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EXPLORATION OF THE RELATIONSHIP BETWEEN THE MEAN POWER SPECTRAL DENSITY OF ELECTROGASTROGRAPHY AND GESTATIONAL MATURATION OF PRETERM INFANTS

by

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ABSTRACT

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Feeding preterm infants can be a challenge due to gastrointestinal (GI) immaturity which can lead to feeding intolerance, malnutrition, and poor neurodevelopment. Currently there is no non-invasive and quantitative method to determine GI maturity in infants. Electrogastrography (EGG) provides a non-invasive method of measuring gastric myoelectrical activity and has been used on adults to determine gastric abnormalities. EGG was explored as an option for determining GI maturity in preterm infants by quantifying the power spectral density (PSD) of EGG data and its spectral means. The power spectral density and spectral means were calculated during three gastric rhythm (GR) bands (mPSDgr) pre-, during, and post feeding to explore the relationship between EGG and the gastrointestinal development process.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Paper Overview

In neonatal intensive care units (NICU) feeding the preterm infants is of the utmost importance but can be challenging. In the NICU, preterm infants are fed by the enteral route, but due to gastrointestinal (GI) immaturity preterm infants do not always tolerate feeding. This feeding intolerance, which occurs in 75% of very low birth weight infants, can lead to malnutrition and poor neurodevelopment (Neu, 2005) (Moore, 2017). Current indications of feeding intolerance are non-specific measures such as the presence of vomiting, abdominal circumference, and gastric residual volume. These are poor biomarkers that do not produce quantitative data to determine GI immaturity.

This creates a need for a non-invasive (and quantitative) method such as electrogastrography (EGG) that records gastric myoelectrical activity (such as slow waves or gastric rhythms (GR) and spike potentials) which correlate to the smooth muscle contractions in the stomach (Riezzo, 2003). There are three gastric rhythm (GR) bands to focus on for EGG analysis between 0.5-9 cycles per minute (cpm). The three GR bands of interest are bradygastria (0.5 to 2 cpm), normogastria (2 to 4 cpm), and tachygastria (4 to 9 cpm).

EGG has been used in adults to examine patients with a variety of gastric abnormalities, but little has been done to investigate the uses of EGG on neonates. In current literature, EGG studies on neonates have produced varying and limited data.

Ortigoza et. al. described a significant increase in dominant power across the entire gastric spectrum during the post feed period while Lange et. al. reported no significant difference in the EGG power ratio or dominant frequency in pre- and post-feeding periods. Most of these studies were limited to recordings of only the pre- and post-feeding times which excluded the period when the neonate is feeding, and the parameters used (dominant frequency, dominant power, and power ratio) were introduced decades ago which may be the cause for inconsistent results. These results lead us to turn to power spectral density (PSD) as an alternative analysis tool that is already a well-accepted processing tool, especially for electroencephalography (EEG). Power spectral density evaluates the distribution of power into frequency components of the signal which is a far different approach than time-frequency analysis. Power spectral density (PSD) is an effective analysis of seemingly random signals (such as EGG) because the amplitude value is normalized to the frequency bin width. This allows for the visualization of the power level of each frequency component.

1.2 Feeding Intolerance

Feeding intolerance is defined as the inability to digest enteral nutrition. It occurs in 75% of low-birthweight infants and is a major cause of preterm infant mortality (Fenaro, 2013) (Neu, 2005). However, researchers and clinicians have used slightly varying definitions based on clinical signs. In addition to the varying definitions, there is no differentiation between developmental feeding intolerance (DFI) and pathologic feeding intolerance (PFI). The former is from GI immaturity while the latter is related to necrotizing enterocolitis (NEC) which is spontaneous intestinal perforation (Ortigoza, 2022). Since the clinical presentation of the two are so similar, DFI is often confused with PFI which leads

to delays in feeding advances (Fenaro, 2013). Regardless of the type of feeding intolerance, both often lead to parenteral nutrition (through the vein) which increases risk for sepsis and prolongs a patient's hospital stay (Neu 2005).

1.2.1 Signs and Symptoms

The non-specific signs and symptoms of feeding intolerance include gastric residual volume, blood in the stool, abdominal distension, vomiting, and desaturation from cardiac events (Ortigoza, 2022). Gastric residual volume is determined by the feeding rate, feeding tube size, and infant position which makes it unreliable to be used as an indicator for feeding intolerance (Metheny, 2005). Blood in the stool can be a result of feeding intolerance, but it can also happen because of food allergies, constipation, or instrument trauma; meaning that fecal blood cannot predict feeding intolerance on its own (Pickering, 2016). Abdominal circumference or distension can be a result of abdominal growth/girth but is also common in infants on continuous positive airway pressure (CPAP) devices (Shulman, 2011). Once again, the identified sign of feeding intolerance is non-specific and therefore cannot be used on its own to diagnose feeding intolerance. While the regurgitation of gastric residual volume (vomiting) can be indicative of GI immaturity, it is also common in all infants even after being discharged which makes it another non-specific symptom. Desaturation and cardiac events often lead to pausing enteral feeds especially if they occur during feeding, but cardiac events are also common in premature infants because of cardiovascular and respiratory immaturity (Kuzma-O`Reilly, 2003).

1.2.2 Technologies for Evaluating Feeding Intolerance

There is a need for a non-invasive technology to quantitatively determine feeding intolerance since the signs and symptoms of feeding intolerance cannot be used to make

an official diagnosis alone. Technologies that have proven to provide further insight into feeding intolerance include abdominal near infrared spectroscopy (NIRS), electronic bowel sound monitoring, and electrogastrography (Ortigoza 2018). Abdominal NIRS measures the tissue oxygenation in the abdomen which is determined by blood flow and oxygen content (Gay, 2011). As for bowel sounds, they can vary significantly based on the feeding state and time, and are subjective to the listener (Reintam, 2015). Electrogastrography (EGG) utilizes electrodes on the abdomen to measure gastric myoelectric activity. Of these technologies, EGG and abdominal NIRS are the most quantitative and in this case, EGG is explored further.

1.3 Electrogastrography

Electrogastrography detects gastric slow waves. For humans, the normal range is 2-4 cycles per minute(cpm) (Yin, 2013). Gastric dysrhythmias are categorized into bradygastria (0.5-2 cpm), tachygastria (4-9 cpm), and arrhythmia, the absence of rhythmic slow waves (O'Grady, 2012). In a healthy individual, each slow wave (measured with internal electrodes) corresponds to a gastric contraction, measured by strain gauges. When dysrhythmia occurs, no slow waves or contractions can be measured (Yin, 2013). However, this direct correlation does not exist with EGG recordings because EGG is the measure of a large group of slow waves while manometry measures slow waves of a more precise location (Chen 1994). EGG recordings can also be defective if the skin is not prepared correctly, the subject moves too much, the subject falls asleep, or the length of the recording is too short (Verhagen, 1999).

