

# Pulse Oximetry as a Fifth Pediatric Vital Sign

William R. Mower, MD\*; Carolyn Sachs, MD\*; Emily L. Nicklin\*; and Larry J. Baraff, MD†

**ABSTRACT.** *Purpose.* To determine the utility of pulse oximetry as a routine fifth vital sign in acute pediatric assessment.

*Design.* Prospective study using pulse oximetry to measure oxygen saturation in children presenting to emergency department triage. Saturation values were disclosed to clinicians only after they had completed medical evaluations and were ready to discharge or admit each child. We measured changes in medical treatment and diagnoses initiated after the disclosure of pulse oximetry values.

*Setting and Participants.* The study included 2127 consecutive children presenting to triage at a university emergency department.

*Measurements.* Changes in select diagnostic tests: chest radiography, complete blood count, spirometry, arterial blood gases, pulse oximetry, and ventilation-perfusion scans; treatments: antibiotics,  $\beta$ -agonists, supplemental oxygen; and hospital admission and final diagnoses that occurred after disclosure of triage pulse oximetry values.

*Results.* Of 305 children having triage pulse oximetry values less than 95%, physicians ordered second oximetry for 49, additional chest radiography for 16, complete blood counts for 7, arterial blood gas measurements for 4, spirometry for 2, and ventilation-perfusion scans for 2. Physicians ordered 39 new therapies for 33 patients, including antibiotics for 15, supplemental oxygen for 11, and  $\beta$ -agonists for 8. Five patients initially scheduled for hospital discharge were subsequently admitted. Physicians changed or added diagnoses in 25 patients.

*Conclusions.* Using pulse oximetry as a routine fifth vital sign resulted in important changes in the treatment of a small proportion of pediatric patients. *Pediatrics* 1997;99:681-686; *oximetry, vital signs, triage, oxygen saturation.*

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ABBREVIATIONS. Sao<sub>2</sub>, arterial oxygen saturation; ED, emergency department.

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Simple clinical signs, including respiratory rate, presence of retractions or nasal flaring, grunting, cyanosis, pallor, and general appearance, are used to assess the cardiorespiratory status of infants and children. Previous investigators have found that although these clinical signs are frequently present, their absence does not reliably exclude the possibility

of serious cardiopulmonary disease or lower respiratory tract infections.<sup>1-5</sup>

Pulse oximetry has been advocated as an accurate, simple, and noninvasive method of measuring arterial oxygen saturation (Sao<sub>2</sub>).<sup>6</sup> Pulse oximetry can accurately measure normal Sao<sub>2</sub> and reliably detect desaturation under a variety of conditions<sup>7-11</sup> and may improve our ability to assess the cardiorespiratory status of infants and children. Recent technical advances have enabled the production of inexpensive portable oximeters that make routine pulse oximetry screening possible at low cost.<sup>12</sup> The reliability and simplicity of pulse oximetry have led some to promote its use as a fifth vital sign.<sup>13</sup> However, routine pulse oximetry screening has not been carefully evaluated in the general pediatric population. Careful studies need to be performed to delineate the benefits and pitfalls of pulse oximetry screening before this technology is used on a routine basis.

We performed this prospective study to examine the use of routine oximetry screening of children presenting to emergency department (ED) triage. We used pulse oximetry to measure Sao<sub>2</sub> on all children presenting to our emergency triage. These measurements were revealed to physicians only after they had completed their evaluation of each child. We then measured the changes in medical treatment that occurred after physicians were notified of the triage pulse oximetry values.

## METHODS

### Patient Selection

This study was conducted from November 1993 to June 1994 at a university hospital ED. All patients younger than 18 years presenting to emergency triage were enrolled. Children were excluded from the study if they bypassed triage and were judged by the triage nurse or prehospital care personnel to be in need of immediate resuscitation or medical intervention. Children were also excluded if the triage nurse was unable to measure respiratory rate and pulse oximetry according to study protocols. The study was approved and waiver of informed consent was granted by the human subject review board at our institution.

### Triage Assessment and Measurement Protocols

Triage nurses assessed each child and measured temperature, pulse, and blood pressure using prestudy triage techniques. Respiratory rates were measured by placing a stethoscope on the patient's chest wall and counting the auscultated breath sound for 1 minute. The nurses then assigned triage priorities based on the patient's condition and measurement of the four standard vital signs.

