The Electrocardiogram of a Beluga Whale

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In the course of our study of the comparative anatomy and physiology of the mammalian heart, it became necessary to develop a technic to obtain the electrocardiogram of the largest mammal of all. Because of its availability, the small white Beluga whale in northern waters was the first object of this research, prior to obtaining the record of a large whale, which is our ultimate aim. This article describes the process of obtaining the electrocardiogram and presents the electrocardiogram itself.

THE relationship of heart size to heart rate and to the time intervals of the electrocardiogram, in particular to the P-R interval and the QRS duration, plays an important role in the interpretation of normal and abnormal human tracings. Having become interested years ago in comparative anatomic studies of the auriculoventricular conduction systems of the hearts of the largest mammals, the whale[1] and the elephant,[2] we took electrocardiograms of several circus elephants in 1938[3] and shortly thereafter, in 1939, conceived of the possibility of obtaining such records of the whale. Our plans for this project were partly made in 1940, but they had to be abandoned temporarily because of the advent of the Second World War.

In 1952 when we were at last presented with an opportunity to take an electrocardiogram of a whale, we already possessed certain data concerning the relationship of the size of the heart to its rate and to various time intervals in normal mammals of very different sizes[4] as shown in table 1. It remained for us to discover whether or not the largest mammal of all would fit the pattern. Moreover it was necessary to develop the technic to obtain by the use of harpoon electrodes such a record in the case of the whale, an animal which had not previously been electrocardiographed; it was for that reason that we made our first attempt on a small whale, the white Beluga, in Alaskan waters. It is of this procedure that we are writing in the present paper.

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EXPEDITION, METHOD AND EQUIPMENT

In the summer of 1952 we were able to arrange an expedition to obtain an electrocardiogram of a Beluga (white) whale, at Clarks Point, Bristol Bay, an arm of the Bering Sea, at the mouth of the Nushagak River. On Aug. 6, 1952, a herd of whales was easily located by a small airplane. The party was informed as to the location, to which a small cannery tender ("Monkey boat") carrying the operators and the equipment was quickly dispatched. The four operators and the electrical recording equipment were transferred to a 20-foot heavy duty skiff which was used for approaching and chasing the animal into shallow water before harpooning. This skiff was powered by two outboard motors, one of 10 horsepower and the other of 16. The head or barb of the harpoon was of native design (figs. 1*A* and 1*B*) and was made of Navy brass, loosely attached to a $\frac{7}{16}$-inch steel rod which was fastened in the large end of a tapered wooden shaft approximately $5\frac{1}{2}$ feet in length. To this barb, which became detached when imbedded in the animal, was fastened a $\frac{3}{16}$-inch twisted nylon rope for the purpose of holding the animal to the boat. Also attached was a shielded, insulated microphone cable with a core of copper wire strands. The cable was connected to a Sanborn photographic type of electrocardiograph (Cardiette). When an attempt was made to use a direct writing electrocardiograph (Visocardiette) by converting current from 6 V to 110 V by means of a converter, so much 60 cycle interference was recorded that the tracing was not clearly legible.

The animal was harpooned by hand ac-

cording to the method commonly employed by the natives of that area. With a single harpoon electrode imbedded in the animal's back at the approximate level of the pectoral girdle, several unsuccessful attempts were made to record an electrocardiogram. These failures were found to be due to broken connections of the cables which were insecurely fastened to the harpoon head. The barb was then modified in such a way as to fasten the cable more securely, including the wiring details, utilizing the metal shield instead of the more fragile copper core to complete the electrical connection to the galvanometer within the electrocardiograph.

The following day, after a number of varied vicissitudes of technical and mechanical nature, one of the larger male whales was singled out

TABLE 1.—*The Relationship of Heart Size to Heart Rate and to the P-R Interval and QRS Duration of Normal Mammals*

Mammal	Heart Rate	P-R Interval	QRS Duration
Mouse	620–780	0.03–0.04 sec.	0.008–0.011 sec.
Human infant (newborn)	120–140	0.08–0.12 sec.	0.04–0.06 sec.
Human adult	50–90 (av. 72)	0.14–0.21 sec.	0.07–0.11 sec.
Elephant	24–53 (av. 35)	0.28–0.41 sec.	0.12–0.18 sec.
Beluga (small whale)	12–24 (av. 16)	?? 0.32 sec.	0.09–0.12 sec.

