

The Fetal Reserve Index: Reconceptualizing Electronic Fetal Monitoring—An Update. Lawrence D. Devoe, MD,¹Rebecca Joseph, MD¹, James Maher III, MD,¹ and Mark I. Evans, MD,² ¹Department of Obstetrics and Gynecology, Medical College of Georgia at Augusta University; ²Department of Obstetrics, Gynecology, and Reproductive Sciences Icahn School of Medicine at Mount Sinai, & Fetal Medicine Foundation of America, New York, NY

Background: Electronic fetal monitoring (EFM) was introduced into routine practice more than 50 years ago to prevent intrapartum stillbirths for which it was very successful. The goals of EFM were later expanded to decrease adverse perinatal outcomes including neonatal neurologic impairment (NNI) and cerebral palsy (CP). ACOG's 3-Category EFM pattern classification was adopted into obstetric practice in 2009 without any prospective studies. It has not been shown to improve perinatal outcomes. In fact, following the adoption of this EFM classification scheme, cesarean delivery (CD) rates have increased significantly but with little or no impact on decreasing NNI and CP rates.

We have developed a novel, quantified approach to improve EFM— the Fetal Reserve Index (FRI). The FRI adds four contextual elements—increased uterine activity (>4 uterine contractions per 10-minutes) and maternal, fetal, and obstetrical risk factors (Table 1)—to the standard EFM features of baseline fetal heart rate, variability, accelerations, and decelerations (scored individually). The derived FRI scores are based on the presence or absence of identified risk factors and range from 1.0 (0 of the 8 risk factors present) to ≤ 0.25 (at least six risk factors present). The FRI scores subsequently assign fetuses to colorimetric risk zones of green (low risk or >0.50), yellow (intermediate risk or ≤ 0.50 to >0.25), and red (high risk or ≤ 0.25).

Objectives: (1) To summarize previous approaches to improve EFM performance; (2) To demonstrate the FRI's documented performance for identifying fetal risk and/or adverse perinatal outcomes; (3) To provide an update of ongoing FRI developments toward enabling its clinical deployment.

Methods: (1) We reviewed publications of other groups' past attempts to improve EFM. (2) We reviewed all our previous FRI publications from 2018 up to the most recent 2025 publication illustrating the FRI's potential role in assessing the impact of intrauterine resuscitation (IR).

Results: Table 2 briefly summarizes previous efforts to improve clinical performance of EFM which have done little to improve the accuracy of this screening test. Our own work has progressed from initial concept to more sophisticated approaches and has improved our understanding of the pathophysiology and ontogeny of fetal compromise (Table 3). Our published data demonstrate the FRI's superiority over other methods to predict adverse perinatal outcomes and to provide an actionable timeframe for appropriate intrapartum interventions that include IR or expedited delivery.

To date, the FRI has accomplished the following:

1. Higher sensitivity for predicting CP than either the ACOG EFM Categories or ACOG CP monograph systems.
2. Safe reduction of emergency cesarean and operative vaginal delivery rates by 65%.
3. Earlier identification of impending fetal compromise in labor to enable appropriate IR and reduce the need for emergent deliveries.

Conclusion: The FRI is the most promising development in nearly half a century to improve EFM performance by adding clinical context to the assessment of the basic FHR tracing. An initial AI platform is now being finalized to facilitate FRI deployment into clinical practice. Once this is accomplished, future research plans include the conduct of larger prospective studies to ultimately bring the FRI to labor and delivery units world-wide.

[Word Count:509]

Table 1. 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.

Table 2. Past Efforts to Improve EFM Interpretation.

Authors	System Name	Design	Data Analyzed	Year
Dawes GS et al	Oxford Sonicaid	R-B*	Antepartum FHR	1996
Alonzo-Betanzos A et al	NST-Expert Trace-View	R-B	Antepartum and Intrapartum FHR	1992
Keith RDF et al	INFANT	R-B + AI**	Intrapartum FHR	1994
Bloom SL et al	OxiFirst	Fetal Pulse Oximetry	Intrapartum FHR and Fetal SpO ₂	2006
Ayres-de-Campos D et al	SIS-Porto	R-B	Intrapartum FHR	2000
Elliott C et al	Peri-Calm	R-B+AI	Intrapartum FHR	2010
Olofsson P et al	STAN	R-B	Intrapartum FHR + fetal ECG	2014
Georgieva A et al	None	AI	Intrapartum FHR	2013

* Rule-Based

**Artificial Intelligence

Table 3. Representative FRI studies and their results

Study	Population	Study Type	Objective	Results
Eden RD, Evans MI, Evans SM, Schiffrin 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	Compare FRI to ACOG Categories and CP Monograph to identify CP	For CP cases FRI scores identified 100%, ACOG Category III identified 44%, ACOG CP Monograph criteria found 30%.
Evans MI, Britt DW, Evans SM: Mid-forceps did not cause “compromised babies” – compromise caused forceps: an approach toward safely lowering the cesarean delivery rate. J Matern Fetal Neonatal Med. 2022 Dec; 35 (25):5265-5273	470 cases with mix of NSVDs (288) LO-FOR (120) MID-FOR (30) CD (32)	Retrospective	Compare outcomes predicted with FSS-pH and BE<1 hour before birth, delivery modes or FRI scores	FRI Scores better predicted NN outcomes better than scalp sample BE, pH, or delivery mode
Eden RD, Evans MI, Britt DW, Evans SM, Schiffrin 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	Predict risk of EOD if FRI principles used in management	Comparable incidence of red zone tracings (25%). IR in 1 st group (20%), in 2 nd group (47%). EODs reduced from 17.3% to 4 %.
Britt DW, Evans MI, Schiffrin 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	Predict EOD risk in FRI Red zone ≥ 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	Evaluate CB BE, and pH; 1’ Apgar, non-NSVDs, NHR@16’ postnatal	UCF>4/10’ had higher sensitivity to detect decreased Apgar-1’ and 5’, NHR above 160 bpm, higher BE, and non-NSVD than UCF>5/10’; earlier fetal compromise detection
Evans MI, Britt DW, Eden RD, Evans SM, Schiffrin 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	Assess FRI score as a proxy for fetal pH and BE values from fetal scalp sampling (FSS)	FSS-obtained pH and BE worsens in 1 st stage of labor. FRI Trajectory reasonably approximates FSS-pH and BE trajectory to enable earlier intervention as needed.
Evans MI, Britt DA, Evans SM, Devoe LD. Improving the interpretation of electronic fetal monitoring: the fetal reserve index. Am J Obstet Gynecol 2023 May; 228 (5S):S1129-43	NA	Retrospective	A summary of the essential features of the FRI and its potential impact on future obstetric care	The FRI outperforms all other contemporary approaches to identify risk of adverse perinatal outcomes and is the first model that improves EFM screening performance
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	Derived 2 measures of IR effectiveness based on FRI score changes: (1)Improvement (2)Stabilization	By FRI score changes, 71% improved and 78% stabilized with IR. However, wide variations in clinician practices for using IR were noted that did not necessarily correlate with FRI-calculated fetal risk.