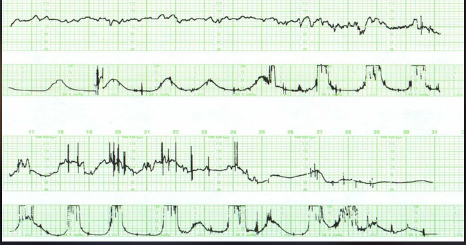

The Fetal Reserve Index: Reconceptualizing Electronic Fetal Monitoring—An Update.

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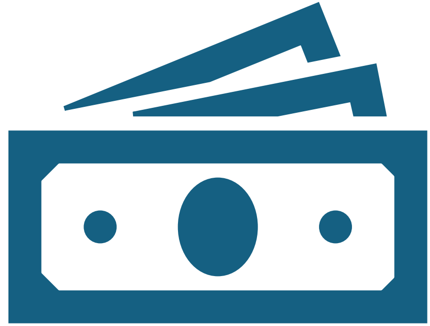
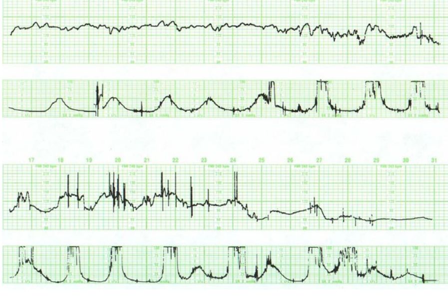
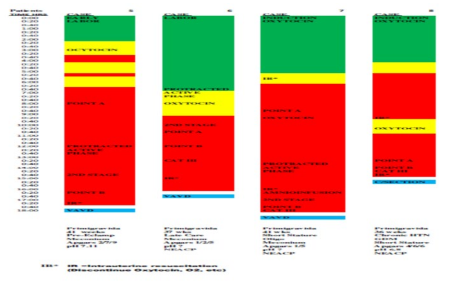
Disclosures

- MCG/AU/USG Retiree
- No honorarium or paid travel expenses for this presentation
- Dr. Mark Evans owns the patents on the FRI process



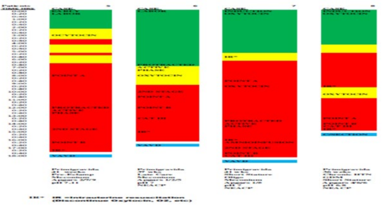


Objectives



- Present background of Electronic Fetal Monitoring (EFM).
- Discuss past attempts to improve EFM performance.
- Introduce the Fetal Reserve Index (FRI) Concept.
- Present results from our group’s previous FRI publications.
- Introduce our initial efforts to develop an AI platform for the FRI.
- Conclude with next steps for the FRI project.

Electronic Fetal Monitoring



- EFM is a screening test not a diagnostic test !!!
- In 1970s, EFM introduced into practice without randomized controlled trials
- Stillbirth rates decreased
- HIE and Cerebral Palsy rates unchanged while CS rates increased considerably.
- FHR tracings often involved in medicolegal cases.

In 2009, ACOG introduced 3-Category system without any clinical trials. *In 2025, reaffirmed by ACOG with no room left for alternatives.*

THE ACOG CATEGORIES

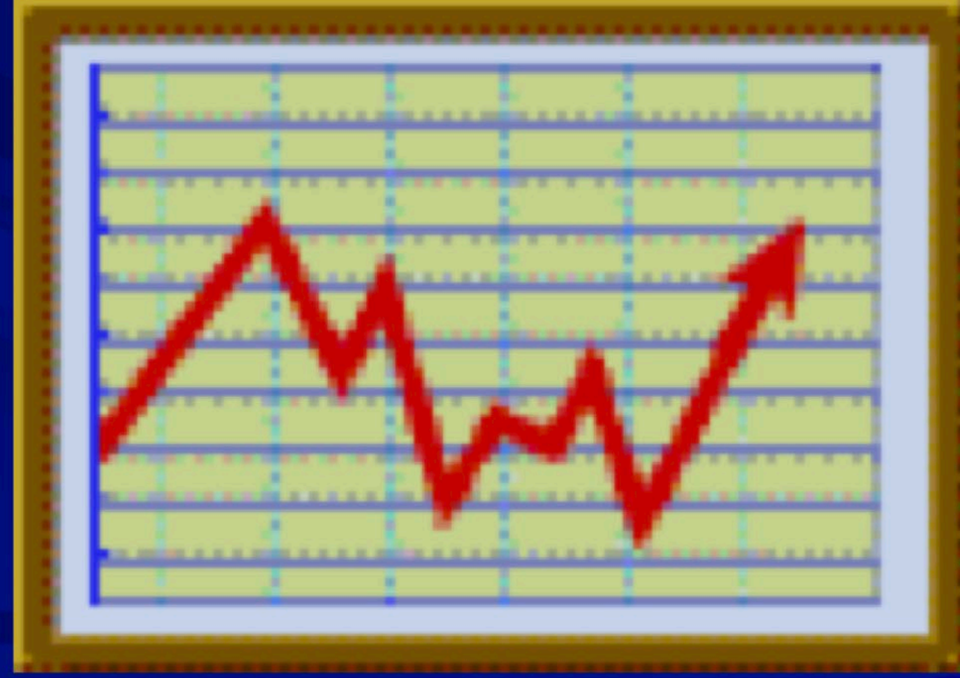
- Category I: no concerns.
- Category III: emergency situation
  - requires immediate action.
- Category II: intermediate concern
  - no uniform response
  - complex management protocols
  - occurs in up to 80% of labors.