Two of the clinically established EGG values resulting from spectral analysis include the dominant frequency and power, and the fasting-fed power ratio (Chen, 1994).

The former can be determined from the power spectral density and is the frequency measured against the power or intensity of the signal. The latter is found by taking the ratio of the power spectral density before and after an intervention/ feeding where a ratio greater than 1 indicates an increase in gastric activity (Chen, 1994).

1.3.1 Applications in Adults

EGG is often used to determine gastrointestinal abnormalities and diseases in adults, specifically gastroparesis (Yin, 2013). During gastroparesis muscles contract slower and weaker than they ordinarily would, which limits gastric emptying. When there is an increase in tachygastria there is a decrease in gut motility which inhibits GI function (Yin, 2013). EGG has also been used to investigate the relationship between slow gastric waves, gastroesophageal reflux disease (GERD), irritable bowel syndrome (IBS), and functional dyspepsia (FD) (Jung, 2012).

1.3.2 Applications in Infants

Electrogastrography has been used on neonates to measure developmental changes in gastric myoelectric activity (Liang, 1998). The presence of tachygastria is more common in preterm infants and may be an indicator of gastric immaturity. Tachygastria is already known to be associated with decreased gastric motility and GI disorders in adults (Ouyang, 2005). Analysis of EGG data, particularly the changes in tachygastria, the power spectral density, and the fasting-fed power ratio may be indicative of feeding intolerance and gastric maturity.

CHAPTER 2

METHODOLOGY

2.1 Data Source

Preterm infants (and a group of term infants used as a reference) underwent weekly EGG monitoring until reaching 40 weeks GA. The Institutional Review Board at UT Southwestern Medical Center approved the collection of this data previously and the study was performed under all relevant regulations and guidelines. The portion of research I conducted was strictly analyzing the data already collected on the GI development of the neonates, but the data collection process was included for the sake of full clarity. The EGG data was collected via three electrodes on the abdomen of the neonates utilizing the BIOPAC system. Neonates had feedings every 3 hours and EGG recordings were taken (at a sampling frequency of 2000 Hz) over the course of six hours: 2 hours pre-feeding, 2 hours during feeding, and 2 hours post feeding.

2.2 Data Pre-Processing

The EGG data was preprocessed using MATLAB with the first step being to down sample the data to 500 Hz using the function "downsample." Then "polyfit" was used to fit a third order polynomial to the down-sampled time series to obtain a temporal trend in the data. This fitted trend was subtracted from the down-sampled data and the detrended time series was put through a 1Hz low-pass filter (using the "filtfilt" MATLAB function).

Then continuous wavelet transform of the EEG data was conducted because the data is non-stationary. To do so a zero-phase bandpass Butterworth filter between 0.5-15

cpm was applied in MATLAB. Next, a time-frequency spectrogram was made from each of the sub-feeding periods for each neonate by using the "cwt" function. This was used to visualize how the signal strength of different frequencies changes over time.

2.3 Data Processing

Next the power spectral density (PSD) over the whole gastric frequency band (0.5-9 cpm) was calculated for each of the feeding periods using the MATLAB function "pwelch" (using the down-sampled frequency and a 4-minute window with 2-minute overlap). Then mean PSD values for the three sub-feeding periods were calculated by averaging the pre-feeding values, during feeding values, and post feeding values of EEG PSD for each week that each infant underwent with EGG recording. In this way mean PSD curves for each feeding period were evaluated. Then spectral means of PSD were calculated for the three gastric rhythm bands: Bradygastria (0.5 to 2 cpm), Normogastria (2 to 4 cpm), and Tachygastria (4 to 9 cpm) for each sub-feeding period. Finally, the data was separated into nine different groups based on the three sub-feeding periods and the gastric rhythm bands.

2.3.1 Individual Subject Processing

For each subject, the nine different groups of data were plotted (mPSD vs. PMA) and a linear regression was completed for each group. This made nine graphs per subject analyzed. However, the linear regression created a wide variety of trend lines with inconsistencies across different subjects. Due to the inconsistencies, a way to normalize the data among subjects was needed; this need led us to use the pre-feeding mPSD and post feeding mPSD ratio, also referred to as the fasting-fed ratio.

2.3.2 Group Processing

The ratio between the pre-feeding mPSD and post feeding mPSD (fasting-fed ratio) for each gastric rhythm was calculated. This acted as a method of normalizing the data so all the subjects could be compared to each other more intuitively. Next the individual subject values were brought together for three different gestational age (GA) groups: GA less than 29 weeks, GA from 29 to 33 weeks, and GA over 37 weeks. These groups are referred to as early term, midterm, and term infants, respectively. Then the mPSD ratio for each GA group was plotted. Linear regressions were completed across all values and then regressions were split into two groups based on post menstrual age (PMA). The first group was 29-34 weeks PMA, and the second group was 35-39 weeks PMA. The mPSD ratio values for the early term and midterm infants were compared using two tailed, sample unequal variance t-tests.

CHAPTER 3

DISCUSSION

A variety of data grouping methods were used to analyze the EGG data to identify potential biomarkers of feeding intolerance and determine trends in gastrointestinal maturity in preterm infants. The following graphs depict the results of those analysis methods.

3.1 Individual Subject Results

For individual subject analysis, nine graphs were created per subject. In this section, graphs from only two subjects are presented as examples since there were inconsistencies in the results among subjects. For each subject and graph there were often trend lines going in opposite directions or with incredibly small R squared values. Below are the graphs for subjects 67 and 69.

