Measurements of calcium and magnesium were made by Dr. C. P. Bianchi.

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Gangrene of a Thumb Following Use of the Photoelectric Plethysmograph during Anesthesia

MARTIN H. LEBOWITZ, M.D.*

The photoelectric plethysmograph is a miniaturized transducer designed to indicate volume changes of a pulsatile flow.[1-3] The device incorporates a light source and a highly sensitive photocell. It is capable of producing a large pulse-wave signal when placed over a surface artery or arteriolar bed. Several transducer models are commercially available, one model specifically for use on the finger or toe pad. The finger transducer has the photocell adjacent to the light source, relying on reflection of the light rather than transillumination. The sensor is housed in a plastic mold and attached to the finger or toe pad by means of a Velcro® strap (fig. 1).

We have found this device of great value in monitoring peripheral blood flow during anesthesia and surgery. Systolic blood pressure can be determined easily by slow deflation of a pneumatic cuff while observing the oscilloscope for the return of the pulsatile flow wave. This method of blood-pressure determination has been of particular value with small children and infants, in whom palpatory or auscultatory pressures may be difficult or impossible to obtain. In the course of many applications of the monitor its performance had been entirely satisfactory until two recent complications involving the great toe of a two-month-old child and the thumb of a newborn infant. In both cases the involved digit was observed to be markedly swollen and plethoric upon removal of the monitor. The condition rapidly improved in one and rapidly progressed to gangrene of the distal phalanx in the other.

* Assistant Professor, Department of Surgery/Anesthesiology, University of California at Los Angeles, Center for the Health Sciences, Los Angeles, California 90024.

REPORT OF TWO CASES

Patient 1. A previously healthy, 2-month-old, 4.9-kg infant girl was admitted because of signs of central nervous system irritability, manifested by hyperreflexia, vomiting, and nuchal rigidity. Meningitis was suspected, but several lumbar punctures showed only xanthochromic fluid, suggesting a subarachnoid hemorrhage. Because of seizures, oral phenobarbital therapy was initiated. The infant's condition improved after several days and she was scheduled for a cerebral angiogram under general anesthesia.

Following premedication with atropine, 0.1 mg, intramuscularly, anesthesia was induced with ketamine,† 50 mg (10 mg per kg), intramuscularly. Anesthesia was maintained with intermittent intravenous ketamine. A 4½-hour bilateral carotid and vertebral angiogram was performed via a percutaneous puncture of the right femoral artery. As a monitor of arterial flow to the right lower extremity, a photoelectric plethysmograph was attached to the right great toe at the start of anesthesia.[2] An adequate pulsatile flow wave was observed until shortly after catheterization of the artery. Thereafter, the oscilloscope showed intermittent pulse waves at diminished amplitude throughout the procedure, despite good color and warm toes.

Ventilation was spontaneous at 25–30 per minute. Rectal temperature stabilized at approximately 34 C. Vital signs remained relatively stable; systolic blood pressure was 90–110 mm Hg and cardiac rate 120 beats/min throughout

† Ketalar (CI-581) (2-(o-chlorophenyl)-2-methylamino-cyclohexanone), Parke Davis.

the procedure despite persistent blood loss from frequent flushing of the arterial catheter. Blood loss was estimated at about 75 ml and was replaced with 250 ml 5 per cent dextrose in water and 40 ml plasma. Near the end of the procedure the hematocrit was found to be 20 per cent (preoperative 31.5 per cent).

At the conclusion of anesthesia, with the oscilloscope still showing an irregular, slightly diminished, pulse waveform, the plethysmograph was removed from the toe which, for the first time, was noted to be slightly swollen and blue. The patient was returned to the ward. An intravenous catheter was placed in the left saphenous vein and 60 ml whole blood administered over the next three hours. The hematocrit that evening was 33 per cent.

The patient was alert and well the next morning. No evidence of intracranial vascular anomaly had been found and she continued to improve. Swelling and discoloration of the right great toe were minimal. By the third postoperative day the toe was completely normal. The patient was asymptomatic, and she was discharged from the hospital.

Patient 2. A 3-kg newborn baby girl with a volley-ball sized, fluid-filled tumor of the sacrum was admitted with poor color and vital signs. An umbilical-vein catheter was inserted, through which $NaHCO_3$, 9 mEq, plasma, 20 ml, Solucortef®, 50 mg, penicillin, 250,000 U, Kantrex®, 20 mg, and polymyxin, 1.25 mg, were administered. The patient's color and vital signs improved temporarily, but ventricular tachycardia was soon noted by EKG. Despite lidocaine, 4 mg, and $NaHCO_3$, 9 mEq, intravenously, ventricular fibrillation ensued. Closed-chest cardiac massage was instituted, oral intubation accomplished, and 20 ml of uncrossmatched O-negative blood administered. After successful resuscitation with further $NaHCO_3$, intravenous epinephrine and calcium gluconate, the patient was transferred to the operating room. Immediate excision of the sacral mass was deemed necessary because of the likelihood of loss of circulating blood volume from baby to tumor.

