






Parental holding of infants improves haemodynamics in the cardiac ICU

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Original Article

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Abstract

We performed a single-centre, retrospective study to assess physiologic changes of infants in the cardiac ICU while being held by their parent. Continuous data streaming of vital signs were collected for infants included in the study from January 2021 to March 2022. Demographic and clinical characteristics were collected from the electronic medical record. The physiologic streaming data were analysed using mixed-effects models to account for repeated measures and quantify the effect of parental holding. Comparison analysis was also performed controlling for intubation, pre-operative versus post-operative status, and whether the holding was skin-to-skin or not. Ninety-five patients with complete physiologic data were included in the study. There were no immediate adverse events associated with holding. Heart rate decreased during the response time compared to its baseline value ($p = 0.01$), and this decrease was more pronounced for the non-intubated and pre-operative patients. The near-infrared spectroscopy-based venous saturation increased overall ($p = 0.02$) in patients while being held. We conclude that parental holding of infants in the cardiac ICU can be safely accomplished, and the haemodynamic and oximetric profile during the holding is favourable compared to the infants' baseline prior to holding.

Given the high prevalence of neurodevelopmental impairments in children born with complex CHD, there is an increasing focus to determine potentially modifiable practices within the cardiac ICU to improve neurodevelopmental trajectories in this population.^{1–3} The inherently unnatural and stressful environment of the cardiac ICU for the newborn infant with CHD has significant potential negative impacts on brain development. Developmentally appropriate practices aiming to mitigate the infant stress experience are promising modifiable factors to improve neurodevelopmental outcomes.^{4,5} However, there is wide variability in developmental care practices across cardiac ICUs.^{6–8} Additionally, there is a growing recognition of the significant stress experienced by families of infants hospitalised with CHD, exacerbated by parental role alteration including the parents' inability to hold their infant in the cardiac ICU.^{9–13} This additional stress and parental role alteration can impede parent–child bonding with the potential for significant negative impact on short- and long-term developmental outcomes.^{14–16}

Being held is not only critical for an infant's motor development, but holding, especially skin-to-skin care, has been shown to reduce pain and stress as well as improve early clinical outcomes in preterm and term infants.^{17–22} Holding is a vital mechanism to facilitate infant–parent bonding and may promote decreased stress in parents of hospitalised infants with CHD.^{23–27} However, particularly within the cardiac ICU, there are potential barriers to holding. These include haemodynamic instability and concern for safety due to possible dislodgement of life-sustaining equipment such as endotracheal tubes, vascular access, and temporary pacing wires. While previous studies have demonstrated the safety of holding critically ill infants, including those with CHD, there is limited data regarding haemodynamic changes that occur when a potentially physiologically fragile infant with CHD is held.^{28–33} This study seeks to leverage a high-fidelity physiologic data monitoring system to investigate the association of parental holding on important physiologic markers for critically ill infants with CHD.

Materials and method

Infants in the cardiac ICU between January 2021 and March 2022 were included in the study. This study was performed in accordance with the standards of the Helsinki Declaration of 1975 and approved with waiver of consent by the Institutional Review Board of Baylor College of Medicine under protocol H-49933. As every episode of holding is not routinely documented in

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the CICU medical record and exact timing of holding is necessary to perform this analysis, infants were included when precise parental holding start and stop times were documented in the electronic medical record by a member of the study team. For purposes of this study, infants undergoing active vasoactive or sedative drip titration and those receiving bolus sedation or analgesia medication doses were excluded. As holding duration varied, we focused on the first 60 minutes of holding for data analysis.

Our cardiac ICU does not have formalised holding criteria, but general guidelines have been developed and are part of required annual nursing training. Contraindications to holding include open chest, central extracorporeal membrane oxygenation support, and patients being actively paced via temporary pacing wires who do not have an adequately perfusing underlying rhythm. For all other eligible patients, the safety and appropriateness for holding are discussed amongst the clinical team, which includes representatives from physicians, nurses, and occupational and physical therapists. Safety considerations for lines, drains, and airway securement prior to holding are shown in Supplemental Table 1. Patients greater than 1-week post-cardiac surgery can be considered for skin-to-skin holding once chest tubes have been removed.

