologist Need to educate nurses on how to use side-lying position Educating radiologists or radiology techs on how to implement side-lying position
Practice protocols	Don't have a consistent protocol for position during MBS Need for protocol or guidelines Protocol on how to implement side-lying
Interdisciplinary collaboration	Address nursing concerns for infant safety Radiologists concerned for radiation dosing Need to address radiology frustration/annoyance

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Part III: The influence of side-lying position on oropharyngeal swallow function in at-risk infants: An exploratory study

Abstract

PURPOSE: The purpose of this exploratory investigation was to determine the effect of side-lying position on infant oropharyngeal swallow physiology as defined by level of airway invasion, location of the bolus at the time of swallow initiation, and suck-swallow-breathe coordination.

METHOD: Infant MBS recordings were retrospectively examined in matched-pairs comparing nine at-risk infants swallowing with the same liquid consistency, bottle, and nipple in both an upright/cradled position and a side-lying position. Swallow parameters were measured independently and through a consensus coding approach, and results were reported descriptively and statistically.

RESULTS: Side-lying position reduced severity of airway invasion during the swallow for some, but not all, medically complex infants. Bolus location at the time of swallow initiation was overall higher, representing decreased risk of airway invasion, when at-risk infants were fed in side-lying position compared to cradled position. Infants fed in side-lying position demonstrated, on average, fewer swallows per breaths compared to when they are fed in cradled position.

CONCLUSION: Side-lying position should be considered as a viable strategy to improve swallow safety in at-risk infants who exhibit oropharyngeal dysphagia. Additional investigation with larger, randomized controlled methods would further inform the effect of side-lying position on infant swallow function.

Introduction

Infants require sufficient nutrition and hydration to thrive and develop. Most infants have the ability to feed successfully at birth. At-risk infants, such as those born prematurely or with certain medical conditions, are more prone to swallowing impairments (i.e., dysphagia) and feeding difficulties (Arvedson et al., 2020; Arvedson et al., 1994; Newman et al., 2001; Weir et al., 2011). Dysphagia in at-risk infants may result in feeding-related bradycardia, oxygen desaturation, stress during feeding, and prolonged transition to oral feeds, as well as medical compromises such as chronic respiratory symptoms, pneumonia, progressive lung disease, undernutrition, and death (de Benedictis et al., 2009; Gewolb & Vice, 2007; Jadcherla, 2019; Lefton-Greif et al., 2006; Mizuno et al., 2007; Serel Arslan et al., 2018; Sheikh et al., 2001; Taniguchi & Moyer, 1994). Promoting safe and efficient feeding experiences for at–risk infants is critical to their long-term health and development (Arvedson et al., 2020; Dodrill et al., 2008; Ferguson et al., 2015; Mercado-Deane et al., 2001; Pickler et al., 2009).

Feeding specialists, such as speech language pathologists, work with at-risk infants to reduce adverse events associated with dysphagia and to improve feeding outcomes (Pickler et al., 2009; Thoyre et al., 2012). SLPs employ a variety of strategies, such as using slow flow nipples, providing breathing breaks, or changing the infant's feeding position to optimize feeding outcomes (Rasley et al., 1993; Thoyre et al., 2012). An elevated side-lying position is one such strategy that is recommended for at-risk infants, given its reported benefits to safe feeding and its natural similarity to the infant's positioning during breast feeding (Dawson et al., 2013; Ross, 2013; Shaker, 2019; Thoyre et al., 2012).

Side-lying position, as compared to a more traditional cradled or upright position, is thought to promote improved state regulation, decrease work of breathing, minimize infant stress cues during feeding, and encourage suck-swallow-breathe coordination (Jones, 2008; Park et al., 2018; Shaker, 2012; Thoyre et al., 2012). Research indicates that side-lying position while feeding promotes higher oxygen saturation scores and decreased variability in heart rate (Clark et al., 2007; Girgin et al., 2018; Park et al,. 2018; Thoyre et al., 2012). Further, feeding in a side-lying position may increase volumes consumed and decrease incidences of choking (Girgin et al., 2018Raczyńska & Gulczyńska, 2019). Unfortunately, the physiology underlying these reported improvements to infant feeding with postural changes are not well researched and are poorly understood (Lau, 2013).

There are several theories as to why side-lying position improves infant feeding outcomes. Side-lying position may allow for improved oxygenation due to decreased work of breathing when the lungs do not have to expand against gravity (Mizuno et al., 2000; Shaker, 2012). Similarly, the lack of gravitational effect pulling the tongue and soft palate into the pharynx may result in improved airway patency regardless of feeding activity (Litman et al., 2005; Mizuno et al., 2000; Thoyre et al., 2012). One prominent theory suggests that side-lying position reduces the flow rate of liquid into the oropharynx, allowing the infant to better control the bolus and reducing pharyngeal pooling of the bolus, thus improving suck-swallow breath coordination and reducing the risk of liquid entering the airway during the swallow (i.e., aspiration) (Girgin et al., 2018; Mizuno et al., 2000; Park et al., 2014; Shaker, 2012). However, to date, no research has examined this theory by directly assessing airway protection during the swallow with the infant in the side-lying position.

Recent qualitative investigation supports that while clinicians, specifically speech-language pathologists (SLP), report regularly using side-lying position as a safe feeding strategy for at-risk infants, there is not a consistent standard for incorporating side-lying position during instrumental assessment of swallowing such as the modified barium swallow study (MBS) (White & O'Donoghue, 2020). Additional findings from that research included that practicing SLPs are concerned about barriers to implementing side-lying position during instrumental assessment (i.e., interdisciplinary conflict and negative impact on productivity), and that SLPs are seeking empirical evidence relative to this practice. Specifically, SLPs indicate that they need research comparing the incidence of penetration and aspiration in upright versus side-lying position for at-risk infants. They stated that this information would promote provider and parent buy-in and would guide their practice both clinically and during instrumental assessment (White & O'Donoghue, 2020). The above study is provided in Part 2 of this dissertation document.

<u>Research Questions and Hypotheses</u>

This research explored the impact of side-lying position on infant swallowing physiology through radiologic imaging of the oropharynx during bottle feeding. The research questions were: 1) does side-lying position decrease the incidence and severity of airway invasion during feeding? 2) does side-lying position impact the location of the bolus at the time of swallow initiation? 3) does side-lying position improve suck-swallow-breathe coordination? The null hypothesis was that there would be no difference in the level of airway invasion, bolus location, or suck-swallow-breathe coordination between upright and side-lying positions when assessed via modified barium swallow study (MBS).

