Effect of a Laboratory Result Pager on Provider Behavior in a Neonatal Intensive Care Unit

L. Samal[1]; TA. Stavroudis[2]; RE. Miller[3]; HP. Lehmann[4]; CU. Lehmann[5,*]

[1]Division of General Internal Medicine and Primary Care, Brighman and Women's Hospital; [2]Division of Newborn and Critical Care, Children's Hospital of Los Angeles; [3]Department of Pathology, Johns Hopkins University School of Medicine; [4]Division of Health Sciences Informatics, Johns Hopkins University School of Medicine; [5]Division of Neonatal-Perinatal Medicine, Johns Hopkins University School of Medicine

Summary

Background: A computerized laboratory result paging system (LRPS) that alerts providers about abnormal results ("push") may improve upon active laboratory result review ("pull"). However, implementing such a system in the intensive care setting may be hindered by low signal-to-noise ratio, which may lead to alert fatigue.
Objective: To evaluate the impact of an LRPS in a Neonatal Intensive Care Unit.
Methods: Utilizing paper chart review, we tallied provider orders following an abnormal laboratory result before and after implementation of an LRPS. Orders were compared with a predefined set of appropriate orders for such an abnormal result. The likelihood of a provider response in the post-implementation period as compared to the pre-implementation period was analyzed using logistic regression. The provider responses were analyzed using logistic regression to control for potential confounders.
Results: The likelihood of a provider response to an abnormal laboratory result did not change significantly after implementation of an LRPS. (Odds Ratio 0.90, 95% CI 0.63–1.30, p-value 0.58) However, when providers did respond to an alert, the type of response was different. The proportion of repeat laboratory tests increased. (26/378 vs. 7/278, p-value = 0.02)
Conclusion: Although the laboratory result pager altered healthcare provider behavior in the Neonatal Intensive Care Unit, it did not increase the overall likelihood of provider response.

Correspondence to:
Lipika Samal, MD, MPH
1620 Tremont Street, Suite BC-003
Boston, Massachusetts 02120–1613
Phone: 617–732–7063
Fax: 617–732–7072
Email: lsamal@partners.org

*This work was done at Johns Hopkins Hospital, Baltimore, MD.

1. Background

Responding to laboratory results in a timely manner may prevent delayed treatment and avoidable deleterious consequences. A computerized laboratory result paging system has been proven to decrease time-to-correction of a life-threatening abnormality and to decrease length of stay [1]. This method of alerting providers about abnormal results ("push") effectively supplements active laboratory result review ("pull"). However, implementing such a system in the intensive care setting may be hindered by low signal-to-noise ratio, which may lead to alert fatigue [2].

Hospital patients, especially patients in intensive care unit settings, are subject to a myriad of laboratory tests [3]. Acuity of illness, such as progression to sepsis or respiratory failure, relates to frequent laboratory testing [4]. Immediate knowledge of results like electrolyte abnormalities may be critical to enable a timely response by the clinician; however, immediate communication for a patient with non-urgent abnormal results could be distracting and detrimental to patient care [5].

The informational value of an abnormal laboratory result is determined by prior results. A small difference from a prior abnormal result reduces the likelihood that an abnormal result will change management because it indicates a stable abnormal condition. If a provider is aware of an abnormal laboratory value in the patient's recent past, such as an elevated white blood cell count, there is often no further need to continue to notify the provider of additional abnormal values. An attempt to push information to the provider is justifiable due to the fact that laboratory result information loses its value to the clinician over time. Depending on the type of laboratory test there is a more or less rapid depreciation of the value of information. For example, the useful interval for arterial blood gas samples would be measured in minutes, whereas hours would suffice for white blood cell counts.

Computerized laboratory result paging systems should incorporate a comparison to prior values in a test-specific time interval or a "delta check" method similar to that used in laboratories to detect errors in specimen identification where test results for specimens obtained at different times from the same patient are compared [6].