Baseline data were collected over the 30-minute period prior to holding. Time zero indicates the start time of infant holding. The response interval was captured during the first 60 minutes of holding. This approach enabled the comparison of each patient's response to his/her own baseline.

The Sickbay clinical platform (Medical Informatics Corp; Houston, TX, USA) installed at Texas Children's Hospital was used to collect haemodynamic and oximetric data. Physiologic data included heart rate, pulse oxygen saturation, diastolic, systolic, and mean arterial blood pressures. These signals are sampled at 0.5 Hz, stored in the Sickbay system, and made available for retrospective studies. In the cardiac ICU, patients are routinely monitored using near-infrared spectroscopy oximeter to measure cerebral and renal venous oxygen saturation. Near-infrared spectroscopy signals were captured at a frequency of 0.2 Hz. The combined near-infrared spectroscopy-based venous oxygen saturation is calculated as: (cerebral oxygen saturation + renal oxygen saturation)/2.

Continuous variables are described as median and interquartile range. To establish a baseline value for each vital sign and patient, the vital sign was collected and averaged over the baseline interval (from -30 minutes to 0 minutes). The response variables provided a quantitative framework to analyse the physiologic changes during the infant holding time. These response variables were evaluated for each patient and subsequently aggregated for statistical tests. The response is the repeated evaluation of each vital sign as non-overlapping 10-minute moving average after the initiation of holding. Effects of infant holding on the physiologic variables were compared between the baseline and the response period using mixed-effects linear regression models to account for the repeated measurements every 10 minutes after the starting of infant holding time. This statistical design ensures that these patients use the data collected before the infant holding time as their controls.

The associations between physiological parameters of the response variables and factors including skin-to-skin holding, intubation status, and pre-operative or post-operative status were computed using mixed-effects models implemented in the "statsmodels v0.12.2" library available in the Python environment. For all tests, statistical significance was considered when the p-value was < 0.05.

Table 1. Demographic and clinical characteristics of the cohort and baseline vital signs (prior to infant holding).

| Patient variables (n = 95) | |
|----------------------------|---------------|
| Sex (male) | 61 (64%) |
| Single ventricle | 27 (28%) |
| Post-op | 48 (51%) |
| Intubated | 32 (34%) |
| Skin-to-skin | 21 (22%) |
| Holder (mother) | 78 (82%) |
| Age (days) | 26 (8–90) |
| Weight (Kg) | 3.5 (3.1–4.1) |
| Vital signs at baseline | |
| HR (bpm) | 147 (131–160) |
| sBP (mmHg) | 83 (72–93) |
| dBP (mmHg) | 43 (38–51) |
| mBP (mmHg) | 58 (51–64) |
| SpO ₂ (%) | 91 (85–97) |
| SvO ₂ (%) | 65 (55–72) |

Categorical variables are listed as number (percentage) and continuous variables are listed as median (interquartile range).

Results

The initial cohort included 105 infants who were eligible for the study, 95 of whom had complete physiologic data available in the Sickbay database. Sixty-one (64%) were male, 27 (28%) had single-ventricle physiology, 48 (51%) were post-op cardiac surgery, 32 (34%) were intubated during holding, 21 (22%) were held skin-to-skin, and 78 (82%) were held by the mother and the rest by the father. The age, weight, and vital signs during the baseline window are listed in Table 1. There were no immediate adverse events, including medical equipment dislodgement, during any episodes of infant holding or while the patient was placed back into their crib.

Using the mixed-effects analysis, infants' heart rate significantly decreased while being held compared to each infants' own baseline ($p = 0.01$), and this decrease is more pronounced for the non-intubated and pre-operative patients (Table 2). Mean, systolic, and diastolic blood pressure decreased but did not reach statistical significance ($p = 0.37$, 0.12 , and 0.82 , respectively). Oxygen saturation increased but did not reach statistical significance ($p = 0.07$). We observed a significant increase in near-infrared spectroscopy-based venous saturation while being held ($p = 0.02$). Haemodynamic and oximetric changes with respect to baseline average values are displayed in graphical form in Figure 1.