Methods

The methods reviewed herein were designed to address the research questions while also detailing the practice protocols that underlie this retrospective investigation. The Institutional Review Boards at both James Madison University and Virginia Commonwealth University Health system (VCUH) approved this research protocol. Given the retrospective approach to data collection, no infants received a modified barium swallow study (MBS) solely for the purpose of this research.

Standard MBS Procedures at VCUH

Modified barium swallow studies (MBS) were completed by a speech-language pathologist and a pediatric radiologist following the VCUH MBS guidelines for infants (Figure 1). Swallowing trials were administered starting with thin liquids (VARIBAR® Thin Liquid barium sulfate powder mixed with sterile water per manufacturer instructions) via the slowest available flow of each infant's typical bottle system (Arvedson et al., 2020; Patel et al., 2016). Subsequent bolus presentations and compensatory interventions (i.e., change in liquid consistencies/viscosity, change in nipple flow rates) were determined as clinically indicated based on the infant's response to the previous swallowing trial, per the discretion of the evaluating speech-pathologist and radiologist (Arvedson et al., 2020; Fishbein et al., 2013; Patel et al., 2016; Sitton et al., 2011; Suterwala et al., 2017). All MBS were conducted using continuous fluoroscopy and were recorded at 30 frames per second on a high resolution TIMS recording system (TIMS Medical Video Platform™, Foresight Imaging, LLC).

Positioning Procedures

All infants were positioned at the beginning of the study in a reclined-upright position (Figure 2.A) using a Tumble Forms 2 Deluxe Floor Sitter (Patterson Medical/Performance Health). If indicated, infants were repositioned into to a semi-elevated side-lying position. This was achieved by rotating the fluoroscopy table top to an approximately 30-degree angle and placing the infant laying on their side on top of the table. (Figure 2.B). Per protocol, the indication for attempting the side-lying assessment was aspiration on all or most previous trials; therefore, side-lying position was implemented only at the end of the study. For all positions completed during an MBS, the swallow was captured in a lateral viewing plane that allowed for visualization of the oral cavity, nasal cavity, pharynx, larynx, and cervical esophagus.

<u>Data Collection</u>

Data was collected from recordings of previously completed modified barium swallow studies (MBS) of infants evaluated at VCUH over a 24-month period. MBS studies adhering to the following criteria were included in this study:

1. The presence of dysphagia, specifically aspiration, on the MBS, as documented in the electronic medical record and confirmed by the primary investigator upon review of the MBS recording.
2. The MBS assessed the oropharyngeal swallow with the infant in both an upright and side-lying position across the same bottles, nipples and consistencies.

3. The ages of the infants included were between 38 to 52 weeks post-menstrual age (38 weeks PMA is the youngest age that infants may participate in an MBS at VCUH).

Modified barium swallow study recordings were reviewed retrospectively. Swallow function was analyzed only for comparative trials; that is, where the infant was imaged with the same bottle, nipple, and liquid consistency in both upright and side-lying position. This approach made postural comparisons more reliable by reducing the impact of extraneous variables such as bottle, nipple, and viscosity on any observed differences in outcome measures. MBS video clips for upright and side-lying position were analyzed in QuickTime player (Apple Inc.) such that frame-by-frame analysis was possible.

Airway invasion was measured using the Penetration-Aspiration scale (PAS) (Rosenbek et al., 1996). The PAS is an 8-point scale that is a reliable measure of airway invasion in infant bottle-feeders (Gosa & Suiter, 2011; Martin-Harris et al., 2020). PAS scores were independently analyzed by a speech-language pathologist (the primary investigator for this research) who did not perform the MBS and who was blinded to patient and examination information (i.e., MBS results and report). The highest observed PAS score was reported for each swallowing clip. After independent analysis, scores were compared to the initial scores from the SLP performing the MBS as documented in the electronic medical record. In cases where the scores differed, a third speech-language pathologist reviewed the images and discrepancies were resolved by a consensus rating approach (Lefton-Grief, et al., 2018; McGratten et al., 2020). All SLPs involved in analysis had at least three years of experience conducting infant MBS.

According to Steele and Grace-Martin (2017), the traditional PAS scale is categorical in nature, and does not fit the criteria for an ordinal outcome measure representing the severity of airway invasion. Therefore, for the purposes of this study, the PAS scale used to rate level of airway invasion was transformed into an ordinal scale with three levels of airway invasion (Table 1). The transformation outlined in Table 1 was based on previous literature using a three-level scale that was specific to a pediatric population (McGratten et al., 2020; Newman et al., 2001; Suterwala et al., 2017). Data was analyzed using the 3-level ordinal scale.

Two additional parameters of swallow function, bolus location at the time of swallow initiation and suck-swallow-breathe coordination, were assessed with the intent to establish the mechanism (i.e., physiologic cause) of potential changes in airway invasion in side-lying position compared to upright/cradled position. Swallow initiation was measured by indicating the location of the bolus head (i.e., base of tongue-BOT, vallecula-V, pyriform sinuses-P) at the onset of base of tongue propulsion (Gosa et al., 2015). Lowest location of bolus (presenting highest risk) was recorded for each swallowing trial (of one infant, one bottle/nipple type, and one modality at either side-lying or cradled position) (Gosa et al., 2015). As with PAS scores, consensus scoring was implemented for bolus location at the time of swallow initiation.

Suck-swallow-breathe (SSwB) coordination was assessed using three ratio measures: between sucks to swallows, sucks to breaths, and swallows to breaths (Barlow, 2009; Lau, 2006; Sakalidis et al., 2013; Sakalidis & Geddes, 2015). Sucks per swallows generally represents sucking efficiency, indicating how many sucks are required to form a bolus, whereas swallows to breaths is more indicative of coordination of swallow-respiration (Fucile et al., 2012, Legarde et al., 2019; Sakalidis et al., 2013). Optimal coordination is considered a 1:1:1 SSwB ratio (Lau et al., 2006; Legarde et al., 2019; Palmer, 1993). The number of sucks (S), swallows (Sw), and breaths (B) were counted for each swallowing trial. Given the retrospective nature of this investigation, visible opening of the larynx was used as a proxy measurement for a breath. Counting started after the first identifiable breath (laryngeal opening) in each swallowing trial recording, in order to accurately measure the full nutritive sucking burst. Suck-swallow-breathe ratios were determined by dividing the number of sucks to swallows, number of swallows to breaths, and number of sucks relative to breaths (Sakalidis et al., 2013).