Past Efforts to Improve EFM Interpretation

- Fetal Pulse Oximetry
- Fetal ECG ST-Analysis (STAN system)
- Automated FHR Analysis
- Intelligent Analytic Systems

None have reduced risk of adverse outcomes in US OB populations

Evans and Devoe Am J Obstet Gynecol 2023



How would you like to *only* see the fetal risk status quantified in real time?

The Fetal Reserve Index: Expert Review AJOG 2023

Improving the interpretation of electronic fetal monitoring: the fetal reserve index

Check for updates

Mark I. Evans, MD; David W. Britt, PhD; Shara M. Evans, MSc, MPH; Lawrence D. Devoe, MD

Electronic fetal monitoring, particularly in the form of cardiotocography, forms the centerpiece of labor management. Initially successfully designed for stillbirth prevention, there was hope to also include prediction and prevention of fetal acidosis and its sequelae. With the routine use of electronic fetal monitoring, the cesarean delivery rate increased from <5% in the 1970s to >30% at present. Most at-risk cases produced healthy babies, resulting in part from considerable confusion as to the differences between diagnostic and screening tests. Electronic fetal monitoring is clearly a screening test. Multiple attempts have aimed at enhancing its ability to accurately distinguish babies at risk of in utero injury from those who are not and to do this in a timely manner so that appropriate intervention can be performed. Even key electronic fetal monitoring opinion leaders admit that this goal has yet to be achieved. Our group has developed a modified approach called the "Fetal Reserve Index" that contextualizes the findings of electronic fetal monitoring by formally including the presence of maternal, fetal, and obstetrical risk factors and increased uterine contraction frequencies and breaking up the tracing into 4 quantifiable components (heart rate, variability, decelerations, and accelerations). The result is a quantitative 8-point metric, with each variable being weighted equally in version 1.0. In multiple previously published refereed papers, we have shown that in head-to-head studies comparing the fetal reserve index with the American College of Obstetricians and Gynecologists' fetal heart rate categories, the fetal reserve index more accurately identifies babies born with cerebral palsy and could also reduce the rates of emergency cesarean delivery and vaginal operative deliveries. We found that the fetal reserve index scores and fetal pH and base excess actually begin to fall earlier in the first stage of labor than was commonly appreciated, and the fetal reserve index provides a good surrogate for pH and base excess values. Finally, the last fetal reserve index score before delivery combined with early analysis of neonatal heart rate and acid/base balance shows that the period of risk for neonatal neurologic impairment can continue for the first 30 minutes of life and requires much closer neonatal observation than is currently being done.

Key words: acidosis, augmented electronic fetal monitoring, base excess, cardiotocography, category system, cerebral palsy, electronic fetal monitoring, fetal reserve index, fetal scalp, keeping labor safe, pH, risk factors, sampling

Introduction

Electronic fetal monitoring (EFM) is a staple of modern obstetrical care, with nearly 90% of labors in the United States using the technology.[1–3] The electronics and basic mechanisms of monitoring have remained fairly stable for decades. Modifications have been regularly introduced for many technologies and interpretations including EFM, with some being kept and others discarded.[4] The unifying theme for EFM modifications has been the attempt to improve statistical performance of monitoring. Initially, the goal was to predict and prevent stillbirth, which is a very discrete and clearly dichotomous outcome[1,2]; this was successful. Later, there was hope to move the goalposts in an attempt to predict and prevent adverse neonatal outcomes.[3] If nothing else, trying to use a subjective test to screen for a multifaceted outcome will always be a recipe for confusion.[5,6] Historically, lack of rigor in the development and application of some screening tests in many fields has led to poor performance metrics, for example, low sensitivity and positive predictive values.[5,6] Disproportionate reliance on screening, unrealistic expectations, additional expenditures, and complications from likely unneeded follow-up diagnostic testing have cast aspersions about screening in general and reducing clinicians' confidence in it.[6–9] Likewise, moving the cutoff point between screen normal and abnormal has sometimes been used to make one test inappropriately seem better than another.[5,6]

Most fundamentally, there has been considerable confusion in how clinicians have really understood what EFM is, namely, whether it is a screening test or a diagnostic test.[4,10,11] Unfortunately, many if not most patients and many physicians do not understand the difference between screening and diagnosis.[4,6] As EFM does not give a definitive diagnosis (eg, fetal death is definitive) in almost all circumstances,

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M.I.E. has patents on the fetal reserve index. The other authors report no conflict of interest.