2. Objectives

We sought to evaluate a computerized prior-value based laboratory result paging system (LRPS) by determining the impact of LRPS on ordering behavior in a neonatal intensive care unit (NICU) in an academic medical center. Our hypothesis was that a LRPS with sophisticated suppression algorithms to reduce noise would increase the likelihood of provider response to abnormal laboratory results.

3. Methods

The laboratory result paging system (LRPS) was developed and implemented in the 45 bed Neonatal Intensive Care Unit (NICU) at Johns Hopkins Hospital. The pre/post design of this evaluation was conducted over a two-month period between April 30, 2007 and July 5, 2007. The patient population consisted of all NICU patients who were found to have an abnormal laboratory value in this time period. The pager for the LRPS was carried by first, second, or third year pediatric residents.

The LRPS was designed to query the pathology clinical information system responsible for laboratory results about 27 specified tests every 10 minutes and, after assessing propriety of alerts according to an algorithm, to send an alphanumeric page to the provider covering the NICU. The tests included chemistry, hematology, coagulation, an inflammatory marker, an antibody, and liver function tests (▶Appendix A). Laboratory results continued to be available on workstations throughout the hospital (▶Fig. 1).

A prototype LRPS was tested and found to have a low signal to noise ratio by healthcare providers. Alert suppression algorithms were developed using the "delta check" method. For each laboratory test, the time interval for past results, the direction of change, a relative suppression threshold, and an absolute threshold for imperative alert was specified as shown in ▶Table 1. In addition, multiple abnormal results in one laboratory panel (e.g., abnormal sodium and chloride) were paged as one alert.

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The outcome for this study was provider ordering behavior. Paper order charts, constituting all orders written by the team, were reviewed the day after an abnormal laboratory result was reported in the pathology information system. Data was collected for 31 days before the implementation of the LRPS and for 36 days post implementation. The set of appropriate orders was defined in advance by a neonatology domain expert(CUL). For example, a low sodium result would dictate that the investigators search for one of six appropriate orders (e.g. the prescription of a sodium supplement, a change in intravenous fluid type). The occurrence of any appropriate order in a 24–48 hour period was considered a positive outcome, as long as the order was timed after the alert. The absence of any such order was judged as a negative outcome.

A second phase of the study consisted of qualitative data collection. A survey was emailed to the health care providers who utilized the LRPS in Phase 1 of the study. The survey was composed of eight open-ended questions describing the main findings of Phase 1 and gathering feedback regarding the utility of the LRPS (▶Appendix B). We conducted semi-structured interviews with all respondents that were available. The qualitative data from the survey of Phase 2 of this study were reviewed.

A logistic regression was performed to determine the association of alerting by the LRPS with the likelihood of any corresponding order. The analysis included the LRPS as a factor along with other factors that could have affected the outcome: log odds (appropriate action) = f(pre vs. post LRPS, confounders). Confounders of concern were simultaneity of alerts, time of day, and patient (i.e., a within-subjects model). Simultaneity of alerts occurred when a laboratory panel resulted in multiple individual alerts at the same time, e.g., a chemistry panel with an abnormal sodium and an abnormal carbon dioxide result. Due to the schedule of provider rounds in the NICU, the time of day could also be a confounder of the main effect. We split the day into four periods and controlled for this as a categorical variable. Interaction terms were tested and were not significant. We also accounted for clustering by patient. Threshold values for statistical significance of p values in comparisons and for regression parameters were taken as 0.05, unless otherwise stated.

The type of orders (e.g., repeat test, medication) performed pre and post implementation were compared using a chi squared test.

Providers were queried about their experience with the LRPS. Representative quotes are included in the results section.

4. Results

There were 611 abnormal laboratory values during the study period from 105 unique patients: 278 abnormal laboratory results pre-implementation and 380 abnormal results post-implementation. (▶Fig. 2) The filtering rules suppressed 199 abnormal results throughout the entire study period (23%). Forty-seven abnormal laboratory results (19/278 (7%) pre-implementation and 28/380 (7%) post-implementation, p NS) could not be included due to unavailable paper charts when a patient was either transferred, discharged or had expired.