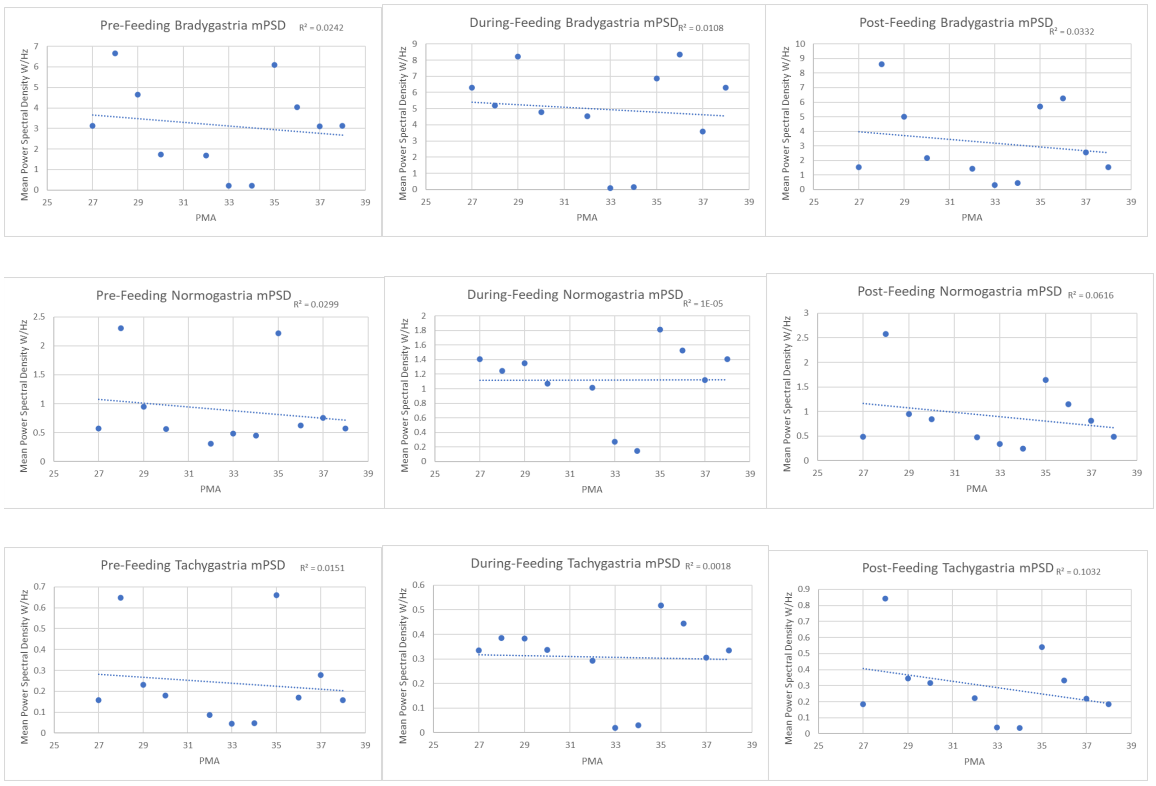

Figure 3.1: mPSD graphs for subject 67 organized by three sub-feeding periods (in three columns) and three gastric rhythm bands (in three rows, respectively).

The graphs for subjects 67 (above) and 69 (below), the R squared values are very small. For subject 67, most of the trendlines have a negative or near neutral slope while subject 69 has positive or near neutral slopes. Other subjects even had both positive and negative slopes within their several graphs. This is likely due to the differences in PMA in which recordings were taken for each subject. For instance, subject 67 was an early term baby with recording starting at week 27 PMA, while subject 69 was a midterm baby with recordings starting at week 33. This is another reason that subjects were grouped based on whether they were early or midterm.

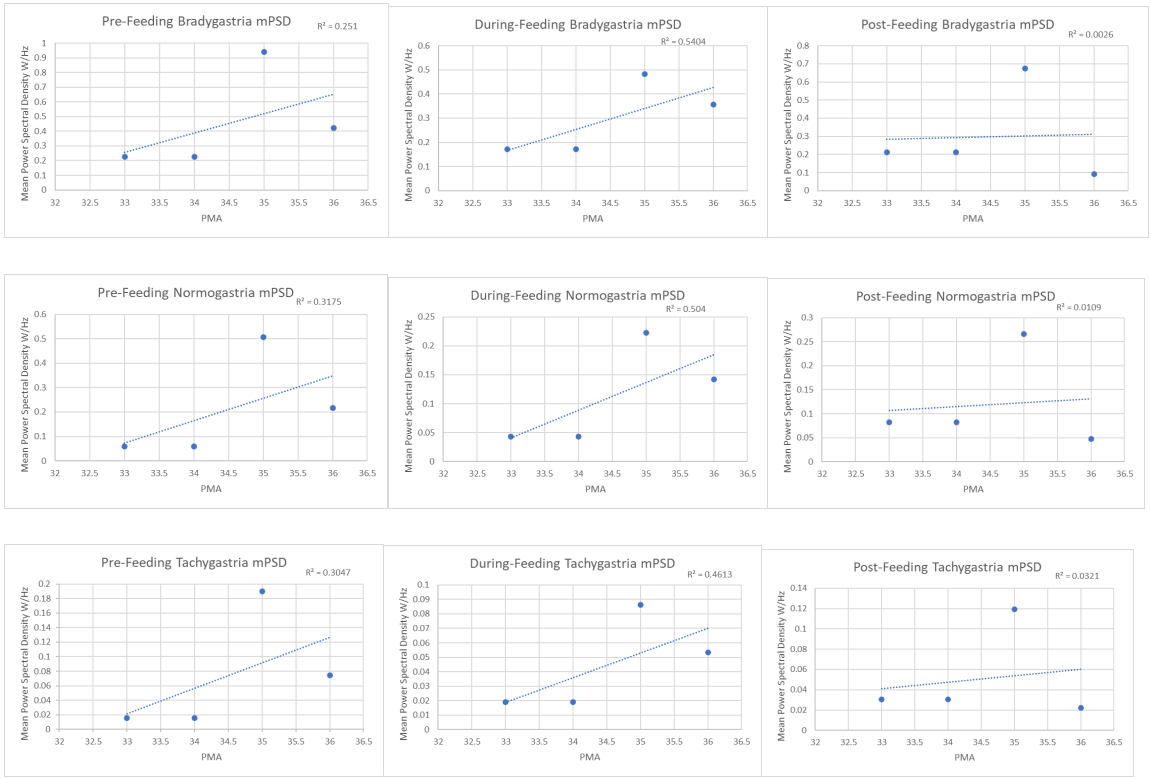

Figure 3.2: mPSD graphs for subject 69 organized by three sub-feeding periods (in three columns) and three gastric rhythm bands (in three rows, respectively).

3.2 Group Results

The ratio between the pre-feeding mPSD and post-feeding mPSD for each gastric rhythm was graphed separately for early term and midterm subjects. The data before PMA week 29 was not used to make a more accurate comparison between early term and midterm subjects. The linear regressions were completed at two different PMA ranges and the results are shown below.