After the triage priority was determined, the nurses measured each patient's Sao<sub>2</sub> using a pulse oximeter (N-20; Nellcor Inc, Hayward, CA). This portable oximeter measures the absorption of red and infrared light signals until five valid pulses are detected and then reports a single Sao<sub>2</sub> value.<sup>12</sup> Triage oximetry values

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From the UCLA Emergency Medicine Center and the Departments of \*Medicine and †Pediatrics, UCLA School of Medicine, Los Angeles, California.

Received for publication Apr 15, 1996; accepted Jun 28, 1996.

Reprint requests to (W.R.M.) UCLA Emergency Medicine Center, 924 Westwood Blvd, Suite 300, Los Angeles, CA 90024.

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represent spot measurements; the device was not used as a continuous pulse oximeter. A variety of reusable sensors can be attached to the oximeter to measure  $SaO_2$  on fingers, toes, or ear lobes. We designated fingers as the preferred sites for pulse oximetry measurements, followed by toes and earlobes.

Each patient was assigned a unique identifying number. This number and age, sex, and vital sign measurements, including pulse oximetry, were recorded on a study data sheet and entered into the study database. Pulse, temperature, blood pressure, and respiratory rate were also recorded on each patient's medical record. Pulse oximetry values were not recorded on the children's medical records but were withheld from physicians until they had completed a child's medical evaluation and were ready to discharge or admit each patient. Only the triage nurse knew the patient's triage oximetry value. Nurses temporarily linked children to their oximetry measurements by recording the unique identifying study number on a questionnaire attached to each chart.

### Medical Assessments and Oximetry Values

Children received medical evaluations in the order of their triage priority. Each patient was evaluated by a senior resident or attending physician. Patients initially evaluated by junior house staff, interns, or medical students were subsequently evaluated by attending physicians. Physicians and nurses evaluated and treated children as usual. When requested, pulse oximetry measurements were repeated, and the results were made available to the requesting physician.

Physicians were asked to complete a brief questionnaire when they were ready to discharge or admit each child. Physicians were asked to specify whether chest radiography, complete blood count, spirometry, arterial blood gases, pulse oximetry, and ventilation-perfusion scanning had been used in evaluating each patient and whether antibiotics,  $\beta$ -agonists, supplemental oxygen, or hospital admission had been necessary. Physicians were also asked to supply their discharge diagnosis for each child. Physicians could not receive the forms needed to discharge, admit, or transfer patients until they had submitted a completed questionnaire. This approach ensured that the physicians would complete the questionnaires on all children. Physicians were given the requested disposition forms along with the corresponding triage pulse oximetry value when the data questionnaire was complete. After receiving the triage pulse oximetry measurements, physicians were free to order any additional tests or therapies they thought indicated and were allowed to alter their dispositions and diagnoses.

To determine whether treatment was altered by the oximetry results, all diagnostic tests and therapies were abstracted from the ED medical record by an investigator blinded to the pulse oximetry measurements. Tests and therapies were considered to have been ordered before oximetry disclosure if they were listed on the questionnaire. Diagnostic tests and therapeutic interventions implemented after the disclosure of the oximetry measurements (if any) were recorded for each patient, as were the physician's final diagnoses. Data collection was limited to events occurring in the ED and did not extend to events occurring after the patient's disposition.

### Data Analysis

To determine whether pulse oximetry measurements altered patient care, changes made in treating children with  $SaO_2$  values of less than 95% were compared with changes made in children having  $SaO_2$  measurements of 95% or greater. These relationships were quantified using Pearson's  $\chi_2$  analysis.

## RESULTS

A total of 2602 children presented to the ED during the study period; 91 patients bypassed triage to undergo immediate resuscitation and evaluation. Triage nurses were unable to measure respiratory rates or  $SaO_2$  accurately for 181 children (6.7%), and data questionnaires were lost for 3 patients. Triage pulse oximetry measurements and respiratory rates were obtained on the remaining 2327 individuals. After

the Northridge, CA, earthquake and surrounding hospital closures, we had an increase in patient visits and lacked sufficient personnel to inform physicians of the pulse oximetry results and collect data forms accurately. This forced us to exclude 80 children for whom pulse oximetry values had been measured but not communicated to physicians. An additional 120 children left our ED before completing their medical evaluations. The remaining 2127 patients form our study population. This population includes 934 girls (43.9%) and 1193 boys (56.1%). Ages ranged from birth to 17 years.