Data Analysis

Data was analyzed and reported both descriptively and statistically. Statistical analysis compared matched-pairs of MBS swallowing clips (same infant, same bottle/nipple, same consistency, in upright/cradled and side-lying positions) using a Wilcoxon signed-rank test. Location of bolus at time of swallow initiation was also compared using a Wilcoxon signed-rank test given that location of bolus head represents level of risk of airway invasion. The suck-swallow-breathe ratios were compared using dependent measures t-tests. An a priori alpha level was set at .05 (Fishbein et al., 2013; Fucile et al., 2012; Mulheren et al., 2018; Thoyre et al., 2012). Effect sizes of <0.3 were considered small, 0.3-0.5 were considered moderate, and >0.5 were considered large (Cohen, 1992; Tomczak & Tomczak, 2014). An a priori power analysis was conducted using G-Power to evaluate the sample size required to detect a statistically significant difference, based on pilot data. The analysis indicated that a sample size of 8 would provide a power of .9 (n = 8 indicates the number of matched pairs required of swallow trials across all infants). The study sample consisted of 44 swallowing clips (22 matched pairs) from 9 modified barium swallow studies (representing 9 unique infant subjects) at VCUH.

Results

Participant Demographics

Of the sample studied (n =9), six infants were in the NICU at the time of their MBS, one infant was on an inpatient pediatric unit, and two infants were seen in an outpatient setting as part of a NICU follow-up program. Two infants were born term while the remaining were born prematurely ($M_{gestationalage}$ = 29.88 weeks, SD = 6.13). Chronological age of infants at the time of assessment ranged from 2 weeks to 4 months (M = 2.56 months, SD = 1.21): between 38 and 48 weeks post-menstrual age (Mean PMA = 40.88 weeks, SD = 3.44). Post-menstrual age indicates the time between the last day of menstruation to birth (gestational age), plus the chronologic age (post-natal age) (American Academy of Pediatrics, 2004). Of the 9 infants included, 7 were male and 2 were female.

Infants whose swallowing clips were included in this study carried a variety of medical diagnoses including, but not limited to, respiratory (i.e., chronic lung disease, pneumonia, upper respiratory infections, etc.), gastrointestinal (i.e., GERD, dysmotility, constipation, anal stenosis, feeding intolerance, etc.), neurologic (i.e., grade 3 or 4 intraventricular hemorrhage, hydrocephalus, VP shunt, abnormal brain imaging, etc.), and structural (i.e., cleft palate, laryngomalacia). Table 2 presents an overview of subject demographics, including number of video clips included in analysis.

Differences in airway invasion

Differences in level of airway invasion between swallows in cradled position and swallows in side-lying position were found in 9 of the 22 matched-pairs (41%) (Table 3). In all cases of difference, the level of airway invasion was higher (more severe on the three-level ordinal scale of 1 = no airway invasion, 2 = penetration, or 3 = aspiration) in swallows observed in the cradled position. Six of the nine (67%) infants demonstrated improved airway protection in side-lying position. Three infants did not experience decreased airway invasion by position (infant IDs 5, 6, and 8). No infants (0%) experienced worsened airway invasion when fed in side-lying position.

A Wilcoxon signed-rank test was conducted to determine if airway invasion differed between swallow trials conducted in upright position versus those in side-lying position. The assumptions of ordinal data and matched-pairs data were met. Based on a significance level of 0.05, there was a statistically significant reduction in airway invasion when infants were fed in side-lying position, $Z = -2.81$, $p = .005$, and a large effect size ($r = .599$) (Tomczak & Tomczak, 2014).

Differences in other swallow parameters

Location of the bolus at the time of swallow initiation was found to be significantly higher (i.e., higher anatomic location indicating lower risk) when infants swallowed in a side-lying position, $Z = -2.000$, $p = .046$ (Table 4).

The ratio of sucks to swallows was not significantly different between swallowing trials in a cradled position (M = 2.56, SD = 1.87) and swallowing trials in a side-lying position (M = 3.42, SD = 3.01), $t(17) = -1.55$, $p = .139$, suggesting efficiency of liquid extraction did not differ by position. The ratio of sucks to breaths was also not found to be different in a cradled position (M = 3.29, SD = 2.00) compared to side-lying position (M = 3.71, SD = 3.17), $t(17) = -.558$, $p = .584$. The ratio of swallows to breaths was found to be statistically significant for differences between swallowing trials in a cradled position (M = 1.49, SD = .96) and side-lying position (M = 1.01, SD = .31), $t(16) = 2.354$, $p = .032$, indicating that infants swallowed more times per one breath when feeding in an upright position. Of note, one infant was noted to have a swallow to breath ratio of 11:1, which was considered an outlier based on a calculation of 1.5 times the interquartile range. To determine whether the outlier influenced results, this inferential statistical test was conducted twice, with the outlier (i.e., the entire sample) and without outliers. Results were nearly identical and both significant at the .05 level.

<u>Individual Differences</u>

Given the small sample size and variability across infants, results are presented here in case report form, in addition to the aggregate results previously outlined.

Infant ID #1

Infant #1 was born extremely prematurely (25 weeks gestation) and carried diagnoses of chronic lung disease, prolonged intubation, GERD, and constipation. This infant, who received his MBS while in the NICU (PMA = 38 weeks), demonstrated swallow initiation at the level of the pyriforms across all trials. There was no difference in level of airway invasion for two of the three modalities (Dr. Brown preemie and bionix level 1). However, while he aspirated (airway invasion level 3, PAS 8) with Dr. Brown ultra-preemie when fed in an upright position, when fed with this same bottle/nipple in side-lying position he demonstrated no higher than an airway invasion score of 2 (PAS 4). Of note, infant #1 demonstrated a swallow run of 11 swallows to 1 breath when fed with the Dr. Brown preemie nipple in upright position.

Infant ID #2

Infant #2 was a late-preterm birth, carried diagnoses including hydrocephalus and absent septum pellucidum, and had a history of multiple upper respiratory infections. He was assessed in an outpatient setting as part of a NICU follow up clinic (PMA = 48 weeks). This infant was assessed in both positions with only one modality, the Dr. Brown bottle with preemie nipple. Infant #2 demonstrated a swallow initiation delay to the pyriforms and silent aspiration (PAS 8) when fed in an upright position. In a side-lying position he initiated his swallow at the level of the vallecula and demonstrated no penetration or aspiration (PAS 1). He did not demonstrate differences in number of swallows to breaths by position.

