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Autonomic Nervous System Function Following a Skin-to-Skin Contact Intervention in Infants with Congenital Heart Disease

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Abstract

Background—Infants with complex congenital heart disease (CCHD) demonstrate impaired autonomic nervous system (ANS) regulation, which may contribute to commonly observed impairments in feeding, growth, and development. Close mother-infant physical contact improves ANS function in other high-risk infant populations.

Objective—The purpose was to examine feasibility of a 2-week daily skin-to-skin contact (SSC) intervention and to describe change in ANS function in response to the intervention.

Methods—Feasibility was assessed by recruitment and retention rates, safety, and acceptability. ANS function was measured with linear and non-linear measures of heart rate variability (HRV) during a feeding prior to the 14-day SSC intervention and 3 times over a 4 week follow-up.

Results—Recruitment rate was 72%; retention rate was 55.5%. Mothers were universally positive about SSC. Ten mothers and infants completed a daily average of 77.05 minutes of SSC during the 14-day intervention with no adverse events. Baseline high frequency HRV, reactivity to challenge, and recovery following challenge improved over the 6-week study. Non-linear measures demonstrated abnormally high sympathetic activity, especially following feeding, in the majority of infants.

Conclusions—SSC is feasible in infants with CCHD. Linear measures of HRV suggested improvements in ANS function with this intervention. This paper is one of the first to describe non-linear HRV measures in infants with CCHD. Additional research is needed to identify variations in linear and non-linear effects based on specific cardiac conditions and with varying intervention doses and timing. This low-cost, low-risk intervention has the potential to improve outcomes in infants with CCHD.

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Infants with complex congenital heart disease (CCHD) requiring surgical intervention within the first days or weeks of life demonstrate impaired autonomic nervous system (ANS) regulation. Specifically, infants with CCHD experience abnormally reduced parasympathetic activity in states of rest^{1,2,Author} and impaired ability to suppress parasympathetic activity in response to stress or challenge, such as feeding.^{Author} Impaired patterns of ANS function may contribute to poor feeding,^{3,4} poor growth,^{5,6} and subsequent problems with social and emotional behavior often observed in infants and children with CCHD.^{7,8} Many factors may influence activity of the ANS in infants with CCHD including compromised cardiac function,⁹ surgery,¹⁰ multiple caregivers,¹¹ and separation from mother.¹² Separation from mother is a factor that may be modifiable.

Schore's Regulation Theory, addressing the development of self-regulation in infants and young children, posits that the development of patterns of response of the sympathetic and parasympathetic divisions of the ANS is directly influenced by the mother's interactions with her infant.^{13,14} Over time, infants of mothers responding sensitively to their infants' cues develop pathways in the brain resulting in coordinated interactions between the sympathetic and parasympathetic nervous systems. These precisely coordinated interactions are primarily responsible for physiologic regulation, i.e. maintaining stability in the face of change or challenge.¹⁵ The primary source of interaction between newborn infants and their mothers is close physical contact.^{16,17} When the infant's environment (e.g., an intensive care unit) elicits primarily sympathetic effects, pathways in the brain are developed that result in a predominance of sympathetic function.¹³ The resulting patterns of function limit adaptive physiologic regulation^{18,19} and may serve as the neurobiological substrate of subsequent alterations in social and emotional behavior.¹³ Increasing contact between mothers and hospitalized infants may moderate the impact of the ICU environment.

Newborn infants with CCHD and their mothers are often physically separated due to infants' need for intensive medical and nursing care. Hospitalized premature infants receiving direct maternal skin-to-skin contact (SSC) demonstrate more rapid maturation of ANS function when compared with infants not receiving SSC.²⁰ Although term infants with CCHD share with premature infants the experience of maternal separation and care in a hospital environment, infants with CCHD have the additional challenges of major surgery and impaired cardiac function. The effect of SSC on the impaired ANS function of infants with CCHD is not known. Implementation of a SSC intervention in this population of infants, who are perhaps the most seriously ill of infants hospitalized at birth, requires study of its feasibility as well as preliminary investigation of outcomes. The purposes of this study were to (1) examine feasibility of an SSC intervention and (2) describe ANS function in response to a feeding challenge before and over the 4 weeks after completion of a 14-day, daily SSC intervention.

Methods

Design

This was a longitudinal pilot study using a single group, pre-test/post-test design with 4 week follow-up. Human subjects review boards in participating hospitals approved the study.