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Review of Representative FRI studies (19 publications to date)

Study	Population	Study Type	Objective	Results
Eden RD, Evans MI, Evans SM, Schifrin BS. **The Fetal Reserve Index: Re-engineering the interpretation and responses to fetal heart rate patterns** **Fetal Diagn Ther. 2018; 43(2):90-104**	50 CP cases 200 controls All cases normal on admission	**Retrospective** **Predict Risk of Cerebral Palsy**	Compare FRI Scores to ACOG Categories and ACOG CP Monograph to identify CP cases	**For CP cases** **FRI scores identified 100%,** **ACOG Category III identified 44%,** **ACOG CP Monograph criteria found 30%.**
Eden RD, Evans MI, Evans SM, Schifrin BS. **Re-engineering electronic fetal monitoring interpretation: Using the fetal reserve index to anticipate the need for emergent operative delivery.** **Reprod Sci. 2018 Apr; 25(4): 487-97**	300 cases with normal neonatal outcomes	**Retrospective** **Predict Risk of Emergent Operative Deliveries (EODs)**	Compare FRI scores and color zones for Emergent Operative Deiivery (EOD) cases with non-EOD cases	**- EOD cases << FRI scores than non-EOD cases.** **- "Red zone" more often and longer for EOD cases with sensitivity of 92%, PPV of 64%, and false positive rate of 10% .**
Eden RD, Evans MI, Britt DW, Evans SM, Schifrin BS. Safely lowering the emergency cesarean and operative vaginal delivery rates using the Fetal Reserve Index. J Matern Fetal Med 2020 May;33(9):1473-1479.	400 control; 400 using FRI All normal outcomes	**Prospective** **Reduce EODs safely**	Predict risk of EOD if FRI principles were Cused in management	**Comparable incidence of red zone tracings (25%). IR in 1st group (20%), in 2nd group (47%). EODs reduced from 17.3% to 4 %.**
Britt DW, Evans MI, Schifrin BS, Eden RD. Refining the prediction and prevention of emergency operative deliveries with the Fetal Reserve Index. Fetal Diag Ther 2019; 46:159-165	1402 term singletons in labor with normal outcomes	**Retrospective** **Prevent EODs**	Predict EOD risk in FRI Red zone $\geq$1 hr and if IR performed	**Reaching Red zone early and remaining > 1 h increases EOD probability. When these risk factors are paired with IR in Stage 1, EOD probability is reduced from 0.93 to 0.15.**
Evans MI, Britt DW, Worth J, Mussali G, Evans SM, Devoe LD. Uterine contraction frequency in the last hour of labor: how many contractions are too many? J Matern Fetal Neonatal Med 2022 Dec; 35 (25):8698-870	475 patients monitored in labor and neonatally	**Retrospective** **Determine Optimal UC Frequency/10'**	Evaluate Cord Blood BE, and pH; 1' Apgar, non-NSVDs, NHR@16' postnatal	**UCF>4: higher sensitivity to detect decreased Apgar-1' and 5', NHR above 160 bpm, higher BE, and non-NSVD than UCF>5, earlier fetal compromise detected.**
Evans MI, Britt DW, Eden RD, Evans SM, Schifrin BS. Earlier and improved screening for impending fetal compromise. **J Matern Fetal & Neonatal Med 2022 Dec, 35 (15): 2895-2903**	475 high-risk patients monitored in labor and neonatally	**Retrospective** **Correlations of FRI score with pH and Base Excess**	Assess FRI score as a proxy for fetal pH and BE values from fetal scalp sampling (FSS)	**FSS-obtained pH and BE worsens during 1st stage of labor.** **Trajectory of FRI provides reasonable approximation of FSSpHBE trajectory to enable earlier intervention as needed.**
Eden RD, Evans MI, Britt DW, Evans SM, Gallagher P, Schifrin BS. **Combined prenatal and postnatal prediction of early neonatal compromise risk.** **J Maternal-Fetal & Neonatal Medicine 2021, 34 (18); 2996-3007**	251 high-risk singleton term pregnancies	**Retrospective** **Predict Neonatal Compromise**	Last FRI score to immediate NHR pattern and umbilical/NN acid-base balance	**FRI successfully predicted neonates with suboptimal adaptation and need for additional support.**
Devoe LD, Britt DW, Macedonia CR, Worth JM, Mussalli GM, Mondestin-Sorrentino M, Evans MI: Reconceptualizing intrauterine resuscitation and its short-term impact. Diagnostics 2025; 15 :255-265 **doi.org/10.3390/ diagnostics15030255**	118 patients receiving Pitocin to induce or augment labor and who had IR	**Retrospective** **Assess Intrauterine Resuscitation Impact**	Derived 2 measures of IR effectiveness: (1)Improvement (2)Stabilization based on FRI score change	**71% improved; 78% stabilized with IR by FRI score changes.** **Wide variation in clinician practices for using IR were noted and did not necessarily correlate with FRI-calculated fetal risk.**

The Fetal Reserve Index

EFM Measured Metrics

- Baseline Fetal Heart Rate
- Baseline variability
- Accelerations
- Decelerations

L&D Measured Metrics

- Uterine activity (increased)
- Maternal Risk Factors
- Obstetrical Risk Factors
- Fetal Risk Factors (separate from EFM)