Infant ID #3

Infant #3 was born term (38 weeks gestation) and was admitted to an inpatient pediatric unit at 40 weeks PMA after a brief resolved unexplained event (BRUE) at which time she was diagnosed with GER (gastroesophageal reflux). This infant demonstrated differences in airway invasion, location of the bolus, and swallows per breaths by position. Infant #3 demonstrated bolus location in the vallecula for all swallows in a side-lying position, and bolus location in the pyriforms for all swallows in an upright position. She also demonstrated a reduction in level of airway invasion for all swallowing trials in a side-lying position (PAS 8 to PAS 1; PAS 4 to PAS 1; PAS 8 to PAS 4). In addition, when feeding in a side-lying position she demonstrated a swallow to breath ratio of 1:1 across all trials, whereas in an upright position she demonstrated more swallows relative to each breath (closer to 2:1 on average).

Infant ID #4

Infant #4 was born at 27 weeks gestation and remained in the NICU at the time of his MBS (PMA = 40 weeks). His medical history included prolonged intubation, chronic lung disease, and gastrointestinal dysmotility. Infant #4 was assessed in both positions with the Bionix bottle set at level 1. While the location of the bolus at time of swallow initiation remained in the pyriforms for both positions, the level of airway invasion decreased from aspiration (airway invasion level 3; PAS 8) in an upright position to penetration (airway invasion level 2; PAS 4) in a side-lying position. Suck-swallow-breathe coordination could not be fully assessed for infant #4 due to lack of identifiable breaths in the recorded swallowing clips.

Infant ID #5

Infant #5 was born extremely prematurely at 24 weeks gestation, had a complex medical course including diagnoses of chronic lung disease, bilateral grade IV intraventricular hemorrhages, and hydrocephalus, and required prolonged intubation and a VP shunt placement. Infant #5 remained in the NICU at the time of his MBS (PMA = 43 weeks). He was assessed with three different modalities in both upright and side-lying position:

the Dr. Brown preemie, the Dr. Brown ultra-preemie, and the Bionix level 1. Infant #5 did not demonstrate differences in location of the bolus at swallow initiation or in level of airway invasion by position in any of the three swallowing trial comparisons (PAS 8 on all trials and all positions). Suck-swallow-breathe coordination could not be fully assessed for infant #5 due to lack of identifiable breaths in the recorded swallowing clips.

Infant ID #6

Infant #6 was also born extremely prematurely at 24 weeks gestation and was in the NICU at the time of her MBS (PMA = 38 weeks). Her medical history included prolonged intubation, chronic lung disease, feeding intolerance, and aspiration pneumonia. Infant #6 also did not demonstrate differences in location of the bolus or level of airway invasion by position, for either of the modalities trialed (Dr. Brown ultra-preemie and Bionix level 1). Of note, she did demonstrate differences in swallow function by bottle type, with a higher level of swallow initiation and decreased airway invasion (penetration without aspiration; PAS 2) when fed with the Bionix level 1. These differences by bottle were observed in both positions. Infant #6 did demonstrate differences in average number of swallows per breaths by position, from an average of 3.33 swallows per breath in upright position to 1.5 swallows per breath in side-lying position.

Infant ID #7

Infant #7 was born at 28 weeks and carried diagnoses of laryngomalacia and feeding intolerance. He participated in the MBS during his NICU stay (PMA = 38 weeks). He was assessed in both upright and side-lying position via the Dr. Brown ultra-preemie. He did not demonstrate differences in location of the bolus at the time of swallow initiation, but did demonstrate a difference in level of airway invasion. When fed in an upright position, infant #7 demonstrated aspiration (PAS 8), while in a side-lying position he demonstrated only penetration (PAS 4). He demonstrated a decrease in average swallows per breathes from 1.33 in upright position to 0.80 in side-lying position.

Infant ID #8

Infant #8 was born term but was also assessed while in the NICU (PMA = 42 weeks) due to his complex medical conditions including 16q11.2 deletion, cleft palate, and laryngomalacia. Due to his cleft palate, he was assessed with the Dr. Brown ultra-preemie with valve, Dr. Brown preemie with valve, Haberman medium flow, and Haberman fast flow. Infant #8 demonstrated PAS 8 in both positions with the Haberman medium and fast flow bottles. However, when fed with the Dr Brown bottle (both preemie and ultra-preemie nipples), he demonstrated a PAS of 2 in an upright position, and a PAS of 4 in a side-lying position. While this did not present as a difference in level of airway invasion with the adjusted 3-level scale, clinically this indicates increased depth of penetration when this infant swallowed in a side-lying position. He demonstrated high ratios of sucks to swallows on all modalities and positions, likely due to oral phase impairments (not assessed in this study), and demonstrated similar swallow to breath ratios in both positions.

Infant ID #9

Infant #9 was born at 37 weeks and was assessed in an outpatient setting (PMA 48 weeks). At the time of his MBS he carried diagnoses of GERD, laryngomalacia, hypertonia, and developmental delays. He had also received treatment for upper respiratory infections. Infant #9 demonstrated differences in level of airway invasion by position with two of the four modalities trialed. He demonstrated a reduction of airway invasion from aspiration to no airway invasino with the Dr. Brown ultra-preemie with valve (PAS 8 to PAS 1), and from penetration to no airway invasion with the Dr. Brown preemie (PAS 4 to PAS 1). There were no differences in level of airway invasion by position for the remaining two trials, nor were there differences in location of the bolus at time of swallow initiation or suck-swallow-breathe ratios.

Summary of Case Report Findings

Of the nine infants included in this study, six (66.7%) demonstrated improved airway protection in a side-lying position. Three (33.3%) did not demonstrate differences in airway invasion, or location of the bolus at swallow imitation, between upright and side-lying position (Infants # 5, 6, and 8). All three of these infants were in the NICU at the time of their MBS. Both infants #5 and #6 were born extremely prematurely (24 weeks gestation) and were diagnosed with chronic lung disease (CLD). Infant #5 also had multiple neurologic diagnoses, including bilateral grade IV IVH, which are associated with higher rates of feeding and swallowing problems (Slattery et al., 2012; van den Engel-Hook et al., 2011). Of note, other infants in this sample who carried neurologic or respiratory diagnoses did demonstrate improvements in airway invasion by position (Infants # 1, 2, 9).

