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Development and Physiological Assessments of Multimedia Avian Esophageal Catheter System

(鳥類用マルチメディア食道カテーテルの開発と生理学的な評価)

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2. Summary

In order to recognize the autonomic nerve condition of birds, multimedia esophageal catheters were developed and confirmed the physiological assessments to measure RR interval of the ECG and blood pressure approximated scientifically with angular velocity while anesthetized, at rest, and in flight. The electrophysiological data obtained by this study provided especially the state of the avian autonomic nervous system activity, thereby identifying the health condition of an individual bird. If the change of the RR interval was small, isolation or screening from the group can be performed to prevent pandemics of avian influenza. This catheter shall be useful in analysing avian autonomic systems, performing screening, and planning positive policies regarding massive avian influenza infections.

3. Introduction

Our research team attached wireless packet transceivers equipped with three-axis angular velocity sensors on the backs of whooper swans, then released the birds into the wild. In the present study, to gather basic data, a multimedia esophageal catheter system was developed, it was equipped with both differential ECG electrodes and angular velocity sensors incorporated into the transceivers attached to the swans.

In attempting to screen for avian influenza infections, it is imperative to monitor not just breathing patterns associated with pneumonia, but also the autonomic nerves, including the circulatory system. This paper describes a special esophageal catheter incorporated into a multimedia system to gather circulatory system data and to analyze and assess the physiological features of birds.

Many birds have a crop in the lower esophagus, comparable to a diverticulum. However, crows lack this crop. This allowed us to insert an esophageal catheter relatively easily with no special equipment. In humans, the thoracic esophagus runs next to the posterior mediastinum; in birds, the esophagus runs next to the left atria. This means that vibrations generated by cardiac pulsation have significant impact on esophageal catheters.

In birds, the thoracic and abdominal skeletal muscles act as a diaphragm to control the air sacs. Breathing is generally involuntary, but can be controlled voluntarily when needed. In most cases, the skeletal muscles are believed to be controlled by the brainstem. At the center of the thoracic cavity, the EMG values anticipated are near zero because the EMG from skeletal muscles is circumferential (0 to 360 degrees). When performing ECG in the esophagus, we can have a benefit of noise reduction due to its topological position.

In birds, the esophagus runs adjacent to the left atrium. In other words the vibrations of cardiac pulsation have significant impact on an esophageal catheter. For this reason, we performed measurements using an angular velocity sensor.

Regarding the catheter, the angular velocity sensor of the esophageal catheter was secured by applying an adhesive to the tip and at 60 mm from the oral-side end. The differential ECG electrodes were 10 mm in width and were positioned 10 mm apart to ascertain catheter depth based on ECG waveforms. These +1 and +2 electrodes were designed mainly to measure the ventricle and atrium, respectively. For the angular velocity sensor, a reference sensor was implanted 60 mm from the oral-side end to eliminate the effects of up and down movements during flight and isolate cardiac beats.

With chickens, we induced inhalation anesthesia with isoflurane for continuous direct blood pressure monitoring on the axillary artery. Carrion crows were allowed to fly outdoors, and local

anesthesia was administered to attach the electrodes. The subjects were chickens, pigeons , and carrion crows.

The main three methods of examination were as follows;

- A. Comparison of esophageal catheter and thoracic wall ECGs. Using seven carrion crows, we compared esophageal catheter ECG and thoracic wall ECG to ascertain the noise reducing effects of the esophagus on EMG.
- B. Correlation between blood pressure and esophageal catheter angular velocity.
- C. Correlation between catheter depth and angular velocity.

Results were as follows;

A. Comparison of signal-to-noise ratios between esophageal catheter and thoracic wall ECGs. The signals were obtained with the thoracic wall ECG (electrodes on the left and right thoracic walls, neutral electrode on the back) and the esophageal catheter ECG (electrodes inside the esophagus). Birds lack diaphragms and use air sacs like bellows. Since thoracic wall muscles are always in tension to allow control of air sac tension, EMG interfered with thoracic wall ECG. In contrast, the esophageal catheter ECG was largely free of EMG interference. An improvement of about 8 dB was found for the S/N ratio with the esophageal catheter ECG compared to the thoracic wall ECG.