The physicians, after receiving triage pulse oximetry measurements at the time of patient disposition, ordered 12 additional diagnostic tests and 22 additional therapies in 29 (1.6%) of the 1822 children having triage pulse oximetry values of 95% or greater. Physicians ordered 81 additional diagnostic tests and 39 additional therapies in 95 (31%) of the 305 children having pulse oximetry readings of less than 95% ( $\chi^2 = 307$ ;  $P < .00001$ ). Physicians changed the admission plans for 5 of the 1822 patients with  $SaO_2$  values of 95% or greater and for 5 of the 305 children with  $SaO_2$  values of less than 95% ( $\chi_2 = 7.53$ ;  $P < .0061$ ).

Table 1 summarizes the treatment changes that the physicians initiated after receiving  $SaO_2$  measurements for the 305 patients having pulse oximetry values of less than 95%. After receiving oximetry measurements, clinicians ordered additional pulse oximetry for 49 children and ordered an additional 31 tests (excluding pulse oximetry) for 23 children. Physicians ordered additional chest radiographs for 16 children, complete blood counts for 7, arterial blood gas analyses for 4, spirometry for 2, and ventilation-perfusion scanning for 2. The clinicians ordered antibiotics for an additional 15 children, supplemental oxygen for 11, and  $\beta$ -agonists for 8. Five children initially scheduled for discharge were subsequently admitted.

Overall, for the 305 patients with  $SaO_2$  values of less than 95%, the clinicians ordered 81 additional diagnostic tests for 62 patients (20%) and 39 additional treatments for 33 children (11%). Clinicians changed or added diagnoses for 25 children (8.2%).

**TABLE 1.** Number of Patients in Whom Additional Diagnostic Tests or Therapies Were Ordered or Changes Were Made in Diagnosis or Disposition After Disclosure of Triage Pulse Oximetry Results in 305 Children With Oxygen Saturation Values of Less Than 95%

Tests and Treatments	n (%)
Diagnostic tests	
Additional pulse oximetry	49 (16.1)
Chest radiography	16 (5.2)
Complete blood count	7 (2.3)
Arterial blood gas analysis	4 (1.3)
Spirometry	2 (0.7)
Ventilation-perfusion scan	2 (0.7)
Treatments	
Antibiotics	15 (4.9)
Supplemental oxygen	11 (3.6)
$\beta$ -agonists	8 (2.6)
Hospital admission	5 (1.6)
Diagnostic changes	25 (8.2)

Table 2 presents the diagnostic, testing, and treatment changes in terms of specific final diagnoses. Upper respiratory tract infection was initially diagnosed in 44 individuals, making it the most frequent diagnosis given to the 305 patients with  $SaO_2$  measurements of less than 95%. An additional 6 diagnoses were made after the clinicians received the oximetry results. These 6 diagnoses represent 12% of the final 50 diagnoses of upper respiratory tract infection. Fourteen (28%) of these children underwent additional diagnostic testing after oximetry measurements were revealed, and 6 (12%) had adjustments made to their therapy. Asthma, pneumonia, congenital heart disease, and bronchitis were other diagnoses frequently seen in patients having oximetry values of less than 95%. No new cases of congenital heart disease were made on the basis of oximetry measurements, and pulse oximetry did not affect the treatment of these patients.

$SaO_2$  levels were related to the frequency with which physicians altered their medical treatment. As shown in Table 3, physicians were most likely to change their treatment of patients with oximetry readings between 86% and 92%, with the greatest relative number of changes occurring at the 89% saturation level. Two-thirds of patients having  $SaO_2$  values of 89% underwent additional testing, and 40% had changes made in their treatment. This level also had the highest rate of diagnostic changes, with 20% of the diagnoses changed as a result of pulse oximetry measurements.

Seventy-three patients had  $SaO_2$  values of 90% or less. Only 23 (32%) had tachypnea (defined as a respiratory rate in the upper 5% by age), and only 35 (48%) had respiratory rates within the upper 20% for their age. Of this same group of 73 children, clinicians either rechecked pulse oximetry or admitted 50 (68%), whereas 23 children were discharged without having their pulse oximetry rechecked.