Infant #8 was the only infant in this sample with a cleft palate and a diagnosis of 16p11.2 deletion syndrome, both of which are associated with feeding difficulties

(Shinawi et al., 2010). Infant #8 also carried a diagnosis of laryngomalacia. He did not demonstrate differences in the 3-level scale of airway invasion between upright/cradled position and sidelying position. However, he did demonstrate deeper penetration (to the level of the vocal folds) when fed in side-lying position compared to shallow penetration when fed in upright penetration with 2 of the 4 modalities trialed. This may indicate slightly worsened swallow function for this particular infant in side-lying position. The other infant in this sample with laryngomalacia (Infant #7) demonstrated improvements in airway invasion by position (aspiration in upright to penetration in side-lying).

Of the infants who demonstrated improvements in airway invasion by position, two (33.3%) demonstrated differences in location of the bolus at the time of swallow initiation, and three (60%) demonstrated differences in swallows to breaths ratios (60% represents three of five infants, as one of the six infants had missing swallows:breaths data so could not be assessed). The locations of these six infants varied across NICU, inpatient pediatric units, and outpatient settings, suggesting that the impact of side-lying position may not be exclusive to NICU patients.

Discussion

The findings of this preliminary study suggest that 1) side-lying position reduces severity of airway invasion during the swallow for some, but not all, medically complex infants, 2) bolus location at the time of swallow initiation may be higher, representing decreased risk of airway invasion, when at-risk infants are fed in side-lying position compared to cradled position, and 3) infants fed in side-lying position may demonstrate, on average, fewer swallows per breaths compared to when they are fed in cradled position. Each of these three findings are expanded upon below.

Airway Invasion

Observed changes in penetration/aspiration in the current study are consistent with previous research regarding feeding outcomes by position. Raczyńska and Gulczyńska (2019) found that premature infants demonstrated fewer choking episodes when fed in side-lying position than when fed in upright position, which could be due to decreased incidence of aspiration events. Research using fiberoptic endoscopic evaluation of swallowing (FEES) to assess swallow changes by position found that penetration and aspiration resolved in infants when fed in a semi-prone position compared to a cradled position (Mills et al., 2020). These latter findings were specific to breastfeeding infants (both term and preterm) with laryngomalacia, and indicated a semi-prone position rather than a strictly elevated-side-lying position; however, they support the finding that positioning may have a positive impact on infant swallow physiology, including a reduction of airway invasion. Interestingly, in the current sample, only one of the two infants with laryngomalacia (Infant #9) demonstrated improvements in swallow function in side-lying position compared to cradled position. However, the other infant with laryngomalacia (Infant #8) also carried diagnoses including cleft palate and genetic syndrome which could further impact the effect of side-lying position on swallow function.

The relationship between infant position and physiologic stress cues found in previous literature may reflect the infant's improved ability to protect their airway during the swallow (Sellars, 1998; Sherman et al., 1999; Thoyre et al., 2012). Clark, Kennedy, Pring, and Hird (2007) were the first to publish findings that side-lying position improved "infant physiologic stability", defined as mean oxygen saturation and standard deviation of heart rate. These findings have been supported in more recent studies (Park et al., 2014; Girgin et al., 2018; Thoyre et al., 2012). The reduction in penetration and aspiration events evidenced in the present study may assist, in part, to explain these improved physiologic markers for infants fed in side-lying position, although more research is needed to investigate this relationship in the infant population (Mizuno et al., 2000; Steele & Cichero, 2014; Thoyre et al., 2012).

Location of the bolus at swallow initiation

The present study explored the impact of positional changes on swallow physiology that may explain differences in airway invasion. Previous literature hypothesized that side-lying position reduces the flow rate of milk between the nipple the oropharynx, therefore decreasing the incidence of oral and pharyngeal pooling (Mills et al., 2020; Mizuno, et al., 2000). Given the complexity of rapidly coordinating the suck, swallow, and breathe pattern, if liquid is flowing too quickly into the oropharynx, the infant may experience difficulty protecting the airway during the swallow, resulting in increased incidences of aspiration and subsequently worsened physiologic stress cues (Mizuno, et al., 2000; Thoyre, et al., 2012). Mills and colleagues (2020) documented that when infants were fed in a semi-prone position rather than a cradled position during FEES, milk remained in the oral cavity rather than flowing into the pharynx prior to the swallow.

The current investigation found that infants fed in a side-lying position had statistically significantly higher location of the bolus at the time of swallow initiation (i.e., closer to the base of tongue than the pyriforms) suggesting more timely swallow initiation, as compared to a cradled/upright position. These findings support the theory that fluid dynamics and the pull of gravity on the bolus appear to be an important factor in infant swallow physiology (Mills et al., 2020; Mizuno et al., 2000). Infants fed in a side-lying position, or a semi-prone position, may have decreased pharyngeal pooling prior to the swallow, which in turn may reduce penetration and aspiration events (Mills et al., 2020, Morton et al., 2002; Steele & Cichero, 2014). However, not all infants in this sample who demonstrated improved airway invasion also demonstrated higher location of the bolus at the time of swallow initiation. Therefore, this relationship does not entirely explain observed changes in level of airway invasio, and should be further investigated.

Suck-swallow-breathe coordination

For the purposes of this study, suck-swallow-breathe coordination was divided into three measurements: the ratio of sucks to swallows, the ratio of sucks to breaths, and the ratio of swallows to breaths (Fucile et al., 2012; Sakalidis & Geddes, 2015; Sakalidis et al., 2013). Optimal coordination is considered a 1:1:1 SSwB ratio (Delaney & Arvedson, 2008; Goldfield et al., 2006; Lau et al., 2003; Legarde et al., 2019; Palmer, 1993; Vice & Gewolb, 2008). While in totality they are used to capture SSwB coordination, they individually represent slightly different physiologic function. This study found that the number of sucks per swallow did not change between side-lying and cradled position, indicating that sucking efficiency, or how many sucks completed to form a bolus, is not position dependent. This is somewhat in contrast with the idea that infants modulate their sucking to compensate for fast flows or stress with feeding (Bu'Lock et al., 1990; Mizuno & Ueda, 2003; Mizuno et al., 2007; Legarde et al., 2019). Given that side-lying position decreases the hydrostatic pressure of the liquid from the bottle, and therefore reduces milk flow rate, one might also expect sucking rate to change (Park et al., 2014). However, the present study did not specifically examine sucking rate; rather, it assessed the average number of sucks per swallow. Future research should investigate this relationship.