We did not find a statistically significant effect of the LRPS on the outcome before or after controlling for confounders (▶Table 2, unadjusted odds ratio 0.97, 95% CI 0.70–1.36, p-value 0.87; adjusted odds ratio 0.90, 95% CI 0.63–1.30, p-value 0.58). The simultaneity data were as follows: two hundred thirty-one orders after abnormal laboratory results were in response to laboratory panels, accounting for 40% of pre-implementation orders and 36% of post-implementation orders. With borderline significance of p-value 0.06, simultaneous alerts were 40% more likely to be responded to with an appropriate order (unadjusted odds ratio 1.41, 95% CI 0.99–1.99, p-value 0.06). The time of day was categorized into four six-hour periods and three hundred ninety-nine orders were for results between 7 am and 1 pm, accounting for 66% of pre-implementation orders and 65% of post-implementation orders. A laboratory result occurring between 7 pm and 1 am was about 70% less likely to be responded to with an appropriate order than one occurring between 7 am and 1pm both pre and post implementation (unadjusted odds ratio 0.31, 95% CI 015–0.63, p-value 0.00; adjust odds ratio 0.28, 95% CI 0.11–0.72, p-value 0.01).

Although the number of responses to lab results was no different, the type of response did differ in the post implementation period. Post-implementation, providers were more likely to react by or-

dering a repeat laboratory test rather than by ordering a medication, IV fluid, or other response (26/378 versus 7/278, p-value = 0.02) (▶Fig. 3).

Phase 2: Qualitative Results

Representative quotes from healthcare providers follow. One resident responded, "When [I] cross-covered … patients overnight who I did not know as well, the lab pager reminded me to check labs on those patients." Others believed that the house staff did not incorporate the pager into their workflow, "I don't think it changed our actions because I think we would have had the same reaction to the result … at a later time." Another response was "It was a nuisance and you would hear it beeping and just open and shut it to make it stop beeping."

We discovered that the existing workflow was that a senior resident and an intern reviewed all of the new laboratory results together around 3:00 AM when morning laboratory results become available. "All the labs would come through and so we would just review them all at once. Also in the daytime labs would come in just before rounds and each intern would review labs on their own seven to nine patients." One respondent expressed the belief that the existing workflow was superior to intermittent laboratory result review in response to the LRPS.

Another resident remarked, "If you're carrying a pager there's not the same level of responsibility as if someone [from the laboratory] calls you and you have to give your name and you know it's going to be in the electronic patient record – then you're going to be more apt to take action on it."

5. Discussion

This study was the first to examine a computerized laboratory result paging system in a neonatal intensive care unit. We did not find an increase in provider response to abnormal laboratory results from a computerized laboratory result paging system with suppression algorithms to decrease noise. Our results show that provider responses are more common to laboratory panels than to individual results and are more common between 7 am and 1 pm than other 6-hour time periods.

Our results are surprising in light of the fact that we took the experience of other centers into account and that the system utilized prior lab values [7–9]. We speculate that the negative results are a function of the sheer number of alerts (nearly 20 abnormal results per day), the harm done to residents' expectations by prior over alerting with the prototype system, and the short duration of the study. Most importantly, unlike many of the computerized laboratory result paging systems that have been previously studied, (e.g., Kuperman et al. included 12 tests, Palen et. al. included drug levels only, Rind et. Al. included creatinine only) the LRPS was active for 27 different laboratory tests. The suppression algorithms only suppressed about one quarter of potential alerts, and so providers received many more alerts than in other similar studies.

Our LRPS design was built on prior studies of computerized alerting systems that have been published since 1980 and was intended to address limitations of those systems [10]. One system at Cedars-Sinai Medical Center includes immediate alert to senior providers. The authors report that involvement of senior providers disrupts team functioning. Yet our experience contradicts their findings, because we saw an increased likelihood of orders during rounds (7 am-1 pm) which suggests the involvement of senior providers, despite our explicit design not to target them in response to the Cedar–Sinai experience [11].