Setting and sample

A convenience sample of infants diagnosed with CCHD and their mothers were recruited prior to surgery within the first week of the infants' lives from two major Midwestern children's hospitals. Eligible infants were: (a) 37 weeks gestation and (b) scheduled for surgical intervention within the first 30 days of life. Infant exclusion criteria were: (a) co-existing, non-cardiac congenital defects or syndromes, (b) exclusive nasogastric feedings post-operatively, and (c) ongoing post-operative cardiac pacing. Eligible mothers were: (a) English speaking, (b) 18 years of age, (c) the infant's primary caregiver, and (d) able and willing to participate in the intervention for 14 consecutive days.

Intervention

SSC was initiated when the infant was extubated and chest incision closed, was not receiving vasopressors, and had begun oral feedings. Consistent with previous research,^{21,22} mothers provided SSC for a minimum of one hour a day for 14 consecutive days, beginning immediately after a feeding. The procedure was as follows: The infant was undressed except for a diaper. The mother stood by the infant's bed and lifted the infant unto her chest, positioning the infant upright and prone on her bare chest between her breasts. A receiving blanket folded in half covered the infant's back from the back of the head to the toes. The mother then sat in a recliner at an approximately 40° angle. The bedside nurse assisted in the transfer of the infant to the mother until the mother and nurse agreed that the mother could safely and comfortably make the transfer independently. The PI worked with the nursing staff to reduce interruptions and distractions in the environment and to provide as much privacy as possible. The actual time of SSC in minutes was documented in a diary completed by mothers daily for the 14-day intervention.

To ensure intervention integrity, the PI or research assistant (RA) was present for the first four SSC episodes for each participating dyad. Daily attendance continued until the mother had been observed correctly placing and maintaining the infant on her chest in the position described above for two consecutive interventions. At this point, the PI or RA reduced direct observation to every other day, then every third day until the infant was discharged home or the 14-day intervention was complete. If the infant was discharged home before the end of the 14-day intervention, the PI or RA contacted the mother by telephone at the same time intervals.

Measures

Intervention feasibility—Feasibility was assessed by recruitment and retention rates, safety, and acceptability to families and staff based on written diary and survey responses from mothers and staff nurse interviews. Mothers completed a daily written diary of frequency and duration of SSC in minutes and commented on the experience. A survey with closed- and open-ended questions was completed by the mother following the 14-day intervention. Questions included: (a) satisfaction with providing SSC, (b) experiences with SSC in hospital and home, and (c) suggestions about SSC timing and duration. Closed-ended responses related to satisfaction were recorded on a 5 point scale with 1 = very unsatisfied and 5 = very satisfied.

ANS function—Heart rate variability was used to measure ANS function using continuous electrocardiographic (ECG) recordings collected with a three-channel ambulatory Holter recorder. The ECG data was initially sampled at 250 Hz and filtered to 125 Hz by the GE MARS 5000® Ambulatory ECG Analysis and Editing System (General Electric, Inc.) for R wave detection. Each ECG complex was identified and characterized with regard to morphology by the computer software. The MARS system uses a template pattern-matching method for detection of R waves which is updated in real time. Each new R wave is then matched with pattern templates and classified accordingly. This preliminary analysis was then verified by the PI to assure proper labeling of heart beats and artifact. Interbeat intervals associated with ectopic beats, non-sinoatrial node-initiated complexes, and artifact were excluded from analysis.

Linear HRV: Linear measures of HRV were calculated using frequency domain methods, determined by power spectral analysis (PSA) using the Lomb-Scargle periodogram, which accurately produces estimates directly from the inherently unevenly spaced heart beat data.^{23–26} The power values most often quantified for short-term recordings are high frequency power (HF HRV), reflecting primarily parasympathetic activity (band width: 0.3 – 1.3 Hz for neonates), and low frequency power, reflecting a mix of parasympathetic and sympathetic activity (band width .04–.30 Hz). HF HRV was used for analysis in this study. Measures of HF HRV expressed in $\ln(\text{ms}^2)$ were calculated in 1-minute epochs, averaged for each feeding phase (pre-feeding, during-feeding, and post-feeding), and compared within feeding and over time.