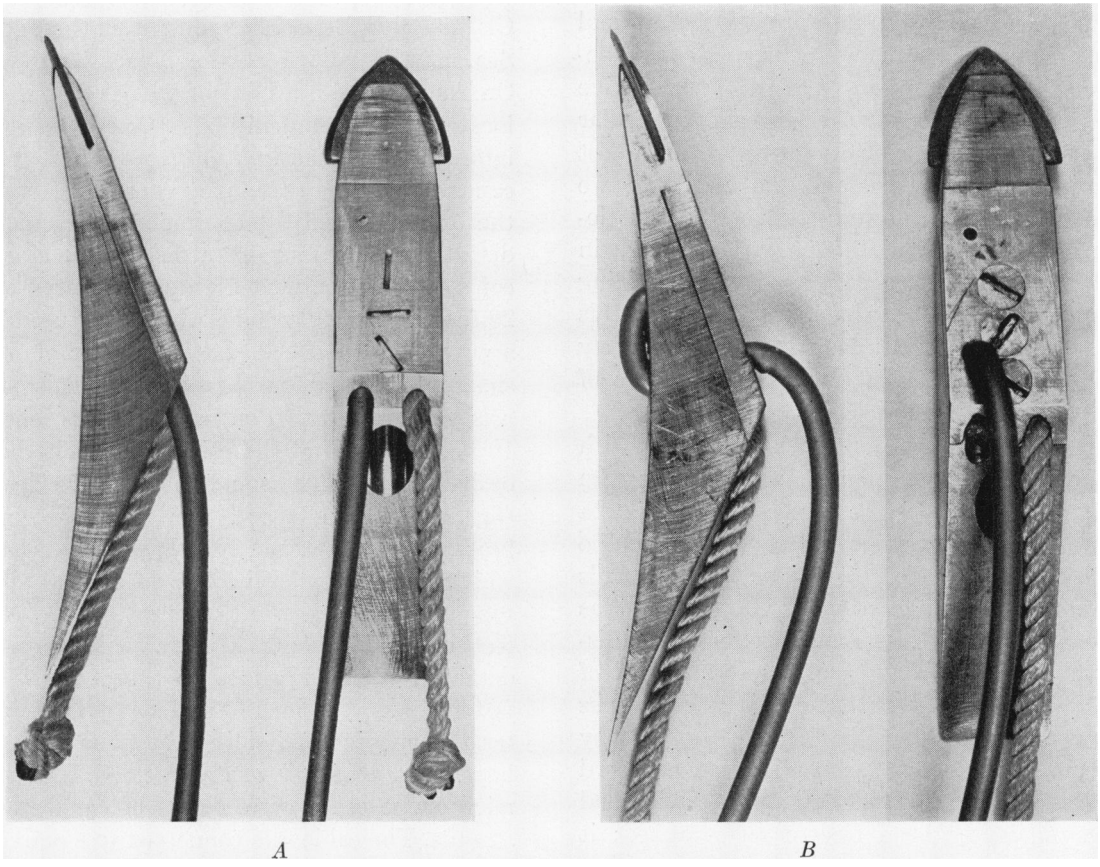

FIG. 1. (*A*) Harpoon head, original design, showing cable and nylon rope attached. (*B*) Harpoon head, modified. (The actual dimensions of the harpoon head were: length, 135 mm.; width, 23 mm.; thickness, 22 mm.)

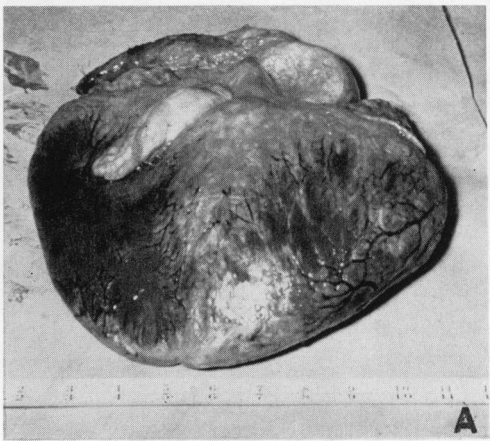

FIG. 2(*A*) (*Right*) Heart of Beluga whale, ventral aspect. (*B*) (*Above*) Heart incised to show the upper parts of the chambers of both ventricles with their respective auriculoventricular valves.

and pursued. A single ordinary harpoon head was first inserted for the purpose of holding the animal to the boat while it was alternately diving, blowing and frantically trying to escape. Then a second harpoon head, this time an electrode, was inserted into the back at the level of the pectoral girdle. This attempt was made to use a single harpoon as a unipolar electrode, with the sea water and a copper plate suspended over the side of the boat to complete the circuit. Despite electrical connections which seemed adequate, no movement of the shadow of the galvanometer beam could be detected. Therefore, a second harpoon electrode was inserted about half way down the animal's back approximately three feet from

the first electrode. With such a connection (grossly approximating lead III), definite low amplitude deflections of the galvanometer beam were observed. The standardization was increased from 1 cm. per millivolt to about 1.2 cm. per millivolt. These heartbeats were recorded intermittently over a period of approximately 30 minutes. The wounded animal was then killed by rifle fire into its head and towed to the cannery for partial dissection and utilization as food by the inhabitants of the native village.

