Fetal bradycardia is a poor predictor of fetal physiologic derangement: reinforcing the need for multiparameter continuous fetal monitoring in fetal surgery

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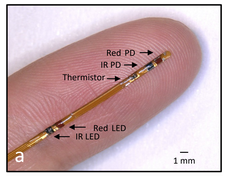
Background

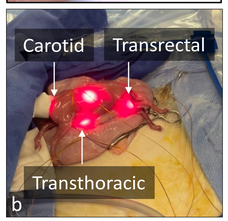
- Fetal echocardiography (FE) is the gold standard for intraoperative monitoring during fetal surgery[1]
- FE hinges significantly on the identification of fetal bradycardia as the reliable indicator of fetal distress[2]
- Fetal bradycardia may be a late finding, indicating the terminal stage of fetal distress[3]
- Intermittent FE can miss critical windows where intervention could potentially prevent progression to fetal demise[4,5]

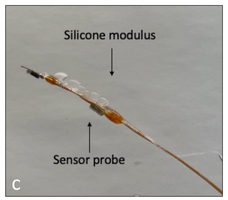
- **Hypothesis:** Significant fetal physiologic derangement (FPD) can occur without fetal heart rate (FHR) changes in a lamb model of fetal myelomeningocele (MMC) repair

Methods

- We employed a novel integrated fetal physiologic monitoring probe developed at our institution capable of providing continuous core measurements of fetal oxygen saturation (SO_2), temperature, and FHR (a)
- Probe measurements validated at multiple locations in the fetal lamb model (b), with transrectal placement providing most consistent measurements
- Modifications such as addition of silicone modulus added for translational applications (c)
- Correlated measurements to serial umbilical artery (UA) blood gas and FE measurements during:
  (a) Normal fetal surgery
  (b) Experimentally-induced FPD trials
  - **Umbilical cord occlusion (n=7)**
  - **Maternal hypoxia (n=2)**
  - **Controlled fetal hypothermia (n=2)**







Fetal Physiologic Derangement (FPD):
- Fetal SaO_2 < 20%
- pH < 7.2
- pCO_2 > 60 mmHg
- Core temperature < 36.0C

Experimental Timeline	EGA (Days)	
Open MMC Defect Creation	75-85	
↓		
Open vs. Fetoscopic Repair	95-105	Probe Validation
↓		
Terminal Harvest	115-125	Experimentally-Induced FPD

Results

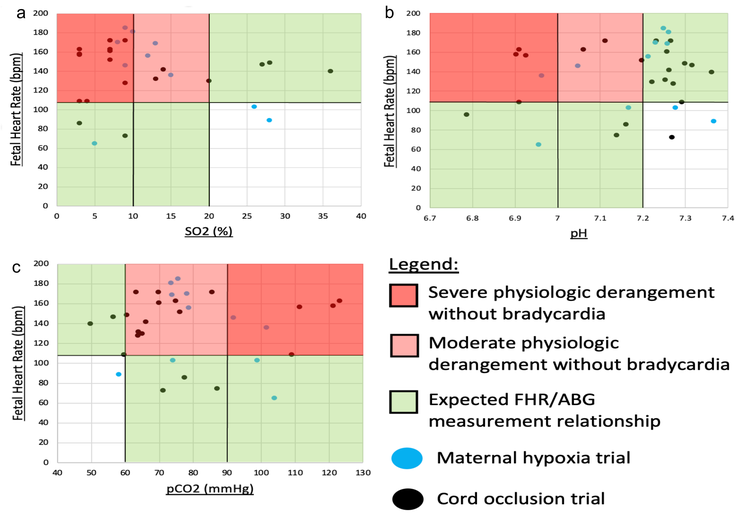


Fig. 1. Correlation of fetal heart rate with measures of fetal physiologic derangement. Fetal bradycardia (defined as FHR<110) most often occurred in the setting of FPD, with positive-predictive value of 60% for (a) fetal hypoxia, 55.6% for (b) acidosis, and 85.7% for (c) hypercarbia. However, the negative-predictive value of bradycardia was only 12.5% for hypoxia, 62.5% for acidosis, and 12.0% for hypercarbia. This indicates that a significant proportion of FPD events is not captured by changes in FHR.