Non-linear HRV: Power spectral analysis provides information about linear aspects of autonomic regulation of heart rate, reflecting periodic oscillations in interbeat intervals primarily associated with respiration.^{27,28} However, complex interactions of sympathetic and parasympathetic influences on cardiac sinus node activity may result in non-linear, e.g. non-periodic, effects as a result of changes in psychological state, physical activity, or baroreceptor responses²⁸ that are not captured with spectral frequency approaches.^{29,30} Poincaré plots (graphical plots of beat-to-beat intervals between successive pairs of heart beats),³¹ allow assessment of these non-linear influences on heart rate,^{30,32} which have been associated with mortality risk in adults.^{28,30,31,33} In healthy individuals, a comet shaped elliptical dispersion is seen in which the interbeat intervals grow more variable with slower heart rates^{28,31} (see Figure 1). Poincaré plots can be analyzed quantitatively by measuring the width of the ellipse (SD1) and the length of the ellipse (SD2). SD1 and SD2 are strongly correlated with the spectral analysis indices of HF HRV and LF HRV respectively.^{34,35} In contrast, the ratio of SD1 to SD2 (SD12) reflects non-linear effects on heart rate,^{29,33,35,36} providing information about sympathetic activity not available with linear methods.²⁹

Abnormal Poincaré plots are associated with altered autonomic regulation, specifically, abnormally increased sympathetic activity,^{30,32,37} and reflect a more random heart rate.³⁸ Two types of abnormal plots have been identified that are associated with cardiac risk in adults with heart disease.³² A narrow, torpedo shape is seen when there is little variability in the timing of interbeat intervals with slower heart rates²⁸ (see Figure 1). Torpedo type plots can be identified quantitatively by an SD12 of < 0.15 milliseconds (ms).³⁷ A fan-shaped

pattern is seen when the range of interbeat intervals is restricted, but the dispersion is greater than seen in healthy individuals²⁸ (see Figure 1). Fan-shaped plots can be identified quantitatively by an SD12 of $> 0.55\text{ms}$.³³ The fan-shaped plots of abnormally clustered points are labeled complex and may contain multiple clusters.³⁰ Although torpedo shaped Poincaré plots are closer to normal patterns, both torpedo and complex plot types are associated with elevated levels of norepinephrine and risk of mortality in adults with heart disease with the complex plots being associated with more disturbance of autonomic regulation of heart rate.^{30,32,33}

In this study, SD1, SD2, and SD12 are reported using the mean values of 5 minute segments before, during, and after feeding at each time point. SD12 was the primary unit of analysis. Individual plots were categorized by type before, during, and after feeding for each time point.

Procedures

The 14-day intervention was implemented as described above. The maternal diary was completed each day of the intervention, and the survey was completed at the end of the intervention. Demographic information was collected at recruitment, and data were collected at four time points (see Figure 2). Time 1 was a pre-intervention baseline and took place in the hospital shortly after initiation of oral feedings post-operatively, approximately 7 days after surgery when the infant was about 2 weeks old. Times 2, 3, and 4 took place at successive two week intervals beginning two weeks after Time 1 at the completion of the intervention when the infants were approximately 4, 6, and 8 weeks old. Data were collected either in the hospital or the home based on discharge of the infant.

To collect ECG data for HRV analysis, a small, portable ECG recorder was attached to the infant's chest using seven neonatal electrodes. For each data collection, a recording was made 30 minutes prior to feeding, for the duration of the feeding beginning with the first placement of the nipple in the mouth, and for 60 minutes after the feeding was completed beginning immediately after the final time the nipple was removed. To confirm the frequency range for HF HRV, a respiratory rate was obtained by counting respirations for one minute via direct observation at the beginning and end of each recording and the beginning and end of feeding. Infant illness information was abstracted from the infant's hospital record.

Data Analysis

Descriptive statistics were calculated for all variables. General linear mixed models (GLMM) for repeated measures³⁹ were used to compare HRV indices. Type 1 error rate was set at 0.1 for this exploratory study. Poincaré plots were created and quantified. Event history analysis⁴⁰ was used to describe the length of time required post-feeding to return to pre-feeding mean HF HRV values (recovery). Two variables were calculated. First, time-to-criterion marked the time of recovery. The start of recovery was defined as the first of 5 consecutive minutes in which HF HRV values were at or above the pre-feeding mean HF HRV value.^{Author} Second, the censor variable was defined as 0=no recovery before the end of the 60 minute post-feeding observation or 1=recovered before the end of the observation.

These variables were defined for each time point. The Kaplan-Meier survival function was then run.⁴¹ The minute at which 50% of the infants achieved pre-feeding HF HRV values was identified for each data collection point.