TABLE 4

Fetal reserve index risk factors

1. Maternal risk factors
Decreased cardiac output/vascular perfusion of the placenta
a. Cardiac disease with risk of decreased cardiac output in pregnancy
b. Hypertension (chronic and pregnancy-induced)
c. Systemic lupus erythematosus
Oxygen carrying capacity
a. Pulmonary disorders (eg, asthma)
b. Anemia and hemoglobinopathy
Infection (chronic and acute)
Chronic debilitating disease
Malabsorption/poor weight gain
Endocrine—diabetes mellitus and thyroid disorders
Advanced maternal age
Drug abuse, addiction, and smoking
Obesity—body mass index >35
Short stature (<5'2")
2.Obstetrical risk factors
Intrauterine growth restriction/Macrosomia
Oligohydramnios
Polyhydramnios
Bleeding and abruption
Previous cesarean delivery
Placental and umbilical cord anomalies
Rupture of membranes (preterm premature rupture of membranes, spontaneous rupture of membranes, artificial rupture of membranes)
Dystocia (protraction and arrest disorders of labor)
Malpresentation
3.Fetal risk factors
Abnormal Dopplers/biophysical profile
Genetic disorders
Fetal arrhythmia
Meconium passage
Chorioamnionitis
Second stage of labor—pushing
Amnioinfusion
Discontinuation of Pitocin owing to fetal intolerance
Conversion patterns (acute prolonged tachycardia [>170 bpm])
Ominous overshoots
Bradycardia (<100 bpm)
Missing important data in labor (eg, lack of electronic fetal monitoring in second stage)

Adapted from Eden et al.[68]

Evans. Improved interpretation of electronic fetal monitoring. Am J Obstet Gynecol 2023.

Evans & Devoe Am J Obstet Gynecol 2023

Fetal Reserve Index Scoring

- Scoring Each of the 8 Risk Factor Categories
  - Normal = 1
  - Not Normal = 0
  - Maximum = 8 points = 100%
  - 6 of 8 = 75%
  - 4 of 8 = 50%
  - 1 of 8= 12.5%
  - 0 of 8 = 0%
- Colorimetric Zones:
  - Green >50 to 100%
  - Yellow >25 to 50%
  - Red 0 to 25%

Normal

Cerebral Palsy

Note Amount of Red Zone Time Spent in CP cases

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COMPARISON OF METHODS FOR IDENTIFYING CEREBRAL PALSY

60 CP CASES 360 CONTROLS	ACOG 2003 MONOGRAPH CP CRITERIA*	ACOG Category III**	FRI**
SENSITIVITY	28% [17/43]	45% [27/33]	100% (60/0]
SPECIFICITY	100% [0/360]	100% [0/360]	76% [86/274]

*Postnatal data ** Prenatal data

EVERY CP BABY WAS IN RED ZONE >2 HOURS

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800 control cases – all with good outcomes:
Compared to Standard Management, FRI reduced emergency CS rate by >60% and doubled rate of Intrauterine Resuscitation

	REACHED RED ZONE	TOTAL EMERGENCY DEL	ECS	IR USED	ECS (when FRI did not improve)
ROUTINE MGMT. (NO.)	104	69	34	80	25
%	26%	17.3%	8.5%	20%	31.3%
FRI MGMT (NO.)	113	16	13	188	13
%	28.2%	4.0%	3.3%	47%	6.9%
X^2 P VALUE	.474	.000	.002	.043	.001

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Why UCF Thresholds of >4/10' are better than >5/10'

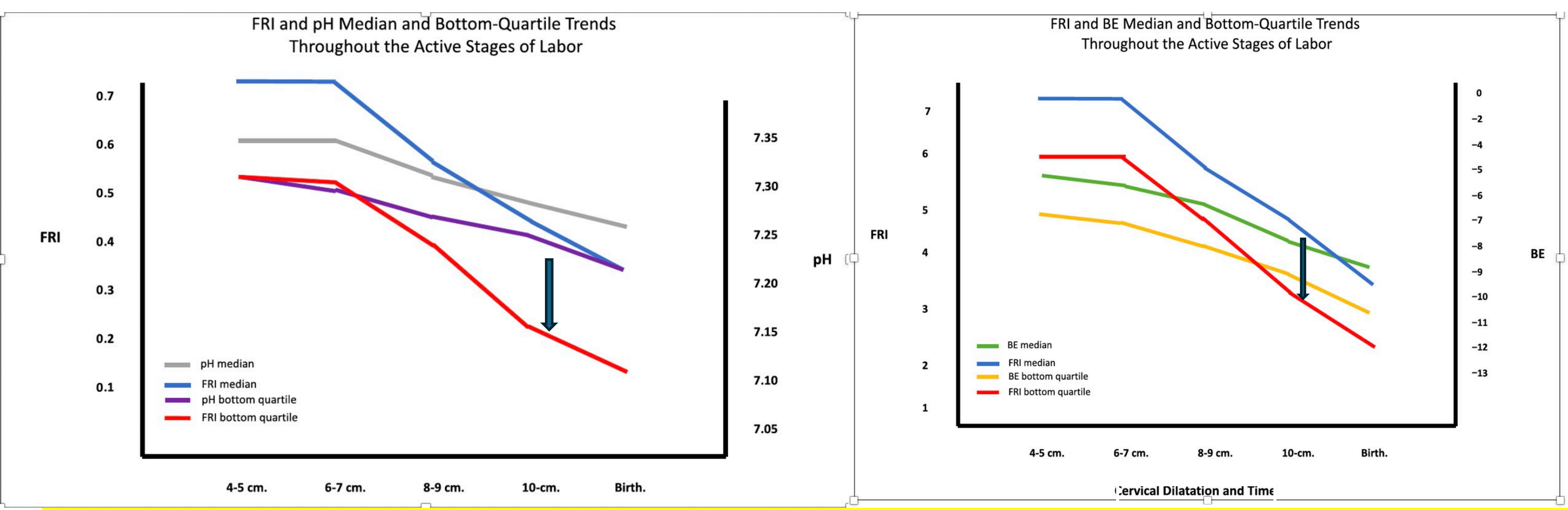
Table 5. Comparison of UCF > 4 and UCF > 5 with respect to metrics.