The 21 infants who were held skin-to-skin did not exhibit significantly different physiologic responses compared with the 74 infants who were not held skin-to-skin (Table 2). While patients who were not intubated ($n = 63$) had a significant decrease in heart rate compared to intubated patients ($p = 0.01$), there were no significant physiologic differences noted in other parameters. Similarly, pre-operative patients ($n = 47$) displayed a significant decrease in heart rate compared to post-operative patients ($p = 0.02$), but significant differences in other parameters were not noted.

Table 2. Mixed-effects analyses of vital signs during the response window.

| | HR | | mBP | | sBP | | dBP | | SpO ₂ | | SvO ₂ (NIRS) | |
|--------------|--------------|-------------|-------|---------|-------|---------|--------------|-------------|------------------|---------|-------------------------|-------------|
| | coeff | p-value | coeff | p-value | coeff | p-value | coeff | p-value | coeff | p-value | coeff | p-value |
| Intercept | -3.46 | 0.01 | -1.22 | 0.37 | -2.32 | 0.12 | -0.29 | 0.82 | 0.83 | 0.07 | 3.09 | 0.02 |
| Skin-to-skin | 3.09 | 0.13 | -1.48 | 0.48 | 0.64 | 0.79 | -2.65 | 0.19 | 1.21 | 0.08 | -0.57 | 0.79 |
| Intubated | 5.32 | 0.01 | -2.52 | 0.16 | -0.59 | 0.76 | -3.35 | 0.05 | -0.66 | 0.26 | -0.38 | 0.84 |
| Pre-Op | -3.79 | 0.02 | 1.24 | 0.46 | 0.30 | 0.87 | 1.34 | 0.40 | -0.59 | 0.29 | -2.26 | 0.19 |

dBP = diastolic blood pressure; HR = heart rate; mBP = mean blood pressure; sBP = systolic blood pressure; SpO₂ = pulse oxygen saturation; SvO₂ = NIRS-based venous saturation. All patients were held for at least 1 hour (response window). "Skin-to-skin" is a binary variable referring to whether the patient was held skin-to-skin or not. "Intubated" is a binary variable referring to whether the patient was held while also being intubated. "Pre-Op" is also a binary variable referring to whether the episode of holding was prior to index cardiac operation.

Discussion

This study demonstrates that infants in the cardiac ICU exhibit improved haemodynamic changes while being held by a parent in comparison to a baseline period prior to being held, including evidence of improved systemic oxygen delivery as derived from regional near-infrared spectroscopy data. These findings are consistent with our team's anecdotal experience that many infants often become more "calm" when being held characterised by reduced heart rate and increased near-infrared spectroscopy. By utilising data from a high-fidelity physiologic data monitoring system, we were able to quantify these changes in a relatively stable cohort of infants within the cardiac ICU. Additionally, it is important to note that over 100 instances of holding of critically ill infants with CHD were accomplished without any immediate complications or adverse events.

It has been consistently shown that longer ICU and hospital length of stay are associated with worse neurodevelopmental outcomes for infants with critical CHD.^{34–36} Although specific in-hospital factors have not been delineated, disruptions to natural neonatal developmental progression may provide some answers. Infants born with critical CHD are exposed early to an inherently unnatural and stressful environment. They are routinely separated from their parents and encounter frequent noxious stimuli from medical procedures as well as poorly controlled light, sound, and temperature stimulation. Necessary perioperative care in the cardiac ICU frequently disrupts the infant's natural cues and sleep patterns, further exacerbating stress, pain, physiologic instability, and disorganised behaviour.^{37–39} Historically, this care has been practiced primarily in concordance with the daily rhythm and convenience of cardiac ICU providers. However, as we strive to improve cardiac ICU care to optimise long-term outcomes, it is important to consider that providing developmentally appropriate care and facilitating parental bonding may not only have important longitudinal benefits but also promote positive physiologic states in this fragile population.