Results

Eighteen infants and their mothers were recruited. Two infants expired prior to intervention initiation, 2 infants were too sick to complete intervention. Four families withdrew after discharge home (2 unable to reach; 2 overwhelmed with caregiving). Results reflect the 10 remaining infants. See Table 1 for demographics. Eight infants were treated for single ventricle conditions (seven hypoplastic left ventricle; one hypoplastic right ventricle) and two for transposition of the great arteries. Two of the single ventricle infants and the two transposition infants underwent complex surgical procedures requiring cardiopulmonary bypass. The remaining six infants underwent the hybrid procedures for initial palliation in infants with single ventricle disease, which required sternotomy, but not cardiopulmonary bypass.⁴² Data collection occurred in the hospital for all 10 infants at Time 1 (ICU = 4), for 3 infants at Time 2 [step-down unit (SDU)], and for 1 infant at Times 3 and 4 (SDU).

Time in SSC

SSC was initiated on average at 9 days post-op, at which time all infants were on oral analgesics, e.g. acetaminophen or ibuprofen, and no sedatives. Mothers and infants spent a daily average of 77.05 minutes in SSC during the 14-day intervention with a minimum of 0 minutes and a maximum of 210 minutes. Most SSC sessions were provided in private step-down unit rooms or in the home (see Table 2).

Feasibility

Recruitment rate was 72%; retention rate 55.5% as described above. No adverse events related to SSC occurred. All mothers reported being satisfied with the SSC experience with 80% responding “very satisfied” (mean = 4.88). Aspects of the hospital experience described as helpful included the quiet environment, a set schedule of SSC times, help with positioning, and having someone observe the first few sessions. Aspects of the hospital experience that were not helpful included people coming in the room, clinicians wanting to examine the infant, intravenous lines, and scheduling around breast pumping and infant cares.

Reported helpful aspects of the SSC experience in the home included being in their own environment, feeling more comfortable and relaxed, more privacy, obliged to take time to hold the infant, and family support. The aspect of SSC in the home identified as not helpful was having additional children needing care. Five mothers felt the SSC could have been initiated earlier; the rest felt the timing was about right. Four mothers reported worry about holding with wires and tubes. Eight of the ten mothers felt the 14-day intervention was the right duration for the study although several commented that they planned to continue providing SSC; the remaining 2 felt the intervention should be longer. In responses to open-ended questions, mothers often reported feeling they missed out on the early bonding generally experienced by mothers and healthy infants, and SSC helped to make up for that

lost time. Mothers also felt their infants benefited from SSC through improved sleep and comfort. Representative comments recorded by the mothers are reported in Table 3.

No staff nurses responded to multiple invitations to participate with a semi-structured interview on the impact of SSC in the CTICU setting. Informal conversations with nurses providing care to study participants suggested minimal impact of the intervention on unit activities or the ability to deliver nursing care.

Autonomic function

Descriptive statistics for HRV variables are presented in Table 4.

Linear HRV—Steady increases in baseline HF HRV over time were found with significant increases at T3 and T4 (T1 v. T2: $F = 2.17$, $p = .153$; T1 v. T3: $F = 8.05$, $p = .009$; T1 v. T4: $F = 4.88$, $p = .036$).

Pre-intervention, no significant changes in HF HRV were demonstrated across feeding. Significant reductions in HF HRV during feeding and increases post-feeding with large effect sizes were seen at T2 and T3. However, at T4, no differences were found across feeding (see Figure 3 and Table 5).

In examining recovery to pre-feeding HF HRV values, 50% of the sample recovered within 6 minutes at Time 1, within 4 minutes at Times 2 and 3, and within 1 minute at Time 4 (see Figure 4)

Non-linear HRV—No significant changes in mean pre-feeding (baseline) SD12 over time were observed (T1 v. T2: $F = 0.21$, $p = .653$; T1 v. T3: $F = .29$, $p = .600$; T1 v. T4: $F = 1.35$, $p = .256$). Significant increases in SD12 (increased sympathetic activity) with large effect sizes were observed post-feeding at Times 2, 3, and 4. A significant decrease in SD12 during feeding was observed at Time 3 (see Table 5).

Abnormal Poincaré plots were observed in all infants with 9 of 10 infants demonstrating both torpedo- and complex-type patterns. The most common abnormal Poincaré plot was of the complex-type (see Figure 5) which decreased in frequency as the infants aged. The majority of complex plots were observed during post-feeding recovery (see Figure 6).

Discussion

In this study, we examined the feasibility of a SSC intervention in newborn infants with CCHD and described autonomic nervous system (ANS) function as indexed by heart rate variability (HRV) before and in the 4 weeks following a 14-day, daily skin-to-skin contact (SSC) intervention. Findings demonstrated that SSC is acceptable, safe, and valued by mothers, and that, although nonlinear measures were concerning, linear measures of HRV may have been enhanced.