The whale from which the electrocardiogram was made was considered to be fairly large for a Beluga. The over-all length was 14 feet. Facilities for weighing the animal were not available; however, the estimate by a number of fishermen and natives was 2500 pounds (1136 Kg.).

TABLE 2.—*Measurements of a Male Beluga Heart*

Weight of heart (fresh specimen)	2722 Gm.
Transverse diameter of heart (at base)	18.5 cm.
Right ventricular wall thickness	6 mm.
Left ventricular wall thickness	20 mm.
Circumference of right atrioventricular ring	22.5 cm.
Circumference of left atrioventricular ring	18.5 cm.
Diameter of pulmonary artery	5 cm.
Diameter of aorta	5 cm.

The heart of this animal had the general appearance and characteristics of cetaceans, being broad and flattened from top to bottom, the length being somewhat less than the width at the base. It will be noted that the apex of the heart is formed by both right and left ventricles which is true also of other marine mammals such as the porpoise. After being photographed (fig. 2*A*), the specimen was frozen for further study. Later the heart was incised to show the upper parts of the chambers of both ventricles with their respective auriculoventricular valves (fig. 2*B*).

The dissection of the hearts of male and female Beluga whales of approximately the same size, revealed structural features similar to those of other mammalian hearts. The coronary arteries and veins were similar in location, size, thickness of major branches, and distribution, to those of the human heart. The foramen ovale was closed in both specimens.

For more detailed anatomic description of the Beluga heart, the reader is referred to Watson and Young's[9] paper on this subject.

DESCRIPTION OF THE ELECTROCARDIOGRAM

The electrocardiogram which we obtained from this adult male Beluga whale is shown in part in figure 3. The first harpoon electrode was at about the level of the pectoral girdle near the midline, the second about the mid-portion of the back. These positions were considered to correspond to the left arm and the left leg respectively. Thus we believe we have utilized a lead roughly comparable to lead III. The excursion of the galvanometer was standardized so that 1 mv. was equivalent to 1.2 cm.

The chief features of the electrocardiogram were its bradycardia and the low amplitude of the complexes. Due to somatic interference, many of the complexes are so distorted as to render them unsuitable for measurement. At times the record was quite steady, evidently when the whale was less active; at other times there was much gross movement of the tracing doubtless due to much more bodily activity, but the heartbeats were always evident. The rate varied from 12 per minute or a little less up to 24; much of the time during the long tracing taken it was 16 or 17.

The P waves are very poorly defined throughout the entire record, which may be due to the fact that this lead was dorsal in position, a long way from the heart and with the electrodes not very far apart. Many beats showed no evidence of any P waves at all but here and there are to be seen very small inverted movements of the tracing about 0.3 second before the QRS waves, and these may or may not represent auricular activity. It is possible that there was actual auricular standstill with a varying independent rate of the auriculoventricular nodal pacemaker producing ventricular contractions alone. The initial deflection of QRS is downward and does not exceed 1 mm. This is followed by an R wave, the height of

which varies between 3.0 and 4.0 mm. The RS-T segment is very slightly elevated (not more than 1 mm.) and ends in a rather sharp inversion of the T wave. The duration of QRS varies between 0.09 and 0.120 second. The Q-T interval varies between 0.36 and 0.40 second. The T wave is definitely inverted, but is never more than 1 to 1.5 mm. deep. (These measurements are not corrected for standardization which was 1 mv. equivalent to 1.2 cm.)