Coordination of respiration and swallowing is a critical component of functional swallowing , the absence of which may result in aspiration (Butler et al., 2007; Fucile et al., 2012; Goldfield et al., 2006; Kelly et al.,2007; Lau et al., 2003; Mizuno, 2003; Morton et al., 2002; Steele & Cichero, 2014). This investigation found that infants overall demonstrated statistically significantly fewer swallows per breath, represented by a Sw:B ratio closer to 1:1, when fed in side-lying position. Specifically, sixty percent (60%) demonstrated fewer swallows to breaths in side-lying position. Previous research shows that faster milk flows often result in disruption of the infant's respiratory pattern, increased frequency of swallowing, and periods of swallowing without a breathing break

(Lagarde et al., 2019; Mathew, 1991; Palmer, 1993; Park et al., 2014; Thoyre et al., 2012). Conversely, restricted milk flow facilitates suck-swallow-breathe coordination by allowing the infant time to breathe prior to liquid flowing into the pharynx (Mizuno & Ueda, 2003; Lau et al., 1998; Legarde et al., 2019). Slowing the flow to promote swallow-respiration coordination is even more critical in infants with medical complexities such as prematurity and chronic lung disease, for whom sucking and swallowing may override breathing to the point of apnea or aspiration (Mizuno et al., 2007; Palmer, 1993; Uhm et al., 2013; van den Engel-Hook et al., 2011; Vice & Gewolb, 2008). This research supports the use of side-lying position to improve suck-swallow-breathe coordination, thus potentially reducing aspiration events.

Limitations and Directions for Future Research

There are several limitations to the current exploratory study. The sample size, while supported by an a priori power analysis, remains relatively small. Future research should include larger sample sizes that would allow for additional analyses. Next, the retrospective nature of this investigation presents several challenges. Given that all analysis was conducted on previously completed MBS, methodological procedures were restricted to guidelines outlined by a specific institution. Therefore, in each MBS, side-lying position was implemented after upright/cradled position. McGratten and colleagues (2020) found that infants' swallow function declines over time, with aspiration risk highest after several minutes of swallowing. Accordingly, infants would be expected to perform at their worst at the end of the study, which is when side-lying position was implemented in this retrospective data. Interestingly, statistical significance was still found suggesting that side-lying position improved swallow function. However, three of the nine infants did not have improved swallow function in this sample. This might be explained in part by the effect of time and fatigue counteracting the effect of change in position, particularly given that these three infants were the most medically fragile and therefore most likely to fatigue during feeding. Future research would benefit from a prospective study design that randomly assigns order of position to determine if the effect of side-lying position was in fact underestimated in the current sample. There are other limitations of the retrospective study design. First, all samples collected were of infants swallowing thin liquids. A prospective study might include additional liquid consistencies to determine if the effect of side-lying position on swallow function is modulated by thickness of the liquid. Second, no controls were in place for number of swallows captured per swallowing clip, or for length of swallowing trial. Results might be skewed by shorter or longer swallowing trials by position and/or by temporal location of the swallowing clip within the larger study.

Additional areas for future research are also suggested. It is unclear if the use of side-lying position increases radiation dose in these fragile infants. According to the principle of ALARA (As Low As Reasonably Achievable), clinicians should ensure that radiation dose is limited during MBS wherever possible while still procuring high quality diagnostic imaging. Research examining the relationship between positioning and radiation dose, as well as the use of multiple positions (cradled and side-lying) on radiation dose, would be clinically useful.

Finally, the current sample consisted of infants with a wide variety of medical diagnoses. Of the three infants who did not demonstrate improvements in airway protection in side-lying position, one carried diagnoses of 16q.11.2 deletion and cleft palate, one had a history of grade IV IVH and chronic lung disease, and the third had primarily respiratory diagnoses including chronic lung disease. While these three infants were the most medically compromised, other infants in this sample also had complex medical conditions including neurologic and respiratory diagnoses. Future research, with a larger sample size, would further inform the impact of medical diagnosis on the efficacy of side-lying position (Newman et al., 2001; Sitton et al., 2011; Slatterly et al., 2012).

Conclusions

This preliminary study is a first step towards larger, randomized controlled investigations into the effect of side-lying position on infant oropharyngeal swallow function. The current results suggest that side-lying position results in decreased incidence of penetration and aspiration for some, but not all, at-risk infants. The physiology underlying this improved airway protection appears, at least in part, related to timelier swallow initiation and improved coordination of swallowing-respiration. However, future research to further define the mechanisms related to this improvement is needed. Side-lying position should be considered as a potential strategy to improve swallow safety in infants who are at risk for dysphagia, given the potential health consequences (de Benedictis et al., 2009; Duncan et al., 2019; Gewolb & Vice, 2007; Gurberg et al., 2015; Jadcherla, 2019; Lefton-Greif et al., 2006; Mizuno et al., 2007; Serel Arslan et al., 2018; Sheikh et al., 2001; Taniguchi & Moyer, 1994).

Table 1. *PAS conversion to 3-level ordinal scale (Duncan et al., 2019; Gurgert et al., 2015; McGratten et al., 2020; Newman et al., 2001; Rosenbek et al., 1996; Steele & Grace-Martin, 2017; Suterwala et al., 2017).*

Penetration-Aspiration Scale scores (PAS)	Ordinal scale of airway invasion	Definition of ordinal levels
PAS = 1	Level 1	No airway invasion
PAS = 2, 3, 4, or 5	Level 2	Bolus entry into the laryngeal vestibule without progression below the vocal folds
PAS = 6, 7, or 8	Level 3	Entry of the bolus below the level of the vocal folds

Table 2. *Subject demographics including gestational age at birth, age at the time of MBS (both chronological and post-menstrual age), setting of MBS, prior medical history, number of matched-pairs swallowing trials included in analysis, and modalities (bottle and nipple type) of swallowing trials included in analysis*