A minor limitation was the lack of computerized provider order entry in our NICU and the inability to emulate a computerized paging system with a feedback mechanism described by others [9]. This feature would have enabled providers to order the medication or change in care plan immediately and allow the system to know that the alert was received.

Qualitative responses suggest further limitations due to our specific implementation of prior-value-based paging. Providers did not incorporate the LRPS into their workflow and regarded it as a nuisance. Also, because there was a potential delay in paging of up to 10 minutes, providers may have received a page after having reviewed the result using a computer workstation. (▶Fig. 1) We did not study the latency between result availability in the pathology information system, the result avail-

ability in the computer workstation, the LRPS alert, and the time that the provider physically wrote the order in the chart.

Another limitation of our study design is that our list of appropriate responses for the primary outcome may not have been exhaustive. In addition, while we considered absence of an order as a negative outcome, it may have been appropriate based on the provider's reasoning and other information not available to us regarding the patient's condition. Our data collection method was paper order chart review, so we may have missed illegible orders or verbal orders that were not recorded in the chart. Though the total number of missing charts was small, the cause of unavailability of charts may have been a systematic measurement error. For example, a sicker patient may also be more likely to be in the operating room or to have passed away, and their chart would have been more likely to be unavailable. We corrected only for clustering by patient. We also suspect that there may be clustering by provider, but were unable to identify which order was written by which provider.

We expected the value of information of an abnormal laboratory value to depend upon a number of factors (▶ Fig. 4) including the natural history of the condition, its prevalence, its severity, the patient's characteristics, and the effectiveness of therapy. Healthcare providers have differing preferences regarding the laboratory results that should be communicated immediately and how to respond to the abnormalities [12]. Hospitals have different policies regarding reporting. One hospital has a laboratory result paging system that allows users to prospectively request result notification from a wide variety of categories including chemistry, hematology, coagulation, cardiac, arterial blood gas, drug level, and liver function tests [13]. Pathology experts have worked to standardize the definition of a critical value, but have emphasized the importance of customizing the definition to meet the needs of the individual organization [14]. Each hospital has a different list of critical values that are used to decide on the communication of results immediately to providers [15]. The role of a computerized system within the larger organizational program is unclear. A potential solution is to work with the healthcare providers at the local level to incorporate their preferences and to educate them on the added value of the LRPS to their existing workflow.

6. Conclusion

We did not find a significant change in the likelihood of provider response to abnormal laboratory results after implementation of a computerized laboratory result paging system that took prior lab values into account. An alert suppression mechanism may not have reduced the number of alerts to a manageable level. In addition, qualitative interviews indicated that the system was not consistently incorporated into provider workflow. Future studies should aim to reduce the volume of alerts in a way that increases the utility of each alert and the system should be implemented as part of the provider workflow.

7. Implications for Practitioners

Alerting NICU providers about abnormal laboratory results does not necessarily impact provider response to abnormal laboratory results. Issues of provider workflow and information overload are important considerations in future quality improvement efforts.

Human Subject Research
Approval for both phases of the study was obtained from the Johns Hopkins School of Medicine Institutional Review Board.