At birth, the most developed portion of the sensory system is tactile sensation, and providing a positive sensory experience is influential in overall brain development.⁴⁰ Holding is not only a vital aspect of promoting parent–infant bonding but a fundamental process providing positive sensory input for normal newborn development. The preponderance of previous literature related to the benefits of infant holding has focused on skin-to-skin care and the premature infant population, and the findings of this study corroborate relative patient stability during kangaroo care noted in recent meta-analyses on the topic.^{38,41} A recent pilot study examined physiologic stability, pain scores, and salivary cortisol levels during skin-to-skin care specifically in infants hospitalised with CHD.²³ Similar to our current study, they found a relative improvement in vital signs during holding (compared to baseline) as well as lower pain scores despite no change in salivary cortisol levels. While pharmacologic intervention with sedative medications may produce similar physiologic effects, they come with well-described negative sequelae.⁴² As such, it is promising to consider that a simple, low-resource, and physiologically natural activity such as holding may be increasingly incorporated not only to improve long-term patient outcomes but could be considered as a key therapeutic intervention in helping infants with CHD during their period of critical illness.

Although this study focused on measuring infant physiologic changes, it is worth noting that caregivers experience high levels of stress during times when a child is admitted to the cardiac

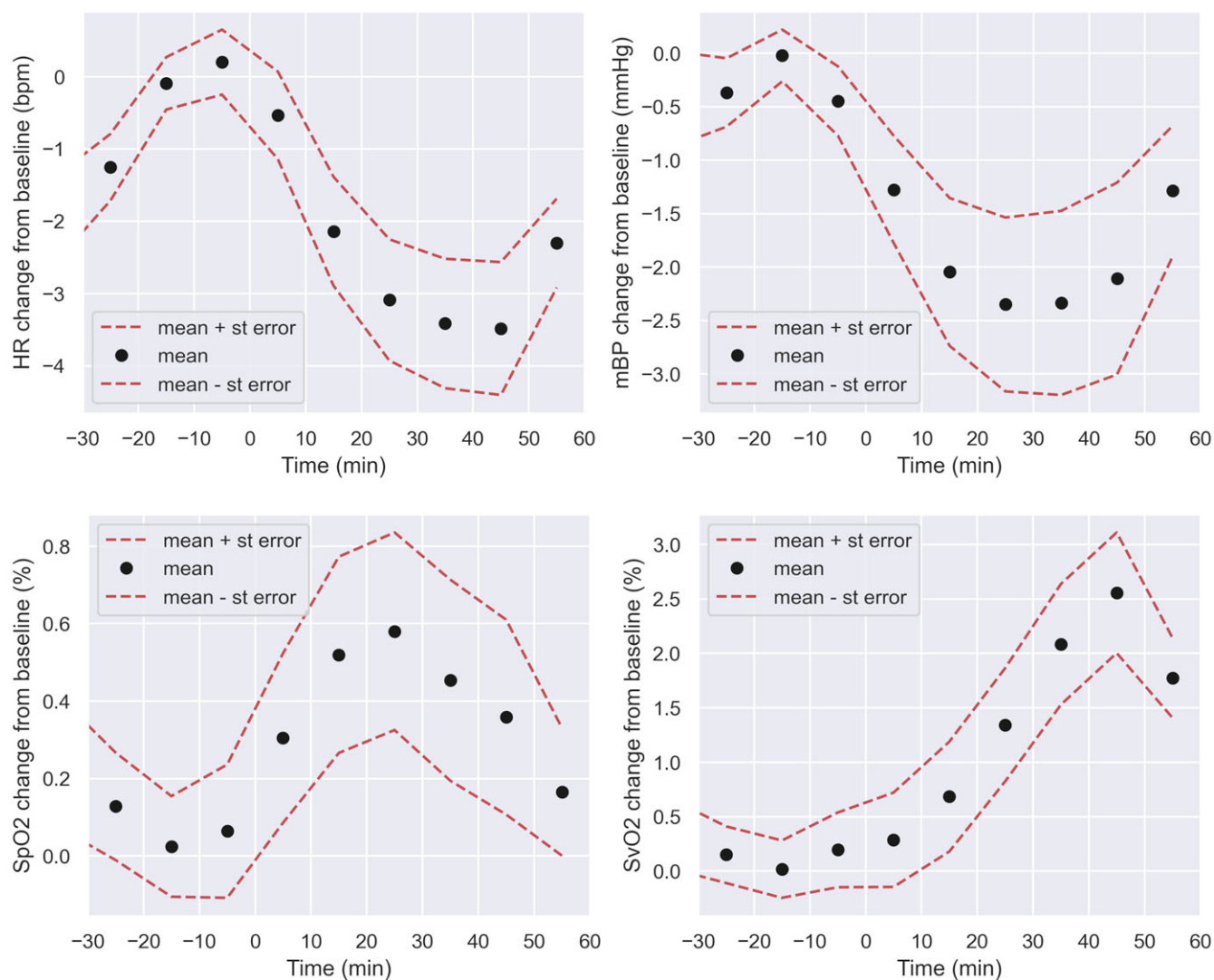


Figure 1. Changes in haemodynamic and oximetric parameters during baseline and response windows with respect to their baseline average values. Time zero indicates the time at which the holding started. The baseline interval ranges from -30 to 0 minutes. The response interval ranges from 0 to 60 minutes. HR = heart rate (top-left). mBP: mean blood pressure (top-right). SpO₂ = pulse oxygen saturation (bottom-left). SvO₂ = venous oxygen saturation (bottom-right).

ICU.^{9,11,43} Care in the ICU may disrupt bonding between caregivers and infants and contribute to a sense of lost parental role. Studies have demonstrated that kangaroo care yields protective effects on parental stress and promotes parent–infant attachment.^{44,45} Given that long-term neurodevelopment is largely influenced by familial factors, facilitation of holding on a more routine basis may have compounded benefit on infants with CHD.¹⁰

While assessing differences in physiologic changes between different groups of patients was not the primary aim of the study, we detected that pre-operative and non-intubated patients experienced a more pronounced decrease in heart rate in comparison to post-operative and intubated patients. This highlights the need for future investigations to determine the association between varying anatomical and physiological states, as well as different points in hospital course, with responses to being held. Additionally, a more detailed study of differences in skin-to-skin versus non-skin-to-skin holding is needed as we suspect that the former may produce a more favourable physiologic response based on previous literature. To facilitate