Uterine Contraction Frequency (No./Min.)	Apgar1' * Sensitivity (Specificity) [PPV] PLR	Apgar5' * Sensitivity (Specificity) [PPV] PLR	NHR 16 * Sensitivity (Specificity) [PPV] PLR	Non-NSVD * Sensitivity (Specificity) [PPV] PLR	BEcg * Sensitivity (Specificity) [PPV] PLR	pHcg * Sensitivity (Specificity) [PPV] PLR
UCF > 4 **	79% (28%) [17%] 1.10	74% (28%) [27%] 0.97	81% (31%) [52%] 1.19	78% (31%) [41%] 1.12	82% (29%) [16%] 1.16	84% (29%) [15%] 1.18
UCF > 5 **	38% (67%) [18%] 1.17	34% (67%) [8%] 1.02	38% (68%) [52%] 1.17	37% (68%) [42%] 1.17	37% (28%) [16%] 1.12	32% (66%) [13%] 1.02

UCF > 4/10' Detected more than twice the number of abnormal perinatal outcomes and operative deliveries than did UCF> 5/10'

After Evans MI, Britt DW, Worth J, Evans SM, Mussalli G, Devoe LD: Uterine Contraction Frequency in the last hour of labor: how many contractions are too many? J Matern Fetal Neonatal Med 2022 Dec;35(25):8698-8705.

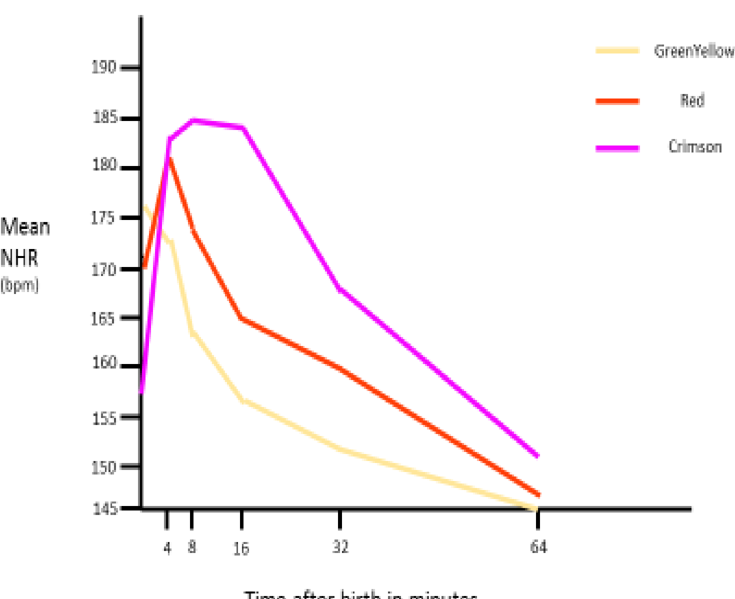
Correlations of FRI with pH and base excess medians over time



FRI parallels pH and Base Excess during active labor and could be a surrogate measure of acid-base balance

After Evans MI, Britt DW, Evans SM, Devoe LD. Improving the interpretation of electronic fetal monitoring: the fetal reserve index. *Am J Obstet Gynecol.* 2023 May; 228(5S): S1129–S1143.

85% OF TERM NEONATES HAVE TACHYCARDIA RELATED TO LAST FRI SCORE



- The lower the final FRI score before birth, the higher the NHR and the longer before It returns to normal.
- pH and Excess worsen before improving! 34% of cases have BE ≤ -12 mMol/L–"threshold of CP risk."
- A significant period for metabolic acidemia occurs AFTER birth – when most term neonates are NOT being evaluated closely.
- Approximately 10% of CNS injury occurs in this period.
- This suggests that all term neonates not admitted to the NICU should receive 1 hour of postnatal monitoring.

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Reconceptualizing Intrauterine Resuscitation and its Short-Term Impact

Objective: Assess short-term IR effectiveness of Pitocin management based on FRI Score

Population: 118 patients receiving Pitocin (PIT) during labor.