Of the 80 children who had pulse oximetry performed but not reported to physicians, 13 had  $SaO_2$  values of 93% or less. Three were admitted to the hospital on their initial visit, and 1 had pulse oximetry measured as part of their medical evaluation. The remaining 9 patients were discharged by their treating physicians, who were unaware of the  $SaO_2$  measurements. The department triage log enabled us to identify these patients and to obtain follow-up information on 8 of them. Six (75%) revisited the ED within 48 hours with the same conditions, and three (38%) were admitted at their revisits. Two patients

reported uneventful recoveries without revisit. We were unable to obtain follow-up information on 1 child.

## DISCUSSION

Many studies have examined the use of simple clinical signs in assessing cardiopulmonary status in infants and children.<sup>1-5</sup> In general these studies have shown that cardiorespiratory disease is frequently present when these signs are manifest, but of equal importance, the studies indicate the many children who have significant cardiorespiratory disease have none of these signs.

Data from physiologic studies indicate that mild to moderate hypoxia produces at most a modest and temporary increase in ventilation.<sup>14-19</sup> Transient hyperventilation is rapidly followed by a return to normal ventilatory levels. This biphasic response is a result of the way ventilation is controlled by the brainstem. Moderate hypoxia initially stimulates peripheral receptors to increase ventilation; however, the increase in ventilation produces a decrease in the  $Paco_2$ , an even more potent modulator of ventilation. In response to the decrease in the  $Paco_2$ , and because of a direct central depressive effect of hypoxia, the brainstem down-regulates the respiratory drive and returns ventilation back to baseline levels.<sup>14-20</sup> Thus, most healthy individuals exposed to moderate hypoxia will not have a significant increase in their ventilation.

Decreasing arterial oxygen pressure to less than 40 to 50 mm Hg produces a sustained increase in ventilation as the respiratory stimulation produced by hypoxia exceeds the inhibition generated by decreasing carbon dioxide levels.<sup>16</sup> It is important to note, however, that most of the initial increase in ventilation is accomplished by augmenting tidal volume and peak flows while keeping respiratory rate constant.<sup>18</sup> An increased respiratory rate occurs as a late response to severe hypoxemia.

These physiologic findings suggest that in the clinical setting, respiratory rate should not be a sensitive indicator of arterial oxygen levels and cardiorespiratory status. Our study confirms this concept. Only 48% of the children with  $SaO_2$  values of less than 90% had respiratory rate elevations above the 80th percentile for their age, and less than one third had rates in the upper 5th percentile for their age. The majority of the moderately hypoxic children in this study had respiratory rates that were indistinguishable from those of other children in the study.

**TABLE 2.** Effect of Routine Pulse Oximetry on Diagnosis, Testing, and Treatment in 305 Children With Oxygen Saturation Values of Less Than 95%

Final Diagnosis*	No. of Patients Diagnosed Before Oximetry	Additional Patients Diagnosed After Oximetry (% Increase)	No. (%) of Patients With Changes in Testing	No. (%) of Patients With Changes in Treatment
URI/viral syndrome	44	6 (14)	14 (28)	6 (12)
Asthma/RAD	36	2 (5.6)	4 (11)	9 (24)
Pneumonia	23	3 (13)	16 (62)	11 (48)
Congenital heart disease	11	0 (0)	2 (18)	0 (0)
Bronchitis	5	1 (20)	3 (50)	2 (33)
Other	186	13 (7.0)	23 (12)	5 (2.7)

\* URI indicates upper respiratory tract infection; and RAD, reactive airway disease.

**TABLE 3.** Changes in Treatment by Pulse Oximetry Value

Oxygen Saturation Level (%)	No. of Patients	Additional Changes in Testing (%)	Additional Changes in Treatment (%)	Additional Inpatient Admissions (%)	Changes in Diagnosis (%)
100	319	2 (0.6)	2 (0.6)	0 (0.0)	0 (0.0)
99	380	0 (0.0)	0 (0.0)	1 (0.3)	1 (0.3)
98	473	1 (0.2)	4 (0.8)	1 (0.2)	4 (0.8)
97	309	1 (0.3)	5 (1.6)	1 (0.3)	3 (1.0)
96	206	1 (0.5)	5 (2.4)	2 (1.0)	2 (1.0)
95	136	4 (2.9)	3 (2.2)	0 (0.0)	2 (1.5)
94	87	9 (10)	7 (8.0)	1 (1.1)	7 (8.0)
93	66	10 (15)	6 (9.1)	2 (3.0)	2 (3.0)
92	42	7 (16)	8 (19)	1 (2.4)	6 (14)
91	24	8 (33)	0 (0.0)	0 (0.0)	3 (12)
90	21	4 (19)	1 (4.8)	0 (0.0)	3 (14)
89	15	10 (67)	6 (40)	1 (6.7)	3 (20)
88	12	3 (25)	0 (0.0)	0 (0.0)	0 (0.0)
87	4	1 (25)	0 (0.0)	0 (0.0)	0 (0.0)
86	5	2 (40)	0 (0.0)	0 (0.0)	0 (0.0)
≤85	28	8 (29)	4 (14)	0 (0.0)	1 (3.6)