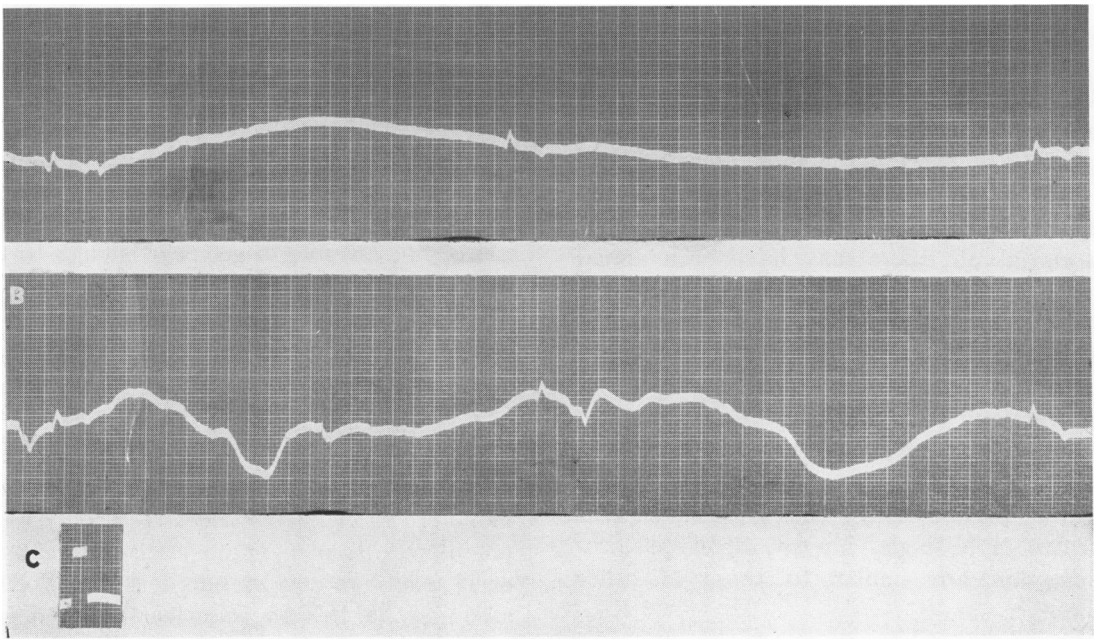

FIG. 3. (*A*) Dorsal lead electrocardiogram of Beluga whale showing a fairly smooth baseline at a time when there was relatively little general muscular activity. There are three heartbeats at a rate of 12.5 per minute. See text for full description. (*B*) Dorsal lead electrocardiogram of the Beluga whale during greater muscular activity. (*C*) Standardization: 1 mv. equals 1.2 cm. Time equals 0.20 and 0.04 second.

DISCUSSION

It is assumed that the whale studied was in good health as evidenced by his community behavior and by the postmortem observations. The electrocardiogram was of a wounded and excited animal which was desperately diving and thrashing about, towing a boat of the estimated weight of 1200 pounds through cold, brackish salt water. There was considerable variation in the R-R interval. This change of rate can quite possibly be attributed, as suggested by the studies of Irving and his associates[5–8] on the seal and on man, to a vagal effect incident to diving. Other investigators have shown that in diving mammals, when it is necessary to suspend respiration and there is a necessity to curtail oxygen consumption or conserve oxygen stores, the heart rate may be reduced to as much as one tenth, the circulation through the muscles is greatly reduced apparently by vasoconstriction, and lactic acid accumulates in the muscle but not in the general circulation. Furthermore, it has been shown that simultaneously the blood flow to the brain is unchanged or increased. It seems reasonable to assume that the frequent or perhaps complete failure of the P waves to appear can be a vagal effect also. The factor of diving may explain the slower rate (15 per minute) in the Beluga whale while submerged as compared with the higher rate (30 per minute) in the elephant whose heart is much larger.

Our inability to obtain a unipolar type electrocardiogram is not clearly explained,

but might possibly be accounted for on the basis of the reduced salt content of the mixture of sea water and muddy water from the river, rather imperfect grounding facilities aboard the skiff, and heavy insulation of the whale itself.

The main value of this experiment is the development of a technic for securing tracings on whales in their native habitat. It is anticipated that this method, or some modifications thereof, will be employed on similar animals of greater size and correspondingly larger hearts.

Summary

A dorsal lead electrocardiogram has been taken of an adult male Beluga whale in Alaskan waters for the first time. It showed a heart rate of 12 to 24 while the animal was engaged in excited and strenuous effort most of the time. The auricular activity was obscured if present at all; there may have been actual standstill of the auricles with escape of the auriculoventricular nodal pacemaker. The QRS and T waves were of low voltage, probably due to the remoteness of the electrodes from the heart and their proximity to one another.

Thus it has been shown that it is possible to obtain an electrocardiogram of a whale in its natural environment. The general characteristics of a single, bipolar, dorsal electrocardiogram are similar to those of other mammals.

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Addendum

In January, 1953, at the kind invitation of the Scripps Oceanographic Institute of the University of California at La Jolla, and with their help and that of the United States Navy, and of Francis (Jeff) Davis, the authors attempted to obtain an electrocardiogram of one of the large gray whales, 30 to 50 feet long, off the coast of Southern California north of San Diego, using a modification of the technic that was successful in the case of the Alaskan white whale. Although several gray whales were encountered and approached, it was not possible to get near enough to use the electrodes thrown by hand harpoon. Another attempt will be made at a later date by the use of different technics.

Sumario Español

En el curso de nuestro estudio de la anatomía comparativa y la fisiología del corazón mamífero se manifestó necesario el desarrollar un método de obtener un electrocardiograma en el mamífero más grande de todos. Por ser asequible, la ballena pequeña Beluga de los mares del norte fué el primer objeto de este estudio, antes de obtener un trazado de una ballena grande que es el objetivo final del estudio. Este trabajo describe el proceso de obtener el electrocardiograma y presenta también el trazado obtenido.

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