Feasibility

Recruitment rates were relatively high (72%) for these vulnerable and highly stressed families, and much of the attrition in this longitudinal study was due to death or illness serious enough to preclude holding. A potential concern of physician and nursing staff is safety of SSC in this population who may experience unanticipated, significant physiologic instability. These concerns were addressed by waiting until the infant was stable post-op prior to initiating SSC. No adverse events occurred. In premature infants, SSC is known to improve cardiac and respiratory regulation and is associated with more mature regulation of central nervous system processes.^{43–47} Support for the positive regulatory effect and safety of SSC in infants with CCHD is found in a small study of five infants in post-operative cardiac intensive care in which attempts at removing respiratory support had failed.⁴⁸ Three cycles of two hours of SSC followed by two hours in an isolette were conducted over 12 hours following the next attempt at extubation. The infants were more regulated physiologically (as measured by heart rate, respiratory rate, central venous pressure, and oxygen saturations) during SSC periods in comparison to non-SSC periods, and all were successfully extubated with this intervention. Consistent with these reports, a case study of physiologic response during the first episode of SSC in one infant in the current study demonstrated significant reductions in heart rate and increases in oxygenation during SSC compared with the 30 minute pre-SSC time period.^{Author}

Mothers universally reported positive experiences for themselves and their infants, focusing on the social and relationship aspects. These mothers' recognition of the importance of physical contact and relationship has been validated in numerous studies of the association between positive mother-infant interactions and subsequent neurodevelopment in healthy and in premature infants.^{49,50} Schore's Regulation theory delineates many of the critical neurobiological processes that occur during mother-infant interaction,^{13,51} including changes in patterns of ANS activity. In newborn infants, this stimulation of regulatory pathways occurs primarily through the day-to-day repetition of holding and feeding.¹⁶ Through these neurobiological mechanisms, infants of mothers able to interact with responsiveness and sensitivity develop more healthy, responsive autonomic systems and subsequent improvements in neurodevelopment.^{16,52} Many of the mothers in the current study had limited opportunity to hold their infants in this ICU setting and were highly motivated to participate in this study expressly because participation ensured more contact with their infant.

Unexpectedly, nursing staff did not respond to efforts to obtain their feedback. Given that the formal semi-structured interview needed to be conducted away from work hours, the time commitment may have been a barrier to participation. It might be expected that if SSC was causing significant interference with clinical care, nursing staff would have shared their experience. It is possible that the intervention did not impact nursing care in meaningful ways. The study team worked with the nursing staff and the mother to identify best times for SSC and were present to support nurses in transferring and positioning the infant and in teaching the mother and other family members these processes to shorten the time to independent delivery of SSC. In future studies, discussions with nursing staff are needed to identify alternate methods of obtaining this important feedback, such as on-line surveys.

Linear HRV

Consistent with Schore's Regulation Theory, which associates positive maternal interaction with enhanced infant ANS function,¹³ findings from this study demonstrated improvements in baseline HF HRV (pre-challenge at rest) across the 6-week study. This finding is important because in healthy newborns, baseline HF HRV initially declines, reaching a nadir during the second month of life, before beginning to increase at about 2 months of age.^{53,54} Infants with CCHD begin life with lower HF HRV compared with healthy neonates^{1,55, Author} and surgery and experiences in the ICU may further depress this regulatory system.^{2,10,55,56} Although it is possible the improvements in HF HRV function over the study were associated with recovery from surgery or with normal developmental changes in this small sample, the intervention may have contributed to enhanced ANS function over time, similar to results of previous studies with premature infants.²⁰ In a quasi-experimental study, 35 premature infants received a minimum of one hour of SSC daily for 14 consecutive days beginning at approximately 32 weeks gestational age. When measured at 37 weeks (3 weeks after the intervention ended), infants receiving SSC exhibited more rapid maturation of baseline HF HRV, when compared with the control group infants.²⁰

In healthy and in premature infants, HF HRV is significantly lower during feeding compared with pre- and post-feeding levels.^{19,53,57, Author} Reduced HF HRV levels reflect the adaptive reduction of parasympathetic activity during the ingestion of food, allowing sympathetic effects to predominate to increase the metabolic resources needed to coordinate the physiologic processes of sucking, swallowing, and breathing. When the feeding is complete, parasympathetic activity increases and sympathetic effects are reduced resulting in a recovery of conditions supportive of growth and restorative processes.¹⁸ In the current study, little to no response was seen pre-intervention. However, multiple subsequent measurements following the intervention demonstrated robust reactivity. These findings are similar to one other study of autonomic response to post-operative feeding challenge in infants treated for CCHD.^{Author} Little reactivity was observed at 2 weeks of age, and reactivity similar to healthy infants was observed at the next data collection at 2 months. Because of differences in timing of measurement between the two studies, it is not known whether development of this adaptive response in the current study was a maturational process of the ANS or if the SSC intervention may have hastened its establishment. Additional studies with larger sample sizes and a comparison group are needed.

