THE EAR OXIMETER AS A CIRCULATORY MONITOR
Preliminary Report

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A series of studies was conducted during the past year to determine the distinguishing characteristics of the electroencephalogram when light narcosis is maintained by nitrous oxide with succinylcholine (Anectine). An ear oximeter was used to check possible effects of anoxia indicated on the electroencephalogram. It was recognized that the ear oximeter might not provide as exact data as could be obtained from gasometric determinations (the absolute values vary from 2.5 per cent to 5 per cent [1]). A continuous record, however, offered certain advantages. It enabled us to note relative changes in arterial oxygen saturation and to judge whether changes in the electroencephalogram were due to oxygen want or to the effects of the anesthetic drugs. During the course of these studies certain characteristics of ear oximetry were noted, and they seemed to deserve further study.

The instrument used was Wood's absolute reading ear oximeter (2), and the electronic recorder was an ink-writing Grass polygraph equipped with model 5 Pl preamplifier. This was built by the Grass Company according to a circuit developed by Perkins, Adams, and Livingstone (3). The high degree of amplification possible and the rapid response made the Grass polygraph an extremely useful instrument.

In the original ear oximeter described by Wood (4), only one scale (100 to 0 per cent saturation) is provided. With the instrument we used it was possible to study the upper portion of the curve of oxygen saturation. This was done by first establishing a full range (100 to 0 per cent), amplifying the signal four times, and then shifting the base line back to its original position. A scale was thus established which indicated degrees of saturation from 100 per cent to 84 per cent. It was then noted that the oximeter provided a wave-like tracing related to the pulsatile flow of blood to the ear. Consequently, changes in the amount of blood coursing through the ear effected a change in the shape of the oximeter trace. Direct evidence of this was seen with the occurrence of extrasystoles. When a premature systole occurs, the heart does not have sufficient time to fill, and the resultant output during that systole is diminished. Evidence of this seen in the oximetric tracing is de-
picted by an absence or a marked change in the height of the wave during that extrasystole. Figure 1 was selected from the record of a patient undergoing aortic commissurotomy. The paper speed was 2.5 mm. per second, the speed at which the pulse is best seen. At the points on the tracing marked by arrows a premature contraction or a burst of extrasystoles took place. The change in the tracing that occurred with each episode indicates a change in cardiac stroke output with each premature beat.

The speed with which the capillary bed refills when it is momentarily blanched by pinching or by pressure has long been applied as a clinical method of assessing the efficiency of the peripheral circulation. At

Fig. 1. The uppermost tracing is the electroencephalogram, the middle tracing, the electrocardiogram, and the lower tracing, the ear oximeter. The paper speed was 2.5 mm. per second. Each of the small squares is 5 mm. by 5 mm. The double line at the top of the oximeter tracing represents 100 per cent oxygen saturation, and the lowest line approximately 86 per cent saturation. Slurs in the oximeter pulse occurred during periods of extrasystoles as seen on the electrocardiogram.

any particular instant refill may be related to one or a combination of several factors: the efficiency of the cardiac pump, the amount of circulating blood, and the tone of the arteriolar bed. A rapid return of color to the skin or mucous membrane when momentarily blanched has been regarded as a sign of good peripheral circulation. Arterio-capillary refill (ACR) can be measured with the ear oximeter. On single scale operation, utilizing 50 mm. to represent a change of saturation from 100 to 84 per cent, when the ear is blanched by inflating the pressure capsule on the ear oximeter and the pressure is released suddenly, a curve such as shown in figure 2B is recorded. This curve we regard as a normal type. The drop from the blood-filled to the bloodless ear exceeds 10 mm. of the scale at this sensitivity. The
return to the flood-filled level takes from 0.5 to 1.5 seconds. These tracings were made at a chart speed of 10 mm. per second. Figures 2A and 2B are tracings taken on the same patient before and after a mitral commissurotomy. In figure 2A the total drop with a bloodless ear was 5 mm., while the return to the blood-filled condition required approximately 2.0 seconds. After the commissurotomy the bloodless ear provided a tracing indicating a drop of 17 mm., with a rapid return to the blood-filled state in 0.5 seconds. It is reasonable to conclude that the commissurotomy produced a significant improvement in cardiac function.