The patient was placed supine on the operating table and 100 per cent O_2 administered via the orotracheal tube. Lead 1 of the EKG was monitored continuously by oscilloscope. Both lower extremities were wrapped with soft cotton wadding and suspended 90 degrees to the trunk for surgical exposure of the lesion. A large electrocautery plate with a generous amount of conductive jelly was then placed under the patient's back. With the child showing moderate muscular tone and response to stimuli, induction of anesthesia was accomplished with 0.5 per cent halothane in 50 per cent $N_2O:O_2$. When the child was unresponsive, surgical preparation was begun. A blood-pressure cuff 1¾ inches wide was attached to the left arm and the photoelectric plethysmograph attached to the volar surface of the left thumb. The plethysmograph was repositioned several times until the maximum displacement was obtained on the oscilloscope, although initially the waveform was irregular and of small amplitude. Systolic blood pressure was then determined to be approximately 60 mm Hg.

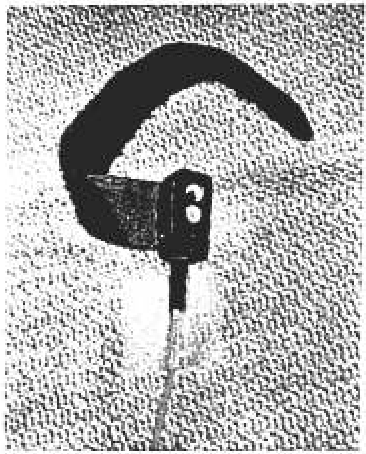

FIG. 1. The Corbin-Farnsworth Finger Transducer with black plastic case and velcro strap.

Anesthesia was maintained with 0.5 per cent halothane in 50 per cent $N_2O:O_2$. Because of suspected low circulatory volume even prior to anesthesia and the immediate and persistent operative blood loss, warmed, uncrossmatched O-negative blood was administered from the beginning of the procedure, to a total 175 ml. As the amount of blood administered increased, the pulse waveform became increasingly higher in amplitude. Approximately 20 minutes after induction of anesthesia, with systolic blood pressure ranging from 40 to 60 mm Hg, marked bradycardia occurred, followed almost immediately by asystole. Halothane and N_2O were discontinued. Closed-chest cardiac massage was instituted immediately and atropine, 0.1 mg, $NaHCO_3$, 5 mEq, ephedrine, 5 mg, and calcium gluconate (10 per cent), 2 ml, were administered intravenously. A normal sinus rhythm with a systolic blood pressure of 60–70 mm Hg was re-established within two minutes. Anesthesia was then continued with intermittent $N_2O:O_2$ and 100 per cent O_2, supplemented by *d*-tubocurarine, 2 mg, intravenously.

Anesthesia time was approximately two hours. The patient's temperature was 34 C at the start of anesthesia and progressively increased to 37.5 C. At the end of surgery the patient was trans-

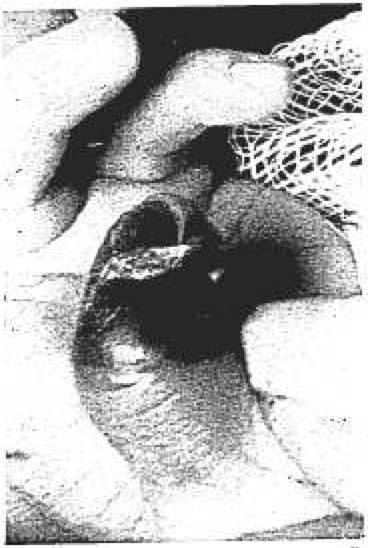

FIG. 2. Four days postoperatively. Note swelling surrounding proximal phalanx of thumb and slough of surface tissue layers around distal phalanx and nail.

ferred to a heated incubator with the orotracheal tube in place and ventilation was controlled by a Bird respirator at a rate of 30 per minute with 100 per cent O_2. Systolic blood pressure was 90 mm Hg, with the oscilloscope showing a strong, steady pulse wave at about 160–170 per minute. As the plethysmograph was removed from the left thumb, it was noted that the thumb was swollen from the metacarpalphalangeal joint to the tip. A blue-purple discoloration was present from the interphalangeal joint to the tip (fig. 2).