Infant ID	Gestational age at birth	Age at time of MBS	Setting	PMH	Number of matched pairs	Modalities
1	25 weeks	3 months (38 weeks PMA)	NICU	Chronic lung disease, prolonged intubation, GERD, constipation	3	Dr. Brown ultra-preemie Dr. Brown preemie Bionix level 1
2	35 weeks	3 months (48 weeks PMA)	OP	Hydrocephalus, absent septum pellucidum, multiple upper respiratory infections	1	Dr. Brown preemie
3	38 weeks	2 weeks (40 weeks PMA)	IP	BRUE, GERD	3	Avent level 0 Avent level 1 Avent level 2
4	27 weeks	3 months (40 weeks PMA)	NICU	Chronic lung disease, prolonged intubation, GI dysmotility	1	Bionix level 1
5	24 weeks	4 months (43 weeks PMA)	NICU	Chronic lung disease, grade IV IVH, hydrocephalus, VP shunt, prolonged intubation	3	Dr. Brown ultra-preemie Dr. Brown ultra-preemie with valve*

						Bionix level 1
6	24 weeks	3 months (38 weeks PMA)	NICU	Chronic lung disease, prolonged intubation, PIE, feeding intolerance, aspiration PNA	2	Dr. Brown ultra-preemie Bionix level 1
7	28 weeks	2 months (38 weeks PMA)	NICU	Chronic lung disease, laryngomalacia, feeding intolerance	1	Dr. Brown ultra-preemie
8	38 weeks	1 month (42 weeks PMA)	NICU	16p.11.2 deletion, cleft palate, Laryngomalacia	4	Haberman medium flow Haberman fast flow Dr. Brown ultra-preemie with valve* Dr. Brown preemie with valve*
9	37 weeks	3 months (48 weeks PMA)	OP	Laryngomalacia, GERD, anal stenosis, hypertonia, developmental delay, upper respiratory infection	4	Dr. Brown ultra-preemie Dr. Brown preemie Dr. Brown ultra-preemie with valve*

	Dr. Brown preemie with valve*

* “with valve” indicates use of the Dr. Brown Infant Paced Feeding Valve which is inserted into the standard Dr. Brown nipple to create a compression nipple system. This valve is often used for infants with complex feeding conditions such as craniofacial anomalies and oro-neuromotor dysfunctions (Dr. Brown's™ specialty Feeding SYSTEM, 2021)

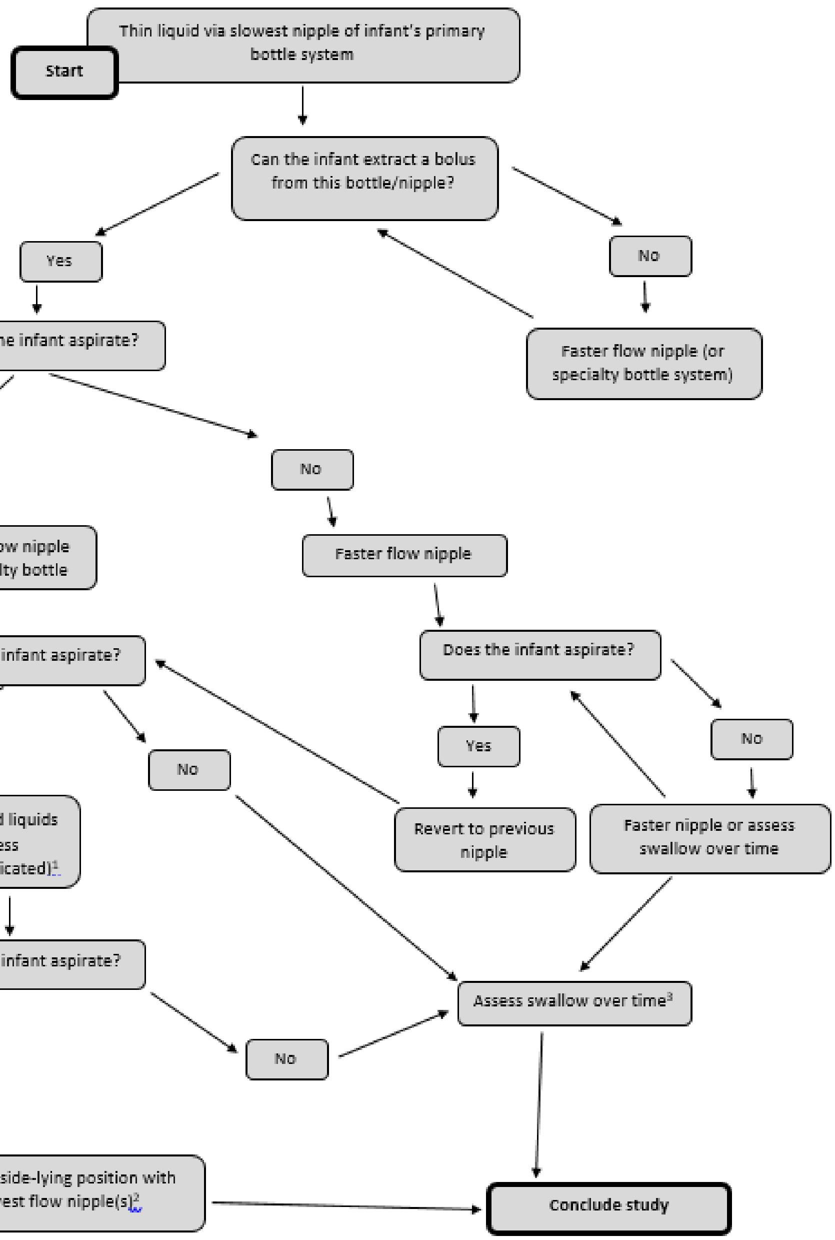
Table 3. *Level of airway invasion (1 = none, 2 = penetration, or 3 = aspiration) for each infant by position, separated into trials of specific bottle and nipple. Original PAS scores are included in parentheses.*