Conflict of Interest
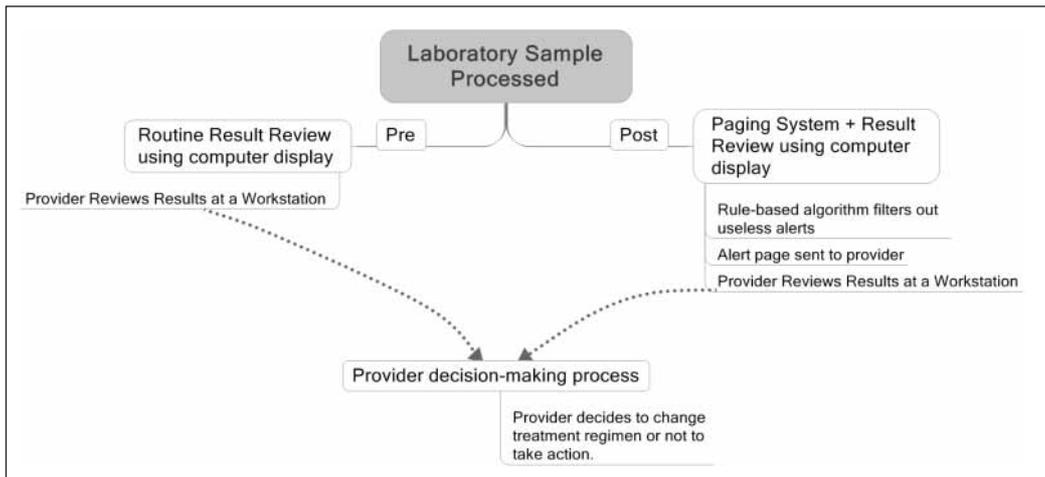The authors have no conflict of interest to disclose.

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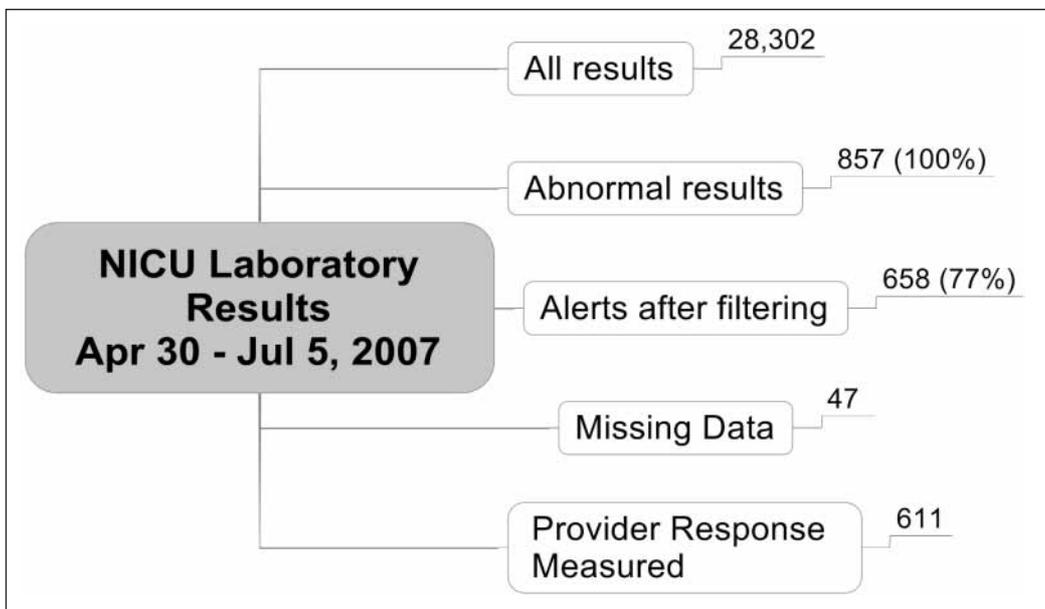**Fig. 1** Workflow of providers pre- and post-implementation

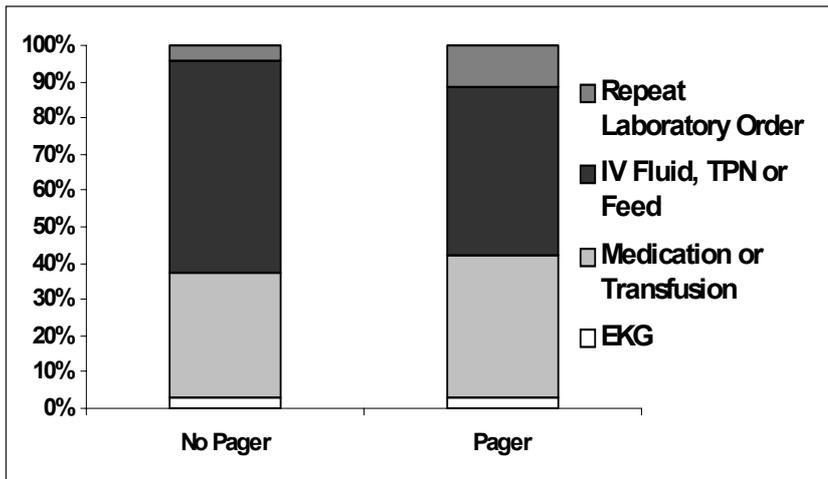**Fig. 2** Total abnormal laboratory results investigated (after LRPS filtering and missing data)