Time to recovery to pre-feeding baseline HF HRV levels demonstrated that prior to the intervention at least 50% of the infants recovered within 6 minutes compared with recovery within 1 minute four weeks following the intervention. These findings are somewhat better than those observed in one other study which examined recovery in this population. Among 15 infants with transposition of the great arteries, recovery of 50% of infants was unchanged between 2 and 8 weeks of age with a recovery time of within 4 minutes.^{Author} The improvement in recovery times demonstrated with this intervention needs additional research. Recovery from physiologic challenge is vastly understudied and may provide as much, if not more, critical information about the infant's capacity for regulating physiologic processes than baseline and reactivity values.

Non-linear HRV

Non-linear analysis using SD12 values showed no change in baseline over time, decreases during-feeding at Time 3 only, and increases post-feeding at each time point. To some extent, decreases in SD12 during-feeding are consistent with lower values of SD1 reflecting the expected parasympathetic withdrawal during physiologic challenge. However, previous research has demonstrated that when SD12 values dip below 0.15ms, depicted with a very narrow, torpedo-like plot, abnormally high sympathetic activity is present.³⁷ A notable percentage of individual infants demonstrated these abnormal torpedo-type plots at each feeding phase at each time point.

SD12 increased post-feeding at each time point. Again, to some extent, increases in mean SD12 reflect the expected increase in parasympathetic activity and resultant decrease in sympathetic activity expected during recovery from challenge.⁵³ However, values which reach 0.55ms, depicted with a fan-like plot, suggest highly random heart rate due to abnormal sympathetic activation.³³ The vast majority of infants in the current study demonstrated abnormal Poincaré plots across feeding. The highest levels of randomness in heart rate were found in the post-feeding time period. Although over time fewer infants were affected, the presence of abnormally high sympathetic activation in the majority of infants suggests that feeding is a highly challenging physiologic event in this population, and these infants may require a different type of care to provide support both during and after feeding.

Assessment of non-linear indices in infants with CCHD is rare. One study by Smith and colleagues was found in which Poincaré plots were examined in 26 infants who were undergoing 3 different types of procedures for different types of CCHD.⁵⁸ Infants with aortic arch reconstructions and Blalock-Tausig shunts, but not procedures for hypoplastic left heart syndrome, demonstrated increases in baseline SD12 between 4 weeks post-procedure and 3–9 months later, suggesting continued and perhaps increasing randomness in heart rate. This difference in trajectories of baseline SD12 from the current study may reflect variability within the population of infants with different types of CCHD and with different types of procedures. It is also possible that the SSC intervention received by the infants in the current study may have supported enhanced autonomic regulation in the infant's resting state.

Examination of reactivity and recovery from challenge was not part of the Smith study. Our findings that abnormally high sympathetic activity was common in these infants, especially post-feeding, needs additional research. In adults, abnormal Poincaré plots are associated with increased risk of mortality.^{28,30,31,33,36} Research is critically needed to assess nonlinear measures of HRV as potential markers of risk in this vulnerable infant population.

Limitations and Future Directions

The small sample in this study precludes firm conclusions about effects of SSC in infants with CCHD. A more complete description of the environments in which SSC was provided, as well as reports of additional days of SSC beyond the intervention would have been useful in differentiating effects of maturation and intervention on ANS function.

The current study was designed to present measures of ANS function as a preliminary outcome of an SSC intervention. Future research needs to include an appropriate comparison group, i.e., infants with CCHD matched by age and type of procedure, to enable more precise assessments of effects of SSC on ANS function. Studies are needed of effects of earlier initiation of SSC, e.g., prior to surgery and early after surgery, and associations made with immediate and long-term outcomes.