Infant ID	Modality	Level of airway invasion	
		Upright position	Side-lying position
1	Dr. Brown ultra-preemie	3 (PAS 8)	2 (PAS 4)
	Dr. Brown preemie	3 (PAS 8)	3 (PAS 8)
	Bionix level 1	3 (PAS 8)	3 (PAS 8)
2	Dr. Brown preemie	3 (PAS 8)	1 (PAS 1)
3	Avent level 0	3 (PAS 8)	1 (PAS 1)
	Avent level 1	2 (PAS 4)	1 (PAS 1)
	Avent level 2	3 (PAS 8)	2 (PAS 4)
4	Bionix level 1	3 (PAS 8)	2 (PAS 4)
5	Dr. brown ultra-preemie	3 (PAS 8)	3 (PAS 8)
	Dr. Brown ultra-preemie with valve	3 (PAS 8)	3 (PAS 8)
	Bionix level 1	3 (PAS 8)	3 (PAS 8)
6	Dr. Brown ultra-preemie	3 (PAS 8)	3 (PAS 8)
	Bionix level 1	2 (PAS 2)	2 (PAS 2)
7	Dr. Brown ultra-preemie	3 (PAS 8)	2 (PAS 4)
8	Haberman Feeder medium flow	3 (PAS 8)	3 (PAS 8)
	Haberman Feeder fast flow	3 (PAS 8)	3 (PAS 8)
	Dr. Brown ultra-preemie with valve	2 (PAS 2)	2 (PAS 4)
	Dr. Brown preemie with valve	2 (PAS 2)	2 (PAS 4)
9	Dr. Brown ultra-preemie	2 (PAS 2)	2 (PAS 2)
	Dr. Brown preemie	2 (PAS 4)	1 (PAS 1)
	Dr. Brown ultra-preemie with valve	3 (PAS 8)	1 (PAS 1)
	Dr. Brown preemie with valve	2 (PAS 4)	2 (PAS 4)

Table 4. *Location of the bolus at the time of swallow initiation for each infant by position separated into trials of specific bottle and nipple*

Infant ID	Modality	Location of the bolus at time of swallow initiation	
		Upright position	Side-lying position
1	Dr. Brown ultra-preemie	Pyriform sinus	Pyriform sinus
	Dr. Brown preemie	Pyriform sinus	Pyriform sinus
	Bionix level 1	Pyriform sinus	Pyriform sinus
2	Dr. Brown preemie	Pyriform sinus	Vallecula
3	Avent level 0	Pyriform sinus	Vallecula
	Avent level 1	Pyriform sinus	Vallecula
	Avent level 2	Pyriform sinus	Vallecula
4	Bionix level 1	Pyriform sinus	Pyriform sinus
5	Dr. brown ultra-preemie	Pyriform sinus	Pyriform sinus
	Dr. Brown ultra-preemie with valve	Pyriform sinus	Pyriform sinus
	Bionix level 1	Pyriform sinus	Pyriform sinus
6	Dr. Brown ultra-preemie	Pyriform sinus	Pyriform sinus
	Bionix level 1	Vallecula	Vallecula
7	Dr. Brown ultra-preemie	Pyriform sinus	Pyriform sinus
8	Haberman Feeder medium flow	Pyriform sinus	Pyriform sinus
	Haberman Feeder fast flow	Pyriform sinus	Pyriform sinus
	Dr. Brown ultra-preemie with valve	Pyriform sinus	Pyriform sinus
	Dr. Brown preemie with valve	Pyriform sinus	Pyriform sinus
9	Dr. Brown ultra-preemie	Pyriform sinus	Pyriform sinus
	Dr. Brown preemie	Pyriform sinus	Pyriform sinus
	Dr. Brown ultra-preemie with valve	Pyriform sinus	Pyriform sinus
	Dr. Brown preemie with valve	Pyriform sinus	Pyriform sinus

Figure 1. *VCUH guidelines for infant MBS*



1. Thickened liquids (thickened using BeechNut single grain rice cereal) are used as a last resort and only if the infant does not have contraindications for use, such as a history of NEC or other GI diagnoses.
2. The same flow chart is re-initiated in side-lying position.
3. The swallow is assessed over time given known changes in swallow function over time, by periodically checking the swallow, approximately every 30 seconds while the infant continues to feed with a consistent bottle/nipple (McGratten et al., 2020). If the infant aspirates on fatigue, the performing clinician re-initiates the flow chart as appropriate.

Figure 2. *MBS set up with infant in traditional reclined upright/cradled position (A), and in elevated-side-lying position (B).*

Appendix A:

Positioning Statement of the Researcher

Given the qualitative nature of this inquiry, it is important to follow in the rich traditions of qualitative research. One such tradition is the expectation that the researcher position herself and transparently explore her biases, prejudices, and experiences that may impact the interpretations of the qualitative findings (Creswell, 2007). This practice of reflexivity and critically reflecting on the self, in the context of viewing the researcher as an instrument for collecting data (Lincoln & Guba, 1985), is an important mechanism for increasing the trustworthiness and dependability of qualitative research (Krefting 2016).

As the primary researcher on this study, I conducted all interviews with participants. I am a 30-year-old Caucasian female currently living in Harrisonburg, Virginia. I am a Ph.D. student in Communication Sciences and Disorders at James Madison University, where I also received a Master's degree in Speech-Language Pathology. I am a licensed Speech-Language Pathologist (SLP) in the state of Virginia, as well as a Certified Lactation Counselor (CLC). I completed my Clinical Fellowship at Virginia Commonwealth University Health (VCUH) system where I continued to work as lead pediatric SLP in the NICU, PICU, pediatric acute floors, and outpatient feeding program. I currently work part-time at both VCUH and at the Sentara Rockingham Memorial Hospital (SRMH) Voice and Swallow Services (VSS). Although I work with both voice and swallowing in the adult population at VSS, my passion, both for clinical practice and for research, remains in pediatric dysphagia.

My experience developing as a young clinician in a level 4 NICU was extremely formative, in that it further propelled my love of treating and assessing infant feeding and swallowing, but also that it opened my eyes to the complexities and challenges of practicing in this fragile population. I learned quickly that the politics of interdisciplinary interactions are just as important as clinical knowledge, and that promoting evidence-based practice is extremely tricky in an environment where priority is given to “the way things have always been done”. These experiences fueled my desire to investigate current practices in the management of feeding and swallowing disorders in the NICU, and this emic positioning certainly framed the interpretations of data collected from other SLPs practicing in NICUs. This particular research question came from actual personal interactions I have had with patients’ parents, medical doctors and nurse practitioners, as well as other Speech-Language Pathologists that highlight the incongruity between clinical and instrumental practice. I hope to use the potential patterns that emerge from these data as evidence that can impact current clinical practice (for myself and others) as well as future research on the use of instrumental testing in medically fragile infants. Finally, although I primarily come from post-positivist training within the field of Speech-Language Pathology, this study (Part II of the dissertation document) employs a constructivist world view as we explore the current experiences of a narrow subset of Speech-Language Pathologists.

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