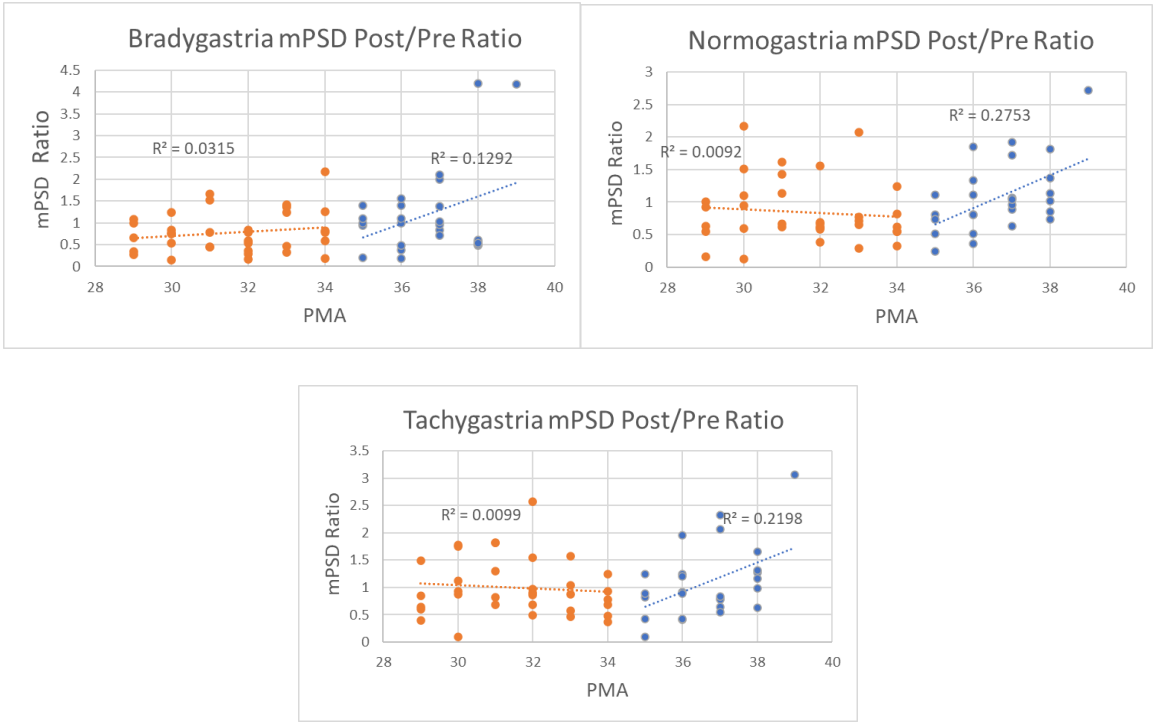

Figure 3.3: PMA-dependent early-term mPSD Post- Feeding/ Pre-Feeding Ratio for three gastric rhythm bands. The figures are separated by two PMA age ranges, 29-34 PMA and 35-39 PMA.

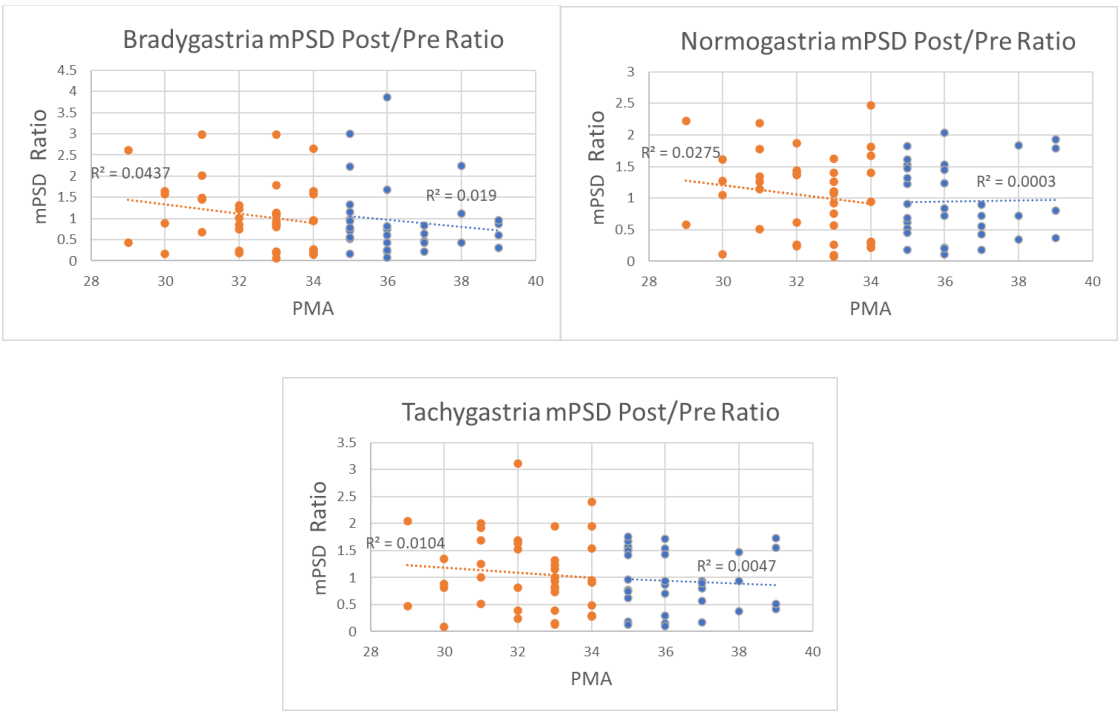

Figure 3.4: Mid-term mPSD Post- Feeding/ Pre-Feeding Ratio.

The mPSD points are quite variable which explains why the trend lines do not have very high r squared values as seen in figures 3.3 and 3.4.