Time frame: After IR started, Six consecutive 20-minute windows with FRI Scores were assessed

IR options employed (All patients received supplemental O_2 and had positional changes):

- **PIT-CON: continued PIT infusion rate**
- **PIT-D: reduced PIT infusion rate**
- **PIT-OFF: discontinued PIT infusion**

Results:

- **Improvement: FRI Score increased (71%)**
- **Stabilization: FRI Score did not decrease further (78%)**
- **Failure: FRI Score lower in Window #6 than in Window #1 (22%)**

Devoe LD, Britt DW, Macedonia CR, Worth JM, Mussalli GM, Mondestin-Sorrentino M. and Evans MI Diagnostics (Basel) 2025 Jan 23;15(3):255.

Comparison of FRI scores and PIT Management During Intrauterine Resuscitation

Table 3. Success Metrics by FRIv2 Risk Level # at Labor Duration Point of IR Administration.

	Percent Improved * (SD)	Percent Stabilized ** (SD)
Green (n = 29)	76% (44)	89% (31)
Yellow (n = 55)	67% (47)	75% (44)
Red (n = 34)	79% (41)	79% (41)

Table 2. Success Metrics by IR Associated with PIT Administration Options.

	Percentage Improved * (SD)	Percentage Stabilized ** (SD)
(PIT-CON) PIT Continuation (n = 39)	76% (44)	78% (42)
(PIT-D) PIT Reduction (n = 64)	75% (44)	84% (37)
(PIT-OFF) Pit Off (n = 12)	58% (52)	67% (49)

- 25% of patients receiving IR in the Green Zone did not need this intervention.
- 34% of patients continuing PIT at same rate during IR did not need this intervention