Conclusions

Infants hospitalized at birth with CCHD experience multiple conditions impacting ANS function. Optimal parasympathetic activity is essential for growth and for restoring and conserving energy and is especially critical for recovery of infants hospitalized with serious health conditions^{18,59} and for subsequent regulation of social and emotional behavior.⁶⁰ Given that close mother-infant physical contact improves ANS function in other high-risk infant populations,²⁰ this study provides initial support for the feasibility of using post-operative SSC to enhance ANS function in infants with CCHD. Additional research on the use of this low-cost, low-risk intervention in infants with CCHD is needed to identify variations in linear and non-linear effects based on specific cardiac conditions and with varying intervention doses and timing. Increasing our knowledge of the impact of increased maternal-infant contact has the potential to improve nursing care and, ultimately, improve the quality of these infants' lives.

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Figure 1.

Examples of Poincaré plots with R to R wave intervals (RR_n) plotted against the subsequent interval (RR_{n+1}) and measured in milliseconds (ms). SD1 = short axis of Poincaré plot, SD2 = long axis of Poincaré plot, SD12 = ratio of SD1 to SD2.

Figure 2.
Schematic of data collection timing.

Figure 3.
Trajectories of high frequency heart rate variability (HF HRV) across feeding over time.

Figure 4.
Time in minutes at which at least 50% of infants recovered to pre-feeding high frequency heart rate variability (HF HRV) levels.

Figure 5. Percentage of infants with abnormal Poincaré plot types by age. Percentages add up to > 100% because many infants demonstrated both types of plots.

Figure 6. Percentage of infants with torpedo-type (A) and complex-type (B) Poincaré plots by feeding phase and age. Percentages add up to > 100% because many infants demonstrated both types of plots.

Table 1

Mother/Infant Demographics and Infant Age and Length of Stay

	<i>n</i>	%	<i>M</i>	<i>SD</i>	<i>Min/Max</i>
Maternal ethnicity/race					
Non-Hispanic/black	1	10			
Non-Hispanic/white	8	80			
Hispanic/White	1	10			
Marital status					
Married, partnered	10	100			
Maternal education					
High school or less	2	20			
Vocational school	3	30			
Some college/degree	3	30			
Graduate school	2	20			
Maternal age (years)			29.50	5.58	22–40
Infant male gender	5	50			
Infant race/ethnicity					
Non-Hispanic/black	1	10			
Non-Hispanic/white	7	70			
Hispanic/white	2	20			
Age (days)					
At surgery			5.7	2.60	2–9
Time 1			14.6	8.24	6–29
Time 2			29.7	8.64	20–45
Time 3			43.6	8.00	35–38
Time 4			58.2	9.57	49–80
Hospital Length of Stay (days)			26.9	21.80	9–84

Table 2

Daily Minutes and Location of SSC over 14-Day Intervention

Infant	Mean	SD	Min/Max	Post-op day of 1 st SSC	# Days of SSC by location		
					ICU	SDU	Home
1	81.64	24.82	20 ^a –126	11	2	1	11
2	66.43	9.69	60–90	4	0	1	13
3	62.14	8.02	60–90	20	0	14	0
4	90.43	43.72	30 ^a –160	3	2	0	12
5	62.28	30.35	0 ^a –112	2	1	9	3
6	33.57	36.71	0 ^b –95	3	2	5 ^b	0 ^b
7	67.86	13.18	60–100	4	0	3	11
8	176.86	26.44	120–210	22	0	5	9
9	62.50	3.41	60–70	6	0	4	10
10	66.79	11.54	45 ^a –90	14	0	14	0
Total	77.05	20.79	0–210	<i>M</i> = 8.9; <i>SD</i> = 7.45	7	56	69

Note. SSC = skin-to-skin contact, ICU = intensive care unit, SDU = cardiac step-down unit

^aOccurred once in the 14 day intervention. Diaries indicated mothers “ran out of time” for unspecified reasons. Infant 5 had intervention in the catheterization lab, resulting in no SSC that day.

^bUnable to provide SSC Days 8–14 due to complications following intervention in the catheterization lab. The mother reported resuming SSC in the SDU and home, which was after the 14-day intervention time period.