Fig. 3

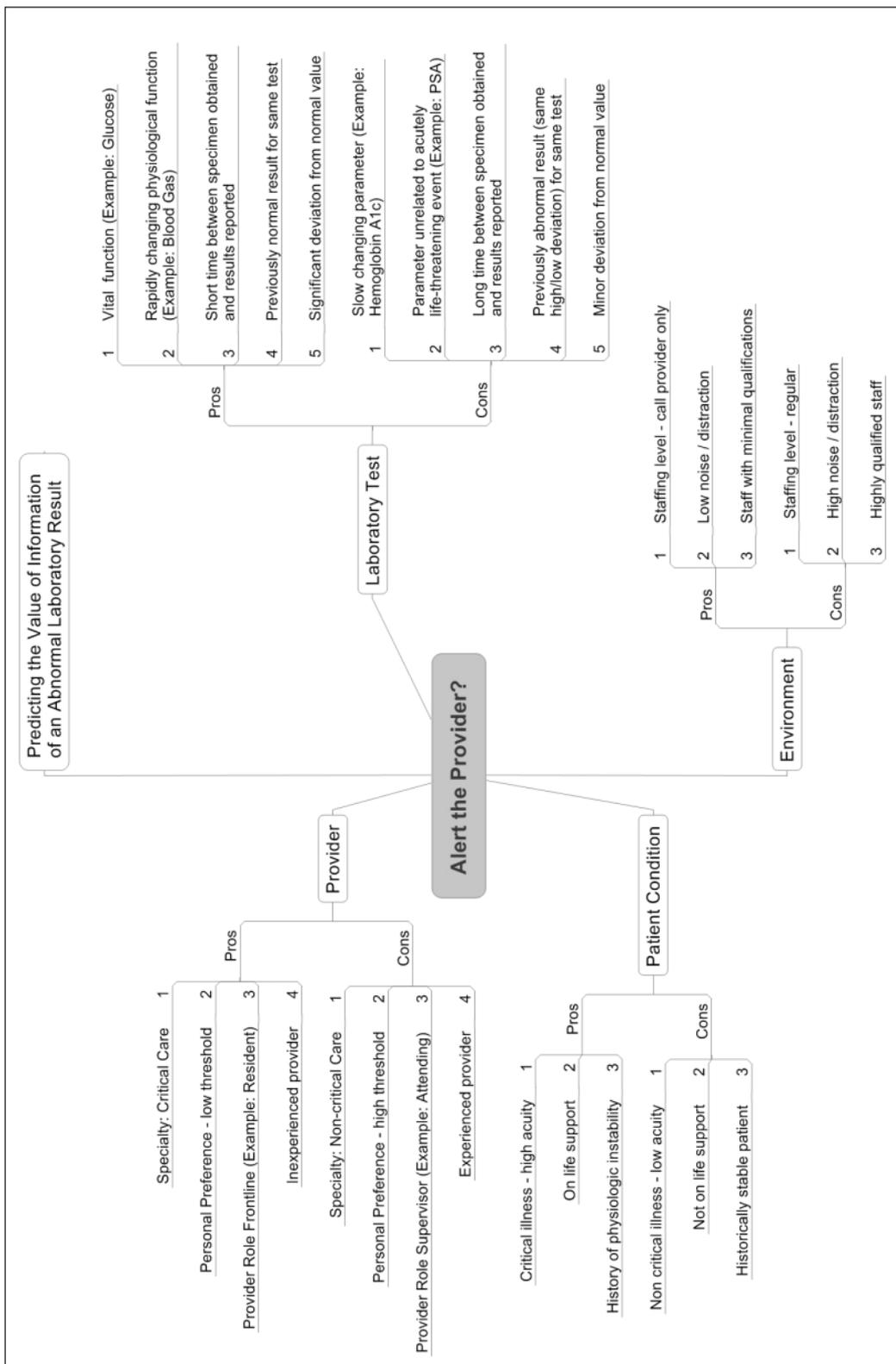Provider Orders in Response to Abnormal Laboratory Results