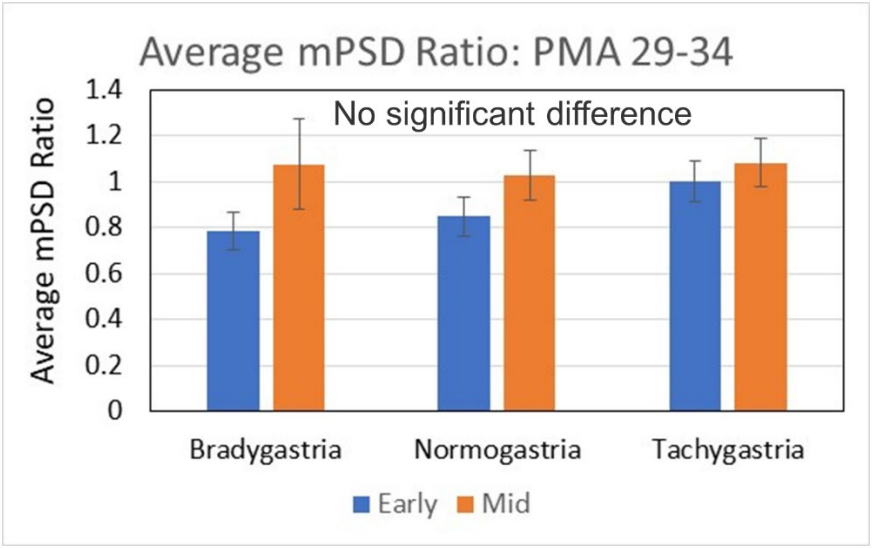

Figure 3.5: Average mPSD Ratio for preterm infants 29-34 weeks PMA.

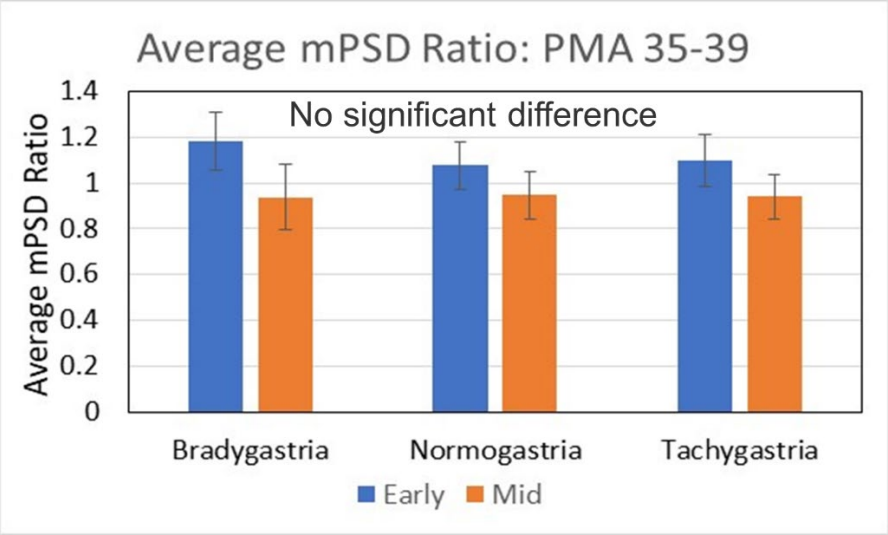

Figure 3.6: Average mPSD Ratio for preterm infants 35-39 weeks PMA.

While the average mPSD ratio for preterm infants is different between early term and mid-term babies, the difference is not statistically significant. The error bars in figures 3.5 and 3.6 represent the standard error of means (SEM) for their corresponding averages. By visual examination, there is an overlap between the SEM indicating that there is not a statistically significant difference between the two groups. The p-values for these calculations can also be seen in appendix D.

CHAPTER 4

CONCLUSION

The mPSD ratio is relatively similar between early term and mid-term infants overall. The following observations were made. There is a statistically significant difference ($p < 0.05$) between early and mid-term mPSD 29-34 weeks PMA in the bradygastria range. There is a positive slope/correlation for early term mPSD between 35-39 weeks PMA and a negative slope/correlation for mPSD between 29-34 weeks PMA except in the bradygastria range for early-term infants. The average mPSD ratio in early-term infants is less than mid-term infants between 29-34 weeks, but there is no statistical significance. The average mPSD ratio in early-term infants is greater than mid-term infants between 35-39 weeks, but there is no statistical significance.

Analysis of the mPSD ratio of EGG data has shown some potential to gauge GI maturity, but further investigation is required. What would specifically help in the future is having knowledge of patient outcomes so all patients with constant progression can be assessed as a group while those with less successful outcomes could be analyzed separately. Further investigation of EGG data should be undertaken in relation to GI maturity and feeding intolerance in preterm infants. Even if EGG is not the sole tool needed to determine GI maturity, it shows potential to be used as a non-invasive and quantitative technique that can be used alongside other methods.