The child was transferred to the intensive care unit. During the next few days the swelling and discoloration of the thumb progressed to dry gangrene of the distal phalanx of thumb, despite excellent vital signs and no further evidence of circulatory insufficiency. The thumb was treated simply by application of antibiotic ointment and bandaging. The necrotic process continued progressively. Eventual loss of the distal phalanx was obvious by the end of the first postoperative week, although recovery was otherwise uncomplicated.

Discussion

Among the numerous electronic devices available to the anesthesiologist, the photoelectric plethysmograph is particularly well suited for infants and children because of its small size, large pulse signal, and ease of surface application. The terminal digit is a common site of application of the monitor, not only because of accessibility and ease of attachment of the sensor but because the amplitude of the pulse waveform of the rich arteriolar bed in the finger pad tends to reflect very early changes in cardiovascular dynamics.[4] We feel that the two complications presented in this report represent a combination of factors related to the characteristics of both the monitor and the terminal digit, rather than an inherent fault in the monitor itself.

The incandescent light source of the unit consumes very little power and thus heat production should be minimal.[5] Nevertheless, tissue burns have been reported during use of the earpiece as well as other transducer models.[5, 6] A thermal effect was no doubt responsible for some of these reported burns, but high-frequency current was suspected in others. With improper grounding of the electrocautery, radiofrequency burns can occur at other electrode sites on the body which lead to ground.[7, 8] We doubt that a radiofrequency effect was the origin of our two complications because the electrocautery was not used during the angiogram and the swollen plethoric digits in both cases had the appearance of ischemic tissue damage rather than a surface burn. In addition, the plastic case surrounding the sensor provides poor electrode contact,[5] thus making this site a poor route to ground.

A thermal effect cannot be eliminated so easily. The unit does become warm during use, increasing from 23 (room temperature) to about 34 C after an hour.‡ Although this maximum temperature is below normal body temperature, and would appear insufficient to cause a surface burn, the relative heat buildup might not be insignificant when applied to a digit that is either hypothermic, markedly vasoconstricted, or both. In this situation the capacity of the tissue to dissipate the heat

‡ This temperature was measured on the instrument used in both cases by allowing the plastic mold to remain in contact with a mercury bulb thermometer, in air, for several hours. The maximum temperature achieved was 34 C.

produced by the device might be insufficient to prevent over-heating of the tissue with time. In the two cases presented, the increased tissue metabolic requirement resulting from heating of the digit may have exceeded the capacity of the markedly diminished blood flow to provide oxygen, thus resulting in relative ischemia and tissue injury.§

There is also the possibility that the monitor was too tightly attached to the digit, resulting in pressure ischemia, venostasis, or both. It is difficult to consider that venostasis alone could account for the necrotic changes we observed. Pressure ischemia, however, certainly could produce such injury, but it is difficult to accept pressure ischemia as a significant factor in the face of an apparently-adequate pulse waveform by the oscilloscope. Even though the significance of the amplitude of the pulse wave is, at best, little understood, most investigators believe that the pulse-wave amplitude does reflect blood supply and tissue perfusion.[1-4, 9] In each of these cases a small or irregular pulse waveform was present during part of the procedure. The small amplitude of the signal appeared to be adequately explained by vasospasm or diminished blood supply in each case. A large pulse signal, suggesting proper positioning of the sensor, was obtainable during some portion of each case, during the period prior to arterial catheterization in the first case and following the increasing administration of blood in the second case. Nevertheless, it is certainly possible that venostasis, pressure ischemia, hypothermia, vasoconstriction and heating of the tissue were present simultaneously, each making its own contribution to the tissue injury.

Conclusion

The photoelectric plethysmograph has proven itself to be a reliable and extremely useful monitor of the peripheral pulse, especially in infants and small children. The heat output of the device is purported to be negligible. However, with hypothermia and peripheral vasoconstriction (particularly secondary to diminished blood volume) thermal tissue damage remains a possibility. When conditions conducive to peripheral ischemia are present, we suggest frequent repositioning or removal of the device from the digit. As an alternative one might use some other arteriolar bed less vulnerable to injury (the nasal septum[10] or palm of the hand) or some other pulse monitor not dependent upon a photocell.[9, 11] There is no doubt that a light source powerful enough to provide a good pulse signal with a truly negligible heat output is needed. We are investigating this possibility with the manufacturer and in our own laboratory at the present time.

§ As heating of the tissue should produce an increase in blood flow by virtue of vasodilation, we propose that such an increased flow did not occur in these cases, primarily because of lack of sufficient arterial supply secondary to vasospasm in one and low circulating volume in the other. A constrictive effect from the velcro strap may also have contributed to a lack of increased digital flow during heating.

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