Table 3**Mothers' Responses to Providing Skin-to-Skin Contact Intervention**

Topic	Direct quotations from surveys
Relationship	<ul style="list-style-type: none"> • Made me feel closer to him, and I felt I made up for lost time. • Skin to skin is GREAT for all infants. For those with heart surgery it gives an awesome opportunity for bonding. • It's a great way to bond with your baby. I could not do skin to skin after my baby was born. So doing when we did was great. I enjoyed it. • I would offer it to all moms but the first two weeks it was difficult to bond, this really helped catch up. • Stay connected under the circumstances.
Benefit to mother	<ul style="list-style-type: none"> • It very theriputic (<i>sic</i>). You get to enjoy your baby. Gives you a chance to feel like you are being a mom by holding and cuddling baby. It also helps with stress. • Helped with breast milk production. • Became my quiet time to de-stress and bond with my baby. It became "our" time. • This was a very relaxing experience. An opportunity to forget about all of the surgery stress and just enjoy baby. • Made me feel comfortable holding and transitioning him. Also, very easy to become emotionally numb in this hospital environment and skin-to-skin allowed time to make me feel and remind me that I'm a mother. • I loved it! I think it help me to recover from the shock of everything that had happened. • One thing to look forward to besides going home. • Get to enjoy your baby.
Perception of infant response	<ul style="list-style-type: none"> • She responded well. She would sleep the whole time. She was comfortable on my chest. • She really took a liking to it. And even when she gets fussy holding her skin to skin can even help calm her down. • The leads often caused discomfort but now she seems to navigate her way to my chest and snuggle in as if it where she belongs. • He really likes to be held and close to me. He enjoyed. • She enjoyed. Slept most of the holds.

Table 4
Descriptive Statistics High Frequency Heart Rate Variability (HF HRV), SD1, SD2, and SD12 across Feeding by Age

	HF HRV			SD1			SD2			SD12		
	Mean	SD	Min/Max	Mean	SD	Min/Max	Mean	SD	Min/Max	Mean	SD	Min/Max
Time 1												
Pre	3.10	.52	2.04–4.65	6.14	1.58	4–11	29.39	16.75	5–70	.29	.19	.08–.97
Feed	3.16	.68	2.08–5.27	6.50	2.17	4–16	25.31	15.03	8–60	.34	.21	.11–.90
Post	3.12	.61	2.10–5.54	6.34	2.31	4–18	23.68	14.30	6–80	.34	.16	.09–.78
Time 2												
Pre	3.32	.55	2.11–5.31	7.34	2.90	5–18	30.36	14.93	5–68	.29	.17	.12–1.04
Feed	3.24	.60	2.20–5.49	6.67	2.23	4–15	32.51	15.55	11–78	.23	.08	.10–.44
Post	3.59	.69	2.21–6.26	7.82	2.81	3–18	28.04	14.84	6–81	.35	.21	.10–1.12
Time 3												
Pre	3.63	.69	2.29–6.67	7.84	2.99	5–17	31.56	13.74	8–60	.30	.17	.10–1.00
Feed	3.16	.74	1.87–7.57	6.70	2.84	4–18	31.28	14.66	10–67	.23	.07	.11–.45
Post	3.62	.91	2.05–7.54	8.72	5.84	5–42	31.60	22.03	6–125	.34	.19	.11–1.05
Time 4												
Pre	3.42	.54	2.06–5.59	6.87	1.51	4–11	29.10	11.18	11–67	.26	.09	.12–.48
Feed	3.46	.65	1.97–5.49	7.37	2.03	5–13	34.53	14.24	14–63	.25	.08	.13–.43
Post	3.58	.66	2.00–6.57	7.80	2.50	5–21	29.67	15.14	8–110	.32	.17	.11–.84

Note. SD1 = short axis of Poincaré plot, SD2 = long axis of Poincaré plot, SD12 = ratio of SD1 to SD2.

Table 5

Change in heart rate variability and SD12 across feeding as calculated by general linear mixed models

	HF HRV			SD12		
	<i>F</i>	<i>p</i>	Effect size	95% CI	<i>F</i>	Effect size
T1 pre-during	0.010	.924	−0.03	[−0.46, 0.44]	1.104	.307
T1 during-post	0.002	.968	0.01	[−0.47, 0.48]	0.000	.995
T2 pre-during	4.382	.066	0.49	[−0.20, 0.64]	1.935	.181
T2 during-post	13.980	.005	−0.91	[−0.91, 0.01]	14.020	.001
T3 pre-during	3.838	.082	0.59	[−0.21, 0.94]	4.891	.040
T3 during-post	10.406	.010	−0.55	[−1.06, 0.28]	12.318	.003
T4 pre-during	0.037	.852	0.06	[−0.38, 0.43]	1.064	.317
T4 during-post	1.300	.284	−0.31	[−0.53, 0.27]	9.034	.008
						−1.00

Note. HF HRV = high frequency heart rate variability; SD12 = ratio of the short axis of the Poincaré plot to the long axis of the Poincaré plot; CI = confidence interval; Time 1 = pre intervention; Times 2, 3, 4 = post intervention.