APPENDIX A

MATLAB CODE

```
%EGG Data Processing
clear all; close all;
sub_fd = 'D:\POOH\POOH072\PSDresults'; %folder with ONLY PSD results!!
cd 'D:\POOH\POOH072\PSDresults'; %copy same folder from above
weeks = [1,3]; %type in the week numbers in numerical order
%if week num is less than 10 add zero in file name

%% Get curves
list_results = dir(sub_fd);

num_results = length(list_results) - 2; %subtract parent folder & subfolder (. & ..) ↙
to get number of PSD files


for i=3:length(list_results)  %start at 3 so you skip . & ..
    fname = list_results(i).name;
    load(fname);
%   Get pre-feed curve for 1 subject
    if(exist('EGG_pre1_psd') && exist('EGG_pre2_psd'))
        EGG_pre_psd = [EGG_pre1_psd EGG_pre2_psd]; %i-2 gets rid of parent folder &↙
subfolder name
        EGG_pre_mean(i-2,:) = mean(EGG_pre_psd,2);    %the curve we'll plot
        EGG_pre_STE(i-2,:) = std(EGG_pre_psd)/sqrt(length(EGG_pre_psd(:,1)));    %its↙
corresponding STE
    end
    if(exist('EGG_pre1_psd') && ~(exist('EGG_pre2_psd')))
        EGG_pre_mean(i-2,:) = EGG_pre1_psd;
        EGG_pre_STE(i-2,:) = std(EGG_pre1_psd,0,1)/sqrt(length(EGG_pre1_psd(:,1)));
    end
    if(~exist('EGG_pre1_psd') && exist('EGG_pre2_psd'))
        EGG_pre_mean(i-2,:) = EGG_pre2_psd;
        EGG_pre_STE(i-2,:) = std(EGG_pre2_psd,0,1)/sqrt(length(EGG_pre2_psd(:,1)));
    end

%   Get during-feed curve for 1 subject
    if(exist('EGG_dur1_psd') && exist('EGG_dur2_psd'))
        EGG_dur_psd = [EGG_dur1_psd EGG_dur2_psd]; %i-2 gets rid of parent folder &↙
subfolder name
        EGG_dur_mean(i-2,:) = mean(EGG_dur_psd,2);    %the curve we'll plot
        EGG_dur_STE(i-2,:) = std(EGG_dur_psd,0,1)/sqrt(length(EGG_dur_psd(:,1)));    %↙
its corresponding STE
    end
    if(exist('EGG_dur1_psd') && ~(exist('EGG_dur2_psd')))
        EGG_dur_mean(i-2,:) = EGG_dur1_psd;
        EGG_dur_STE(i-2,:) = std(EGG_dur1_psd,0,1)/sqrt(length(EGG_dur1_psd(:,1)));
    end
    if(~exist('EGG_dur1_psd') && exist('EGG_dur2_psd'))
        EGG_dur_mean(i-2,:) = EGG_dur2_psd;
        EGG_dur_STE(i-2,:) = std(EGG_dur2_psd,0,1)/sqrt(length(EGG_dur2_psd(:,1)));
```

```
    end

%   Get post-feed curve for 1 subject
    if(exist('EGG_post1_psd') && exist('EGG_post2_psd'))
        EGG_post_psd = [EGG_post1_psd EGG_post2_psd]; %i-2 gets rid of parent folder ↙
& subfolder name
        EGG_post_mean(i-2,:) = mean(EGG_post_psd,2);     %the curve we'll plot
        EGG_post_STE(i-2,:) = std(EGG_post_psd,0,1)/sqrt(length(EGG_post_psd(:,1))); ↙
%its corresponding STE
    end
    if(exist('EGG_post1_psd') && ~(exist('EGG_post2_psd')))
        EGG_post_mean(i-2,:) = EGG_post1_psd;
        EGG_post_STE(i-2,:) = std(EGG_post1_psd,0,1)/sqrt(length(EGG_post1_psd(:, ↙
1)));
    end
    if(~exist('EGG_post1_psd') && exist('EGG_post2_psd'))
        EGG_post_mean(i-2,:) = EGG_post2_psd;
        EGG_post_STE(i-2,:) = std(EGG_post2_psd,0,1)/sqrt(length(EGG_post2_psd(:, ↙
1)));
    end
end

%% Plots
% Create names for legends
week_prefix = "Week";

for i=1:length(weeks)
    week_num = num2str(weeks(i));
    if(weeks(i) < 10)
        week_strings(i,:) = week_prefix + " " + week_num + " ";
    else
        week_strings(i,:) = week_prefix + " " + week_num;
    end
end

% Pre-feeding:
cpm = freq_EGG_psd .* 60; %gastric spectrum: 0.5-9 cpm; 0.48 (9) - 9 (151) (9-51)
for i=1:num_results
    p(i) = loglog(cpm(10:151,:),EGG_pre_mean(i,10:151));
    p(i).LineWidth = 1.5;
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
legend(week_strings);
xlabel('Frequency (cpm)'); ylabel('Power Spectral Density W/Hz'); title('Pre-↙
Feeding');
xticks([0.5 2 4 9]);
xticklabels({'0.5','2','4','9'}); xlim([0.5 9]);
```

```
ylim([0.03 20]); yticks([0.03 0.3 1 3]); yticklabels({'0.03','0.3','1','3'});

%Isolate a singular week
figure;
p(1) = loglog(cpm(10:151,:),EGG_pre_mean(1,10:151));
p(1).LineWidth = 1.5;
hold on;
xlabel('Frequency (cpm)'); ylabel('Power Spectral Density W/Hz'); title('Single Week');
xticks([0.5 2 4 9]);
xticklabels({'0.5','2','4','9'}); xlim([0.5 9]);
ylim([0.03 20]); yticks([0.03 0.3 1 3]); yticklabels({'0.03','0.3','1','3'});

%Find mPSD for singular week
EGG_avg = mean(EGG_pre_mean(1,10:151));

%Find mPSD for a singular week for each frequency range
EGG_brady_avg = mean(EGG_pre_mean(1,10:35));
EGG_norm_avg = mean(EGG_pre_mean(1,36:68));
EGG_tachy_avg = mean(EGG_pre_mean(1,69:151));



%% Find mPSD for ALL weeks during pre-feeding for brady frequency range
brady_pre_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    brady_pre_avg_wk(i)= mean(EGG_pre_mean(i,10:35));
    scatter(i,brady_pre_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Pre-Feeding mPSD Brady');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels ({'0.03','0.3','1','3','6','9'});

%Find mPSD for ALL weeks during feeding for brady frequency range
brady_dur_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    brady_dur_avg_wk(i)= mean(EGG_dur_mean(i,10:35));
    scatter(i,brady_dur_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
```

```
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('During-Feeding
mPSD Brady');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%Find mPSD for ALL weeks post feeding for brady frequency range
brady_post_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    brady_post_avg_wk(i)= mean(EGG_post_mean(i,10:35));
    scatter(i,brady_post_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Post-Feeding mPSD
Brady');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%% Find mPSD for ALL weeks during PRE-feeding for NORM frequency range
norm_pre_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    norm_pre_avg_wk(i)= mean(EGG_pre_mean(i,36:68));
    scatter(i,norm_pre_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Pre-Feeding mPSD
Norm');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%Find mPSD for ALL weeks during feeding for NORM frequency range
norm_dur_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    norm_dur_avg_wk(i)= mean(EGG_dur_mean(i,36:68));
    scatter(i,norm_dur_avg_wk(i),20,'filled');
    hold on;
```

```
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('During-Feeding
mPSD Norm');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%Find mPSD for ALL weeks post feeding for brady frequency range
norm_post_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    norm_post_avg_wk(i)= mean(EGG_post_mean(i,36:68));
    scatter(i,norm_post_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Post-Feeding mPSD
Norm');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%% Find mPSD for ALL weeks during pre-feeding for Tachy frequency range
tachy_pre_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    tachy_pre_avg_wk(i)= mean(EGG_pre_mean(i,69:151));
    scatter(i,brady_pre_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Pre-Feeding mPSD
Tachy');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%Find mPSD for ALL weeks during feeding for brady frequency range
tachy_dur_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    tachy_dur_avg_wk(i)= mean(EGG_dur_mean(i,69:151));
```

```
    scatter(i,tachy_dur_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('During-Feeding
mPSD Tachy');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%Find mPSD for ALL weeks post feeding for brady frequency range
tachy_post_avg_wk= zeros(num_results);
figure;
for i=1:num_results
    tachy_post_avg_wk(i)= mean(EGG_post_mean(i,69:151));
    scatter(i,tachy_post_avg_wk(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Post-Feeding mPSD
Tachy');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 10]); yticks([0.03 0.3 1 3 6 9]); yticklabels
({'0.03','0.3','1','3','6','9'});

%% Find ratio between mPSD Post and mPSD Pre
brady_post_pre_ratio= brady_post_avg_wk./brady_pre_avg_wk;
norm_post_pre_ratio= norm_post_avg_wk./norm_pre_avg_wk;
tachy_post_pre_ratio= tachy_post_avg_wk./tachy_pre_avg_wk;

%Graph brady mPSD post/pre ratio
figure;
for i=1:num_results
    scatter(i,brady_post_pre_ratio(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Brady mPSD
Post/Pre Ratio');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 7]); yticks([0.03 0.3 1 3 6]); yticklabels({'0.03','0.3','1','3','6'});

%Graph norm mPSD post/pre ratio
```

```
figure;
for i=1:num_results
    scatter(i,norm_post_pre_ratio(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Norm mPSD Post/Pre Ratio');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 7]); yticks([0.03 0.3 1 3 6]); yticklabels({'0.03','0.3','1','3','6'});

%Graph Tachy mPSD post/pre ratio
figure;
for i=1:num_results
    scatter(i,tachy_post_pre_ratio(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Tachy mPSD Post/Pre Ratio');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 7]); yticks([0.03 0.3 1 3 6]); yticklabels({'0.03','0.3','1','3','6'});

%% Find ratio between mPSD During and mPSD Pre
brady_dur_pre_ratio= brady_dur_avg_wk./brady_pre_avg_wk;
norm_dur_pre_ratio= norm_dur_avg_wk./norm_pre_avg_wk;
tachy_dur_pre_ratio= tachy_dur_avg_wk./tachy_pre_avg_wk;

%Graph brady mPSD during/pre ratio
figure;
for i=1:num_results
    scatter(i,brady_dur_pre_ratio(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Brady mPSD During/Pre Ratio');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 7]); yticks([0.03 0.3 1 3 6]); yticklabels({'0.03','0.3','1','3','6'});

%Graph norm mPSD during/pre ratio
figure;
for i=1:num_results
```

```
    scatter(i,norm_dur_pre_ratio(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Norm mPSD
During/Pre Ratio');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 7]); yticks([0.03 0.3 1 3 6]); yticklabels({'0.03','0.3','1','3','6'});

%Graph Tachy mPSD during/pre ratio
figure;
for i=1:num_results
    scatter(i,tachy_dur_pre_ratio(i),20,'filled');
    hold on;
%     errorbar(cpm(10:151,:),EGG_pre_mean(i,10:151),EGG_pre_STE(i,10:151),'-b');
%     hold on;
end
xlabel('Weeks'); ylabel('Mean Power Spectral Density W/Hz'); title('Tachy mPSD
During/Pre Ratio');
xticks(weeks);
xlim([weeks(1), weeks(end)]);
ylim([0.03 7]); yticks([0.03 0.3 1 3 6]); yticklabels({'0.03','0.3','1','3','6'});

%% All mPSD Points
pre_psdPoints= [brady_pre_avg_wk(:,1), norm_pre_avg_wk(:,1),tachy_pre_avg_wk(:,1)];
dur_psdPoints= [brady_dur_avg_wk(:,1), norm_dur_avg_wk(:,1),tachy_dur_avg_wk(:,1)];
post_psdPoints= [brady_post_avg_wk(:,1), norm_post_avg_wk(:,1),tachy_post_avg_wk(:,
1)];

ppRatio= [brady_post_pre_ratio(:,1),norm_post_pre_ratio(:,1),tachy_post_pre_ratio(:,
1)];
dpRatio= [brady_dur_pre_ratio(:,1),norm_dur_pre_ratio(:,1),tachy_dur_pre_ratio(:,1)];

allPSDpoints= [pre_psdPoints, dur_psdPoints, post_psdPoints, ppRatio, dpRatio];

xlswrite('allPSDpoints.xlsx',allPSDpoints);
```