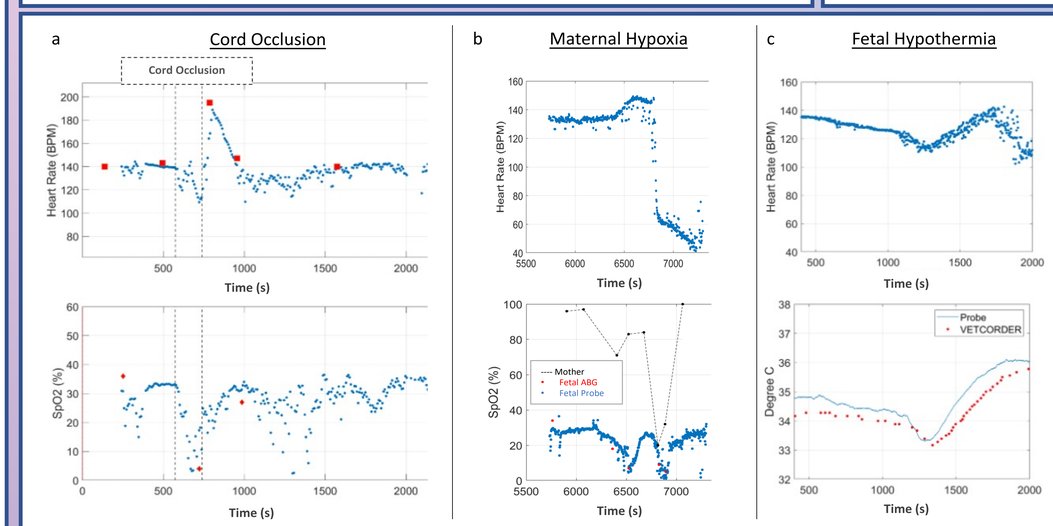


Fig. 2. Characterizing patterns of the fetal response to physiologic stress. Cord occlusion (n=7) produced immediate fetal hypoxia and bradycardia, with minimal detectable latency to onset (a). Upon release of cord occlusion, characteristic reflex tachycardia responses were observed with mean increase from baseline of 28.6 ± 11.9 bpm. In maternal hypoxia experiments (n=2), fetal hypoxia and bradycardia occurred after progressive maternal desaturation beyond a threshold of 89-90% SpO_2. Despite recovery of maternal and fetal SpO_2, irreversible fetal bradycardia ensued, necessitating resuscitative measures in one fetus and resulting in demise in another (b). In controlled hypothermia experiments (n=2), progressive fetal hypothermia (n=2) correlated in a linear fashion with stepwise FHR reductions (r=0.950, p<0.001 and r=0.795, p<0.001, respectively) that did not reach the threshold for bradycardia (c).

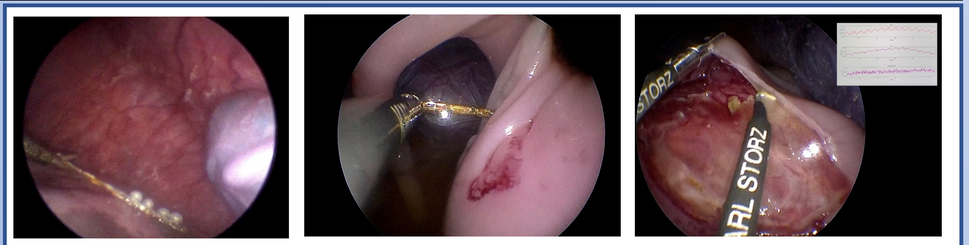


Fig. 3. Real-time continuous fetal monitoring of heart rate, pulse oximetry, and temperature via transrectal probe placement during fetoscopic MMC repair. Intraoperative images of fetoscopic MMC repair demonstrating (a) inflation of silicone modulus prior to placement into fetal rectum, (b) insertion into fetal rectum for monitoring, and (c) fetoscopic MMC repair with continuous fetal monitoring

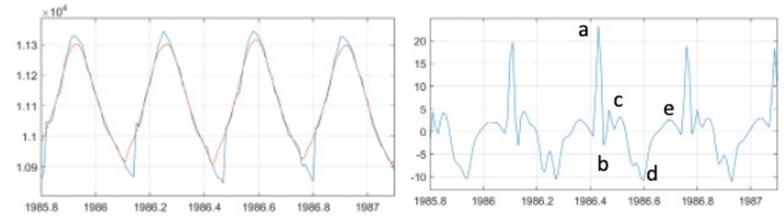


Fig. 4. Pulse plethysmography (PPG) and 2nd derivative (acceleration) PPG for pulse wave analysis. Fetal physiologic monitoring probe provides reliable PPG waveform showing characteristic pulse wave analysis features on 2nd derivative waveform. In the 2nd derivative PPG, the early systolic positive peak (a), early systolic negative peak (b), late systolic re-increasing peak (c), late systolic re-decreasing peak (d), and early diastolic positive peak (e) are readily identified. Ratios of the amplitudes of each measurement correlate with measures of vascular constriction in postnatal models, though the fetal response has not been previously characterized

Conclusions

- Profound fetal hypoxia, acidosis and hypothermia occur frequently in the absence of fetal bradycardia.
- Fetal responses to different physiologic stressors differ significantly, with dramatic fetal bradycardia and hypoxia in response to cord occlusion, and more progressive stepwise reductions in fetal heart rate in response to hypothermia.
- Monitoring of fetal heart rate alone can miss critical periods of FPD, these findings reinforce the need for multiparameter continuous fetal monitoring.

References

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