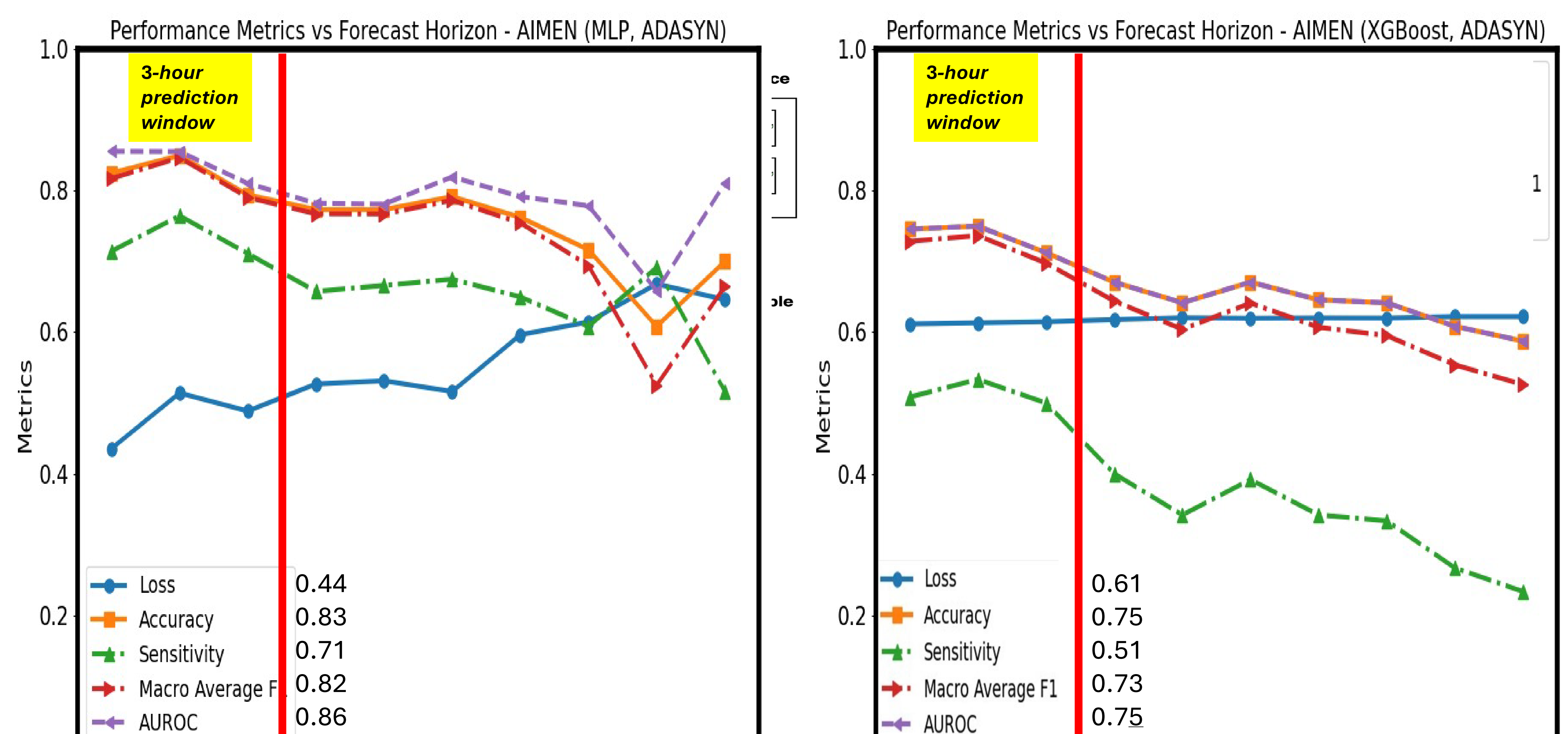
Conclusion

FRI could improve care by uniformly assessing IR impact on subsequent management

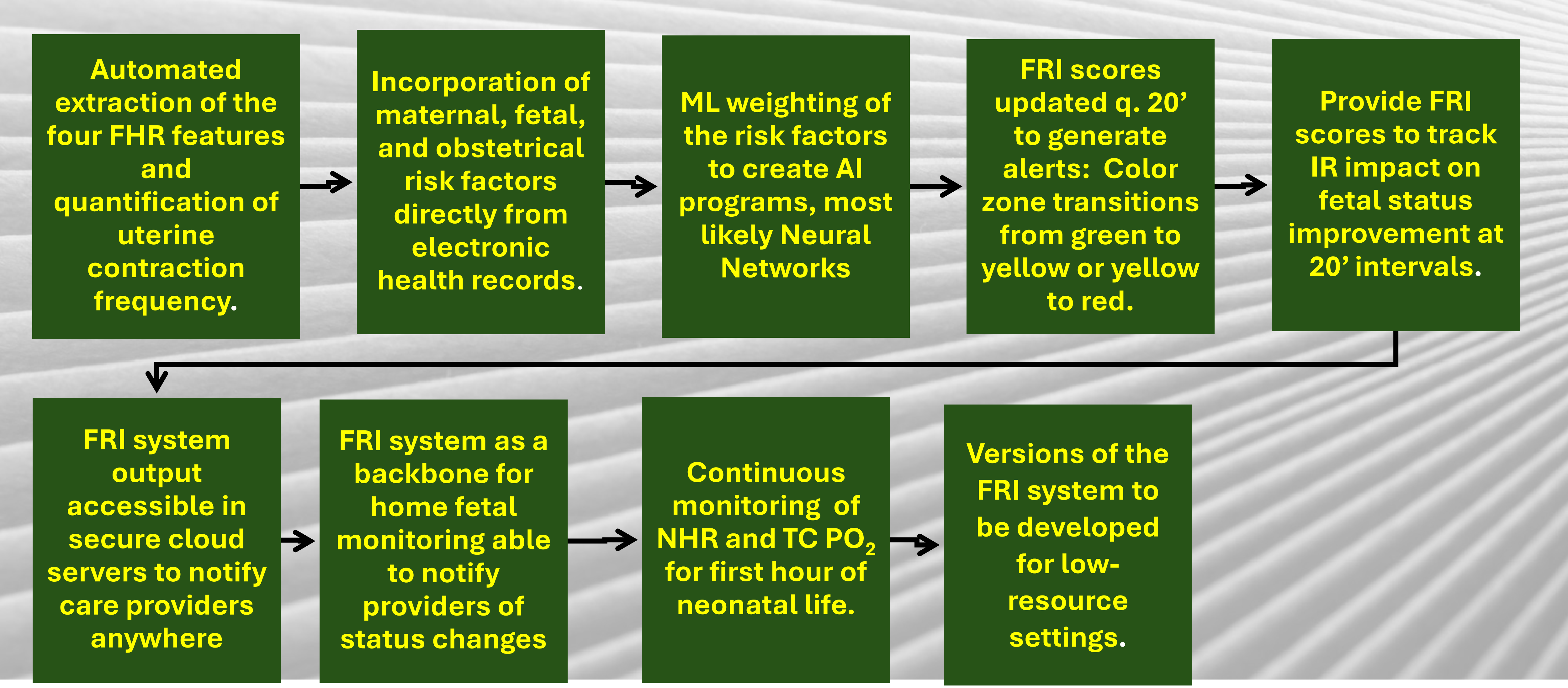
Initial Steps Toward Developing a Deep Learning Platform for the Fetal Reserve Index

Artificial Intelligence for Modeling and Explaining Neonatal Health (AIMEN)