APPENDIX B

EARLY TERM MPSD POST-FEEDING/PRE-FEEDING RATIO

Early Term mPSD Post-Feeding/Pre-Feeding Ratio

PMA	Bradygastria	Normogastria	Tachygastria
24	1.455102	1.79269	1.361319
25	1.008996	0.961241	0.643409
25	1.455102	1.79269	1.361319
26	2.475993	1.631188	1.695181
27	1.630945	0.983441	0.69069
27	1.419839	1.777498	1.59077
27	0.490561	0.857812	1.168224
27	0.558628	0.403031	0.727312
27	4.953576	2.503816	2.874179
28	1.151478	1.350418	1.255439
28	0.730986	0.705519	0.823917
28	1.292098	1.11948	1.302126
29	0.33471	0.625098	0.649027
29	0.988156	0.927931	0.841492
29	1.073878	1.003946	1.491317
29	0.26841	0.158509	0.398331
29	0.653226	0.546256	0.607183
30	0.837613	0.600537	0.930624
30	0.150768	0.122512	0.100108
30	1.238619	1.510599	1.752574
30	0.746397	2.164663	1.784512
30	0.768234	1.101635	1.116426
30	0.52999	0.94261	0.881851
31	0.782646	0.616976	0.680941
31	1.656688	1.429499	1.823096
31	0.442947	0.670486	0.825119
31	1.516567	1.613799	1.81315
31	0.444979	1.132087	1.298914
32	0.583685	0.692174	0.900081
32	0.534945	0.583082	1.539501
32	0.782646	0.616976	0.680941
32	0.838471	1.551641	2.56986
32	0.365486	0.668433	0.966306
32	0.285546	0.379786	0.491051
32	0.163292	0.602978	0.861871
33	1.415448	0.712246	0.87242
33	1.246358	0.771104	1.041415
33	1.36718	2.073125	1.574315
33	0.32656	0.648599	0.466983
33	0.461586	0.293967	0.576432
34	0.180239	0.330594	0.481819
34	0.782646	0.616976	0.680941
34	2.169419	0.551264	0.782417