![Fig. 2 (A and B). The tracings from above downward are the electroencephalogram, ear oximeter, and electrocardiogram. Each small square is 5 mm. by 5 mm. The full scale of the oximeter record represents a change from 100 per cent to 84 per cent oxygen saturation. The paper speed was 10 mm. per second. The oximeter tracing has been altered by inflating the pressure capsule on the ear oximeter. When the ear was thus rendered bloodless, with the sudden and rapid release of pressure, the oximeter tracing returned to its former position. The significant difference before mitral commissurotomy (A) and after mitral commissurotomy (B) is evident.](image)

An interesting record in which a free floating thrombus in the left atrium periodically obstructed the flow of blood through the mitral valve is shown in figure 3. The wavy pattern recorded by the ear oximeter (fig. 3A) in the presence of efficient and adequate tidal exchange measured with a ventilator (5) and with a concentration of oxygen at 50 per cent in the inspired air, suggested an intermittent obstruction to the flow of blood into or out of the heart. At cardiotomy a free floating clot was removed from the left atrium and a very tight

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mitral valve was widely opened. An immediate leveling of the oximeter curve (fig. 3B) occurred.

The electroencephalogram has been regarded as a sensitive indicator of oxygen want. We have seen a number of cases in which the

![Fig. 3 (A and B). The tracings from above downward are the electroencephalogram, ear oximeter, and electrocardiogram. The paper speeds were 2.5 mm. per second (A) and 25 mm. per second (B). Irregular swings occurred in the oximeter tracing before removal of clot from left atrium and mitral commissurotomy (A) and the even tracing (B) was recorded after operation. The entire scale of 50 mm. on the oximeter channel represents a change from 100 per cent to 84 per cent oxygen saturation.

oximeter was a far more sensitive indicator of serious oxygen want than was the electroencephalogram. Figure 4 (A, B, C, and D) indicates the progression of events in a case of mitral insufficiency in which a circumferential suture of the mitral ring (6) was being performed.
Figure 4A is a tracing taken before any changes occurred. Figure 4B shows a beginning fall in the oximeter tracing. As indicated in figure 4C, there was a significant fall in the oximeter reading and abnormal cardiac action developed, but the electroencephalogram remained unchanged. In figure 4D, recorded ten minutes after the incident began, the electroencephalogram showed the beginning changes associated with oxygen want. Thus, the electroencephalogram did not reflect the seriousness of the situation as readily as did the oximeter.
Fig. 4 (A, B, C, and D). The tracings are from above downward: electroencephalogram, electrocardiogram, and ear oximeter. The paper speeds were 25 mm. per second (A), 2.5 mm. per second (B), 25 mm. per second (C), and 25 mm. per second (D). The full oximeter channel represents a change from 100 per cent to 84 per cent oxygen saturation. Note the change in saturation from 100 per cent in (A) to approximately 88 per cent in (C) with no change in electroencephalogram until (D), 11 minutes after the start of the fall shown in (B).
Wood, Knutson, and Taylor (7) have shown that the ear oximeter can be used to determine the arterial blood pressure. Working with a specially designed ear piece and using only a single cell and an IR filter, they recorded an accurate tracing of the blood pressure by inflating the pressure capsule and, while slowly deflating it, reading the point at which the pulsations appear. We have found this is also possible with the single scale oximeter. In instances where, for certain mechanical reasons, it is difficult to ascertain the blood pressure with stethoscope and cuff, this alternate method can be useful. Figure 5, indicating blood pressure, was made by connecting a strain gauge into the line of the pressure capsule of the oximeter. The oximeter was on single scale operation, and the sensitivity was set so that the full 50-mm. scale represented a change of oxygen saturation from 100 to 84 per cent. In this instance the blood pressure in the brachial artery could not be obtained perhaps because of mechanical obstruction. When the patient was turned to the supine position at the end of the operation, an adequate blood pressure in the arm was immediately obtainable. It is possible that the administration of a vasopressor at the time that the blood pressure was unobtainable by conventional means might have been harmful.
Comment and Summary

We regard it as unfortunate that the opinion is prevalent that the ear oximeter is not too trustworthy an instrument. While it is true that individual determinations may not be as accurate as individual gasometric determinations, our observations have led us to believe that as a monitor of changes in oxygen saturation of the blood, as well as an indicator for changes in blood pressure, this not-too-complicated device deserves more attention. Many of the subtle changes in circulation can be detected earlier with the ear oximeter than with other clinical methods currently used.

Several instances have been cited in which the ear oximeter, utilizing the modified Wood ear piece and the Grass polygraph, revealed information not readily available by other clinical methods.

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REFERENCES