The fact that hypoxia may not be accompanied by an increased ventilatory drive may explain many of our study findings. In particular, our study demonstrates that after receiving triage pulse oximetry values, physicians were significantly more likely to change the treatment of children with  $SaO_2$  values of less than 95% compared with those having saturation values of 95% or greater. This is likely because of the difficulty physicians have in detecting cardiopulmonary and gas exchange abnormalities in patients who did not have evidence of respiratory distress. Without some sign of respiratory compromise, clinicians may often underestimate cardiorespiratory and gas exchange difficulties.

Patients with pulmonary diseases such as viral respiratory tract infections, pneumonia, asthma, and bronchitis were most likely to have abnormal pulse oximetry values and were also most likely to have their medical treatment changed. This suggests that there were two reasons that pulse oximetry altered medical treatment: physicians either failed to appreciate subtle cardiopulmonary problems, or they did not recognize the severity of the illnesses they had diagnosed. Routine pulse oximetry measurements often alerted physicians to these problems by revealing  $SaO_2$  difficulties.

Our data also suggest that the ability of physicians to detect hypoxemia is dependent on the  $SaO_2$  level. Clinicians seem to have the greatest difficulty in detecting mild to moderate degrees of desaturation, as evidenced by the fact that the proportion of treatment changes peaked at the 89% saturation level. The decreasing proportion of changes at lower saturation levels suggests that physicians are able to detect more severe hypoxemia. Clinical signs that accompany severe hypoxemia may be important in alerting physicians to increasing levels of desaturation. This is consistent with the findings of Loggan et al,<sup>21</sup> who determined that pulse oximetry produced insignificant changes in the care of patients having  $SaO_2$  values of less than 85%.

An important aspect of our study was to determine whether information revealed by pulse oximetry is already provided by classic vital sign measure-

ments. In particular, we desired to determine whether respiratory rate and pulse oximetry convey redundant information. This aspect required us to provide physicians with accurate respiratory rate measurements. Inaccurate rates may mislead physicians in their respiratory assessments and magnify the utility of pulse oximetry. Respiratory rate measurements are notoriously sensitive to measurement techniques<sup>2,22</sup> and are often assessed inaccurately.<sup>23</sup> We made extensive efforts to ensure that clinicians received reliable respiratory rate measurements, and the counting of respiratory rates was the most tedious aspect of this study. Despite the accuracy of the respiratory rate information, we found that respiratory rates correlated poorly with  $SaO_2$  levels and that clinicians often changed their medical treatment after receiving pulse oximetry measurements. This confirms the findings of other investigators<sup>1-4</sup> and demonstrates the inadequacy of the respiratory rate alone in screening for significant cardiopulmonary disease and gas exchange abnormalities.

We designed this study to examine the use of pulse oximetry as a routine fifth vital sign while recognizing an established role for pulse oximetry in evaluating some patients. Thus, we made pulse oximetry readily available to physicians. We neither provided physicians with treatment guidelines nor defined normal or abnormal saturation levels. Additionally, our ED routinely performs continuous pulse oximetry monitoring on our sickest patients, including most of the children excluded from this study when they bypassed triage. Despite the ready availability of pulse oximetry, the physicians frequently failed to appreciate decreased  $SaO_2$  values in many patients and were unable to reliably identify children who could have benefited from  $SaO_2$  measurements.

Some might argue that the additional testing, treatments, and admissions resulting from routine pulse oximetry are not warranted and represent unnecessary health care expenditures. We considered withholding triage pulse oximetry results from physicians and examining the outcomes of those discharged from the hospital with low saturation values but decided that this approach was poten-

tially harmful and, therefore, unethical. However, the group of 80 patients in whom pulse oximetry was measured but not reported to physicians provides the most convincing support for the necessity of the increased interventions. Most of the children with Sao<sub>2</sub> values of 93% or less returned to the ED with their original symptoms within 48 hours, and more than one third were admitted to the hospital on their revisit.