34	0.822218	0.820721	1.249575
34	1.251573	1.237832	0.93265
34	0.583271	0.55252	0.375027
35	0.202656	0.241032	0.101799
35	1.395827	0.808353	1.24484
35	0.93475	0.737716	0.817254
35	0.999003	1.110022	0.888337
35	1.094488	0.509434	0.417047
36	0.382679	0.802386	0.914891
36	1.395827	0.808353	1.24484
36	0.18465	0.358129	0.408183
36	1.553236	1.849206	1.955354
36	0.999003	1.110022	0.888337
36	1.094488	0.509434	0.417047
36	0.48304	1.329593	1.203349
37	2.002924	0.890668	0.797699
37	1.386846	1.715268	2.322765
37	0.827047	1.064984	0.783611
37	0.964394	0.962628	0.636986
37	0.707865	0.62992	0.550782
37	1.024278	1.042262	0.840572
37	2.109451	1.918286	2.060906
38	0.572266	1.12946	1.272453
38	4.200747	1.81019	1.658287
38	0.603481	0.735654	0.632626
38	0.490561	0.857812	1.168224
38	0.505915	1.367811	1.314873
38	0.528549	1.017032	0.979985
39	4.186104	2.719988	3.067553

APPENDIX C

MID-TERM MPSD POST-FEEDING/PRE-FEEDING RATIO

PMA	Bradygastria	Normogastria	Tachygastria
27	0.766737	0.782397	2.636385
28	0.908696	0.395599	0.313695
29	0.436726	0.576841	0.466216
29	2.619831	2.217669	2.042431
30	0.878861	1.275855	0.81746
30	1.649016	1.612673	1.348964
30	0.167552	0.113556	0.088156
30	1.581223	1.052997	0.880489
31	2.987232	1.25892	1.000533
31	1.471047	1.145241	1.251574
31	1.454165	1.336593	1.694603
31	2.008726	2.183193	2.007032
31	0.675317	0.50862	0.507395
31	1.479205	1.776014	1.920142
32	1.304893	1.370123	1.525855
32	1.225865	1.390831	1.627923
32	0.230296	0.239381	0.233809
32	1.006792	0.620241	0.81528
32	0.741332	1.869966	3.109481
32	0.846646	1.431061	1.690354
32	0.176868	0.260856	0.395915
33	2.987232	1.25892	1.000533
33	1.060553	1.073432	1.159795
33	0.945882	1.398465	1.946387
33	1.142408	0.759982	0.802925
33	0.798249	1.107738	0.73011
33	1.787816	1.62627	0.832286
33	0.878022	0.564232	1.317179
33	0.055559	0.079384	0.158631
33	0.219807	0.100374	0.133523
33	0.870201	1.093652	1.239427
33	1.114038	0.917034	0.931552
33	0.176868	0.260856	0.395915
34	0.263934	0.290411	0.487117
34	0.945882	1.398465	1.946387
34	0.228825	0.314822	0.289844
34	0.177096	0.233358	0.280194
34	1.644623	1.813211	1.535268
34	0.147296	0.21428	0.296173
34	0.949331	2.471642	2.39773
34	2.64356	0.940118	0.907839
34	1.574362	1.667806	0.950661
35	0.747449	1.530559	1.543298

35	2.990215	1.607963	1.583971
35	0.970064	0.618484	0.77733
35	0.715871	0.524223	0.627194
35	2.225095	1.824675	1.494587
35	0.944732	0.902733	1.680885
35	1.332079	1.226045	1.760329
35	0.778793	1.467997	1.416002
35	0.521688	0.456233	0.189325
35	0.55436	0.685096	0.741647
35	0.170306	0.184482	0.123023
35	1.158975	1.32287	0.95811
36	0.747449	1.530559	1.543298
36	3.856976	1.233019	0.871403
36	0.218871	0.218062	0.296884
36	0.598073	1.447715	1.428748
36	1.677059	2.030838	1.717515
36	0.435544	0.714919	0.942896
36	0.259834	0.111539	0.152329
36	0.084645	0.205993	0.108805
36	0.814428	0.841959	0.709638
37	0.464369	0.42254	0.564701
37	0.435544	0.714919	0.942896
37	0.828968	0.553884	0.805633
37	0.648	0.898934	0.899863
37	0.227045	0.179921	0.171482
38	1.11207	1.832067	1.473733
38	0.435544	0.714919	0.942896
38	2.236507	0.34094	0.377998
39	0.868687	1.92796	1.54568
39	0.30647	0.806372	0.414273
39	0.950438	0.369784	0.510485
39	0.606818	1.793872	1.727833

APPENDIX D

STATISTICAL CALCULATIONS

	Average mPSD Pre-Feeding/Post-Feeding Ratio Values				
Early-term	29-34	35-39	Mid-term	29-34	35-39
Bradygastria	0.782188	1.185772	Bradygastria	1.076379	0.93706
Normogastria	0.849152	1.078294	Normogastria	1.045627	0.94673
Tachygastria	1.001126	1.099562	Tachygastria	1.079077	0.940748

	Standard Deviation of mPSD Ratio				
Early-term	29-34	35-39	Mid-term	29-34	35-39
Bradygastria	0.470941	0.993416	Bradygastria	0.78345	0.813639
Normogastria	0.486466	0.544682	Normogastria	0.642169	0.583096
Tachygastria	0.523656	0.531327	Tachygastria	0.703704	0.542718
	Standard Error of Means of mPSD Ratio				
Early-term	29-34	35-39	Mid-term	29-34	35-39
Bradygastria	0.08198	0.198683	Bradygastria	0.127092	0.143832
Normogastria	0.084683	0.108936	Normogastria	0.104174	0.103078
Tachygastria	0.091157	0.106265	Tachygastria	0.114156	0.09594

T-test Results for mPSD Ratio Between Early and Mid-Term		
	29-34	35-39
Bradygastria	0.043659	0.315692
Normogastria	0.144534	0.384152
Tachygastria	0.589654	0.331949

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BIOGRAPHICAL INFORMATION

Elizabeth Rhodes is an undergraduate student with an expected graduation in May 2023 with an Honors Bachelor of Science in Biomedical Engineering. Her academic career included being a lead Honors College Advocate, a math tutor, a leader in the Delta Zeta sorority, and a research and development intern. While in the Honors College she researched and presented functional brain connectivity analysis, network physiology as a new field of research, and the applications of multi-variable calculus to medical technologies. She also created a guide for the FDA approval of medical devices through the 510k pathway and conducted experiments using ECG, EOG, EMG, and EGG.

After graduation Elizabeth plans to pursue her Master of Biomedical Engineering at UT Arlington via the master thesis track. While continuing her education she also intends to continue working at Nanoscope Technologies where she interned during her last semester of undergraduate studies. In this role she will be responsible for cell culture, gene modification, and cell imaging to determine the efficiency of the modification. After the completion of her master's degree, she intends to continue doing research and grow within the industry.