AI Platform Development for the FRI



Next steps for developing an AI platform for the FRI



COMPARISON OF FRI with ESTABLISHED "STANDARDS" FOR ELECTRONIC FETAL MONITORING

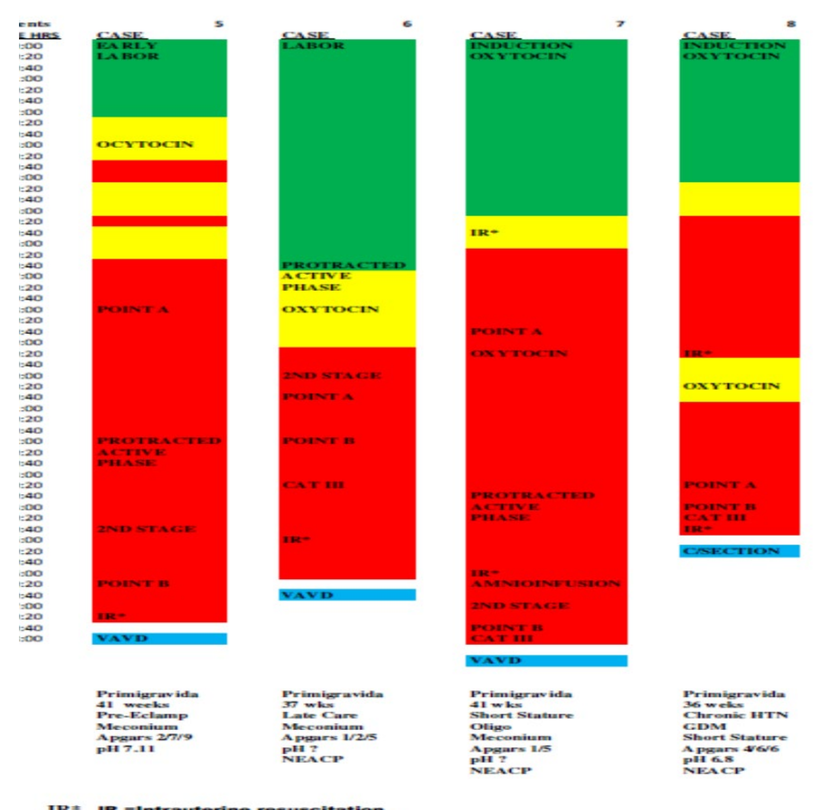
Aspect	FRI (KLS)	ACOG	NICE	Physiology-based	FIGO
Approach & Basis	✓ Quantitative, risk-integrated ✓ CTG + risk factors ★ Objective scoring	✗ Qualitative only ✗ Pattern-based ✗ No risk context	✗ Threshold checklist ✗ Opinion-based ✗ Lacks physiology	★ Physiology-driven ✓ Improves over NICE ✗ Still subjective	✓ Global consensus ✓ 3-tier standard ★ Physiology-informed goals
Clinical Usability	✓ Clear traffic-light ✓ Consistent across users ✓ Software	✓ Simple 3 categories ✗ Category II too broad ✗ Inconsistent	✓ Easy rules ✗ Inflexible ✗ Misclassification risk	★ Deeper insight ✗ Steep learning curve ✗ Variable observer skill	✓ Streamlined classification ✓ Action-linked categories ✗ Observer variability
Predictive Accuracy	★ Early & accurate ✓ Fewer false positives ✓ Detects risk before crisis	✗ Poor prediction ✗ High false positives ✗ Low specificity	✗ Moderate at best ✗ No context ✗ Errors both ways	★ Better risk recognition ✓ Some improved outcomes ✗ Not quantified	✓ High sensitivity/NPV ✗ Low specificity/PPV ★ Early warning focus
Risk Management	✓ Proactive & contextual ✓ Integrates risk ★ Medicolegal defense	✗ One-size-fits-all ✗ Judgment-dependent ✗ Medicolegal gray zone	✗ No risk layering ✗ Protocol rigidity ✗ Litigation exposure	✓ Explains physiology ✗ Ignores a priori risk ✗ No audit trail	✓ Escalation protocol ✓ Fix-first philosophy ★ Nuanced response
Decision Support	★ Dynamic scoring ✓ Clear thresholds ✓ Early warning	✗ Weak for Cat II ✗ Broad guidance ✗ Relies on judgment	✓ Protocolized actions ✗ Crude triggers ✗ Can delay/over-trigger	★ Richer reasoning ✓ Personalized actions ✗ No algorithmic support	✓ Action-oriented ★ Quick reference tools ✗ Needs context
Implementation	✓ Cutting edge, software based, hardware agnostic ✓ Uses existing data ★ Scalable once integrated	✓ Already universal ✓ No tech needed ✗ Outdated performance	✓ Widely taught ✓ Easy rollout ✗ Still flawed	✓ Needs training ✗ Inconsistent adoption ✗ Not mainstream	✓ User-centric design ★ Global endorsement ✗ Resource-intensive
Limitations	✗ New & unvalidated prospectively ✗ Adoption ramp up anticipated ✗ Edge cases unclear	✗ Category II ambiguity ✗ Poor predictive value ✗ Legal vulnerability	✗ Physiologically naïve ✗ Rigid thresholds ✗ Misclassification risk	✗ Operator-dependent ✗ No risk integration ✗ No quantitative trail	✗ High false alarms ✗ Observer variability ✗ No proven outcome gains

✅ = Strength
✗ = Weakness
★ = Strong differentiator

FRI clearly outperforms the currently established approaches for EFM!

Several takeaways from our FRI papers

1. Adds clinical context to improve EFM screening capability and accuracy.
2. Provides more accurate prediction of CP risk than ACOG Categories.
3. Safely reduces EODs, lowering morbidity, mortality, and costs.
4. Earlier detection of intrapartum fetal compromise enabling less risky interventions to allow safe deliveries.
5. Provides objective, uniform assessment of Intrauterine Resuscitation impact on fetal status.
6. Resets maximum UCF threshold from >5/10' to >4 /10' to improve prediction of adverse neonatal outcomes.
7. First hour of life presents increased risk of adverse outcomes like CP for a select group of term infants that would likely benefit from closer monitoring.
8. AI Platform is being developed by a major international software company that will lead to prospective implementation studies.



Questions?