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Fig. 4 Factors affecting value of alerting the provider for an abnormal laboratory result

Table 1 Filtering rules for triggering or suppressing alerts (excerpt)

Laboratory Test	Alert IF	Suppress Alert IF	Always Alert IF
Absolute neutrophil count	≤500 cells/mm³	Prior result within last 48 hours ≤ [Current Value] * 1.03	≤300 cells/mm³
White blood cell count	≥28,000 cells/mm³	Previous result within the past 72 hours ≥ [Current Value]* 0.75	≥50,000 cells/mm³
White blood cell count	≤6000 cells/mm³	Previous result within the past 72 hours ≤ [Current Value]* 1.2	≤3,500 cells/mm³
Sodium	≥150m Eq/L	Previous result within the past 24 hours ≥ [Current Value]* 0.97	≥153 mEq/L
Sodium	≤129 mEq/L	Prior result within last 24 hours ≤ [Current Value] * 1.03	≤125 mEq/L
Hematocrit	60%	Previous result within the past 24 hours ≥60%	65%
Hematocrit	25%	Prior result within last 48 hours ≤25%	20%

Table 2 Likelihood of provider action following an abnormal laboratory result post-implementation

	Unadjusted OR	95% CI	p-value	Adjusted OR*	95% CI	p-value
Presence of paging system	0.97	0.70–1.36	0.87	0.90	0.63–1.30	0.58
Simultaneous alerts	1.41	0.99–1.99	0.06	1.50	0.85–2.65	0.16
7am – 1pm	reference	reference	reference	reference	reference	reference
1pm – 7pm	0.70	0.35–1.41	0.31	0.70	0.28–1.73	0.44
7pm – 1am	0.31	0.15–0.63	0.00	0.28	0.11–0.72	0.01
1am – 7am	0.69	0.40–1.19	0.18	0.70	0.34–1.44	0.33

*Adjusted for presence of paging system, simultaneous alerts, time period of day, and accounting for clustering by patient.

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Appendix A

Absolute Neutrophil	Ionized Ca^{++}	Laboratory tests included in the LRPS system
aPTT	Potassium	
Albumin	Magnesium	
Ammonia	Neutrophil %	
Bands	Nucleated RBC	
Calcium	Hematocrit	
Chloride	Phosphate	
CO_2	Platelet	
CRP	Reticulocyte	
Direct Coombs	Sodium	
Eosinophil %	Total Bilirubin	
Glucose	Triglycerides	
Hemoglobin	White Blood Cell	
INR, PT		

Appendix B
Survey questions

1. Were you working in the NICU between 6/1/07 and 7/5/07?
2. Were you a resident or an NP?
3. What was your level of training/years in practice at that time?
4. Were you aware that an abnormal laboratory result paging system was in place?
5. Did it increase your awareness of abnormal results, and if so please describe a specific instance?
6. Did it change your likelihood of action, such as a repeat lab test or medication or diagnostic test order, on an abnormal result and why or why not?
7. We found that the likelihood of provider actions did not increase in the presence of the paging system, but that the proportion of repeat labs increased. Do you have any thoughts about why this happened?
8. We found that the likelihood of action correlates strongly with the time of day, with 7am-1pm being the most likely time for provider action on an abnormal result. Do you have any thoughts about why this happened?