further investigation into these questions, we advocate for routine accurate documentation of holding in the electronic medical record to the same standards as other vital aspects of care documented during cardiac ICU admission. Routine and accurate documentation of this intervention could provide valuable information about physiologic trends during times of holding, while also providing an avenue for answering additional questions such as the relationships between time held and sedation utilisation, feeding tolerance, cardiac ICU and hospital length of stay, and long-term neurodevelopmental and quality-of-life outcomes.

This study has several limitations. To avoid confounding, we included only infants whose clinical status was not rapidly evolving and excluded those undergoing interventions which might influence their haemodynamic profile. This may limit our ability to extrapolate these findings to infants in a more dynamic physiologic state. A larger study sample inclusive of infants with various physiological states and at different stages of their clinical course would be necessary to better describe which infants might benefit most from holding. Despite our intention to analyse a

haemodynamically stable patient population, it is possible that routine care occurring during either the baseline or holding period (such as feeding or scheduled medication administration) could influence haemodynamic parameters, leading to unmeasured confounding. As mentioned, only infants whose precise holding times were documented by a member of the study team were included – this could lead to selection bias and other infants may not experience the same physiologic responses. Since infants were repositioned during the study, the limitation of our monitoring tools must also be considered.

By using high-fidelity physiologic monitoring, this study demonstrates that infants being held by their parents in the cardiac ICU exhibit evidence of an improved haemodynamic profile. As we continue to investigate opportunities to intervene in the cardiac ICU to improve long-term neurodevelopmental outcomes for patients with CHD, we can utilise these monitoring systems to provide more robust evidence that our interventions may also positively impact physiologic status in the short term.

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Competing interests. None.

Ethical standard. The authors assert that all procedures contributing to this work comply with the ethical standards of Helsinki Declaration of 1975, as revised in 2008, and have been approved with waiver of consent by the Institutional Review Board of Baylor College of Medicine under protocol H-49933.

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