The outcomes for these children also make us concerned about the 23 children who were discharged without rechecking saturation levels, despite having triage oximetry measurements of 90% or less. Presumably these children "seemed" well enough to send home, and their physicians were comfortable with their clinical assessments. We were unable to obtain follow-up on these children, but finding that physicians frequently fail to recognize clinically important oxygen desaturation raises the concern that some of these children may have been inappropriately discharged or discharged with inadequate therapy.

### Limitations and Generalizability

We designed this study to examine the qualitative impact of routine pulse oximetry. The study was not designed to assess oximetry quantitatively. In this regard our study likely underestimates the utility of routine pulse oximetry for the following reasons. First, we examined only a limited number of modalities and restricted our analysis to events in the ED. We did not, for instance, monitor the use of diuretics, corticosteroids, or xanthines, and we did not follow patients past their disposition to determine whether interventions were initiated through admission orders. Second, it is possible that physicians would have ordered fewer diagnostic tests if they had known the triage saturations before completing their evaluations. Third, the physicians' initial impressions and subsequent evaluation may have biased their judgment to the extent that they subsequently disregarded pulse oximetry readings that contradicted their clinical impressions.

We did not design this study to examine the overall use of pulse oximetry in emergency care. Rather, we focused on the utility of routine pulse oximetry screening. We already recognize the importance of pulse oximetry in many patient subgroups, and we routinely perform continuous pulse oximetry monitoring of critically ill children, including most of those excluded from this study. Institutions having limited access to pulse oximetry may find even greater benefits from routine screening.

Because critically ill and unstable children who bypassed triage were excluded from this study, our population consisted mainly of ambulatory patients presenting with acute medical problems. Thus, we are confident in generalizing our qualitative results to other acute care settings, such as urgent care centers, ambulatory care centers and nighttime pediatric centers. We are less confident in extending our results to the general primary care and well infant settings. However, the ease of performing pulse

oximetry measurements combined with their insignificant cost suggest that pulse oximetry should be used as a fifth vital sign when evaluating either unselected acutely ill children or those at higher risk of cardiorespiratory disease.

Clinicians who use routine pulse oximetry must be cognizant of the conditions other than simple gas exchange abnormalities that may alter pulse oximetry measurements. Any disease that decreases peripheral perfusion may produce local oxygen desaturation. Such conditions may be medically important in their own right, but physicians must be aware of the limitations of pulse oximetry and recognize that alterations in Sao<sub>2</sub> do not necessarily imply gas exchange abnormalities. Identifying the specific cause of abnormal Sao<sub>2</sub> is essential in accurate diagnosis and optimal care.

Finally, the use of antibiotics,  $\beta$ -agonists, supplemental oxygen, and hospital admission are all surrogate measures for improved patient outcomes. The true utility of pulse oximetry depends on how accurately these surrogate measures reflect improvements in patient outcome.

### Conclusion

Our study shows that physicians may fail to recognize moderate oxygen desaturation in a small proportion of children, and that providing physicians with routine pulse oximetry measurements may result in significant changes in medical treatment.

### ACKNOWLEDGMENTS

This study was supported in part by a grant from Nellcor Inc. We thank the nurses and clerks of the UCLA Emergency Medicine Center for their participation in this study and for implementing our protocols.

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#### PIERRE ROYER PRIZE

The Pierre Royer Prize is awarded by the Société Française de Pédiatrie to a medical doctor whose work is recognized as having had a major influence on child health. This award has been established as a mark of recognition of the Society in honor of the outstanding leadership and work of Pierre Royer.

The prize of 150,000 FFr is awarded every second year at a meeting of the Société Française de Pédiatrie. The winner of the Pierre Royer Prize is required to present a lecture at the awards ceremony. The prize will be awarded for the first time in October 1997.

Nominations for the award should be sent to the Société Française de Pédiatrie by July 1, 1997. University professors and directors of research programs are particularly encouraged to submit the names and dossiers of possible candidates.

For complete details please contact:

Professeur François Beaufilet  
 Secrétaire Général de la Société Française de Pédiatrie  
 Hôpital Robert Debré  
 48 Boulevard Sérurier  
 75019 Paris  
 France  
 Tel-Fax: (+33) 1 42 06 69 17