FURTHER ANESTHESIA STUDIES WITH PHOTO-ELECTRIC OXYHEMOGLOBINOGRAPH*

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THE DATA we wish to present are a continuation of studies on anoxia in surgery, presented to the Association last year. Those studies on experimental animals and surgical patients were made through the application of Warburg's method for tissue respiration and Van Slyke's manometric method for oxygen saturation of the arterial blood. Both of these methods are not only slow and laborious but, at best, can be applied only at intervals.

During the course of this earlier work the necessity for continuous observations of the oxygen saturation became apparent, and the work of Kurt Kramer and Karl Matthes, published in 1934 and 1935, was reviewed. Both investigators measured the oxygen saturation of the blood by means of light absorption as determined with photo-electric cells and galvanometers. This work was fundamental, as seen in the following excerpts from their papers. Kramer, 1934: "For the study of metabolic-physiologic problems a method was needed which would permit the easy determination of the oxygen content of the blood at short intervals or even continuously in the animal body. This requirement was not met by any of the methods thus far used, including the manometric determination of Van Slyke and the improved spectral analytic determination of Routon and Hartridge. . . . The development of the photo-electric cell technic, especially Lange's barrier layer cells, made it possible to utilize the spectral peculiarities of hemoglobin to carry out oxyhemoglobin determinations *in vitro* and, perhaps, *in vivo* quickly and accurately." Through these investigations Kramer confirmed the validity of Beer's law for hemoglobin solutions.

Based on the original observations, the second paper, of 1935, reported a method for the continuous oxygen analysis of the blood in closed vessels of an animal with accuracy to 1 per cent saturation. In explanation, Kramer stated: "It has been demonstrated that the light absorption of hemoglobin solutions even in high concentrations, is subject to Beer's laws. It, therefore, could be assumed that the condition of the hemoglobin molecule of the normal blood which is found in the erythrocyte, in 30 per cent concentration, would not greatly complicate the laws of light absorption. Therefore, the light permeability of the hemoglobin, which varies with the oxygen content, had to be fundamentally similar to the photo-electric findings in pure hemoglobin solutions. The principle of the method is based on the spectral differences of the hemoglobin and oxyhemoglobin in the red wave length section."

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Karl Matthes, 1934: "Since the fluctuations of the filling of the pulmonary reservoir are changing rapidly, the analysis of blood samples obtained by puncture permitted only a very inadequate picture of the entire process. We, therefore, searched for a method for continued recording of the oxygen content of the blood in arteries and veins. Such a possibility was presented by the well-known differences in the light absorption of oxyhemoglobin and reduced hemoglobin. After the technical part of these investigations had been completed, Kramer published a method very similar in principle." Matthes used mercury vapor lamp after Nicolai. Kramer used ordinary light with Zeiss-red filter R.G.I.—"A method has been evolved which permits the continuous optical registration of the oxygen content and the total concentration of the hemoglobin in the blood of a given vessel, instead of periodic withdrawal of blood which is subject to many technical disadvantages.

"The principle of the new technic which employs photo-electric methods consists in the registration of the absorption of light of two spectral regions through the blood." Under the title "Investigation of the Oxygen Saturation of Human Arterial Blood," Matthes, in 1935, applied the red-sensitive photocell used by Kramer to the ear lobe after histamine iontophoresis. In conjunction, in order to evaluate the passive fluctuations of the vascular bed, a plethysmogram of the other histamized ear lobe was made. These simultaneous records allowed the immediate recognition and the elimination of all distortions of the oxygen saturation curve caused by changes of the blood content of the ear lobe. The oxygen saturation curve was calibrated by blood determinations during oxygen, air and 88 per cent nitrogen respiration. During the first, the saturation was found always to be 100 per cent.

From this analysis of the work of Kramer and Matthes it seems demonstrated that measurement of light absorption by red-sensitive photo-electric cells is capable of giving accurate oxygen saturation values for hemoglobin *in vitro*, in blood vessels or in selected skin areas providing other variables, especially the total hemoglobin in the circulation and the volume of the part within the cell, are taken into consideration. The first of these variables is of secondary importance since large enough changes in the total hemoglobin occur only after adrenalin to materially alter the oxygen saturation values. The second of the variables, that is volume of the part, should be recorded in parallel as it was by Matthes. Kramer dealt with large vessels, filling his rigid cells, thus avoiding this factor. Matthes histamized the ear lobe used and generally obtained plethysmographic records of the other ear lobe using a combination volume and photo-electric cell method. In 1937 and 1938, Hertzman, of St. Louis University, described the use of a photo-electric plethysmograph, for studying the blood supply of various skin areas. This apparatus resembles that of Kramer and Matthes except that a photo-electric cell of the photo-emissive type rather than the red-sensitive or the green-sensitive type was used. Hertzman mentions the influence of reduced hemoglobin-oxygenated hemoglobin ratio on skin opacity, but his detailed observations apparently have not been published.

SUMMARY

(1) In our work, thus far, volume changes of the parts incorporated in the photo-electric cell have not been recorded in parallel, but with the increasing stability and dependability of the machine, volume changes are to be included in these studies.

(2) Volume has been controlled to some extent by heating the area studied through the photo-electric cell and by bringing the light and cell outlets snugly against the skin.

(3) As a guide for the surgeon during anesthesia, low oxygen saturation of the arterial blood and increased volume in the capillary bed are equally significant danger signals; hence if light absorption increases sharply due to one or the other, or both, corrective measures are indicated.

(4) If the respirations are of usual rate and amplitude, oxygen should rapidly reduce the high light absorption. Lack of response to oxygen suggests a dilated capillary bed and low blood pressure.

Discussion.—Dr. Roy D. McClure (Detroit, Mich.): We are inclined to believe that not enough attention is paid to anoxia during anesthesia. In recent years, there have been reported occasional deaths on the operating table during anesthesia. Autopsies have been obtained on these patients and the typical changes of anoxia have been demonstrated. Our attention has also been drawn to several patients in whom mental and physical derangements occurred after anesthesia. It is our opinion that these changes have been produced by anoxia.

We have one patient that I should like to report: A young lady led her class in her particular section of the first year's work. She came to Detroit one morning and had a tooth extracted under nitrous oxide. On returning to her home that afternoon she noticed that her vision was blurred, but neither she nor her parents associated this change with the pulling of the tooth. Later she consulted an oculist who tested her eyes and gave her glasses. On her return to school she noticed no further change in herself, but when the next term examinations came up she made very bad marks, and before the year was out she failed in her work. On the next visit to this dentist, a year later, for another impacted molar on the opposite side, he said to her: "For heaven's sake, don't let anybody ever give you gas again because you just can't take it." It then came out that during her first anesthesia, which was a gas anesthetic, she had become blue and had to be given artificial respiration.

In discussion of this subject with different groups of doctors there are always some who have noticed changes in a patient after anesthesia. We feel that the exact nature of these changes, despite their importance, is often not recognized and that undoubtedly many more cases of slight anoxia with permanent damage occur than is commonly suspected. I do not know how we can detect this condition except, perhaps, by earlier mental tests of patients such as this particular girl had in her school, because such changes were not even recognized by her family.

We have been attempting to study this problem of anoxia by making arterial punctures and estimating the oxygen content of the blood during anesthesia. This method is cumbersome and requires too much time to be of practical value. It is obvious that a method of such blood analysis must be immediate, and the search for some such practical method is responsible for the report given here to-day by Doctor Hartman. This method with the electric eye is immediate and striking, and we hope may soon prove to be of considerable practical importance.