B. Correlation between blood pressure and esophageal catheter angular velocity.

After inducing isoflurane anesthesia and with spontaneous respiration, a pharmaceutical agent was intravenously administered to introduce fluctuations in blood pressure; then the angular velocity of the esophageal catheter and direct arterial blood pressure were measured over time. The results demonstrated an extremely high correlation coefficient, R^2 of 0.93. Short-cycle variations in the RR interval represented respiratory changes, and large up-and-down changes in the RR interval were synchronous with blood pressure changes. Both are under sympathetic and parasympathetic nerve control. In other words, the results indicated that relative changes in blood pressure can be ascertained by measuring RR intervals. Moreover, with carrion crows that were allowed to fly outdoors, the results showed that the blood pressure more than doubled from 90 to 210 mmHg before and after flight. During the actual flight, CVRR fell to less than 1%, pointing to the predominance of the sympathetic nerves in flight. We observed a strong correlation between blood pressure and RR intervals with resting birds and birds in flight.

C. Catheter placement.

The oral-side electrode (“+2”) strongly detected negative bipolar P waves when the electrode was above the atrium. When R waves were negative, the electrode was caudal to the artery. ST increased when the electrode was implanted caudal to the ring-shaped coronary artery. These findings clearly indicated that ECG can be used to determine the depth of esophageal catheter placement. The relationship between ECG (one differential to remove direct current components) and angular velocity, indicating the time difference between the start of the R wave and the first peak of angular velocity. ECG data represents electrical movement; the peak angular velocity indicates the maximum axial rotation of the esophageal catheter associated with the force of blood forced out by the pulsing heart. The reciprocal of the slope of these two lines (average: 1.47 cm/sec) is proportional to the flow rate of blood pumped out to a large vessel by pulsation. If the distance to the axillary artery is 4.5 cm, we would expect the blood to reach the root of the greater pectoral muscle in a little over 3 seconds.

From the standpoint of p waves, RR interval variations can be separated into RP and PR intervals. The RP interval includes the SA node, while the PR interval includes the AV node. Thus, the SA node involves both sympathetic and parasympathetic nerves, while the AV node involves neither.

Visceral vessels are controlled by both sympathetic and parasympathetic nerves. While the peripheral vessels are clearly controlled by sympathetic nerves, it is unknown whether peripheral vessels are controlled by parasympathetic nerves.

4. Discussion

The small magnet and the analog magnetic field sensor set on thoracic wall on either side, and differential electrocardiogram electrodes (a neutral point is the center of the back) on almost the same position, we can record the temporal electrical change received by the magnetic field sensor. Then by applying FFT(Fast Fourier Transform) of this magnetic potential, a frequency spectrum graph could be obtained. When the inverse Fourier transform was carried out on of the high frequency component (not less than 20 Hz), we obtain the temporal electrical change found the high frequency curve.

Since the potential of a magnetic field is the inverse proportion to the square of distance, this change can be the change of the square of the distance between the thoracic wall, and we think that this change depended on muscles vibrations. Both of the ECG and high frequency curves of the magnetic field have a strong relationship. As both graphs show a strong relationship, so we are sure that the thoracic walls of the birds are in a state of continuous burst strain in order to obtain the control of air sacs.

According to an ornithology textbook by Harrison, the histological impulse conduction pathway of ECG in mammals is that, after the AV node, the His bundle runs downward through the interventricular septum. In birds, the His bundle originates from the cardiac wall, runs down the subepicardial region, and turns into Purkinje fibers to reach the subepicardial and myocardial regions and ultimately reaches the endocardium. This suggests that the conduction of the ventricular wall impulse for birds takes the opposite path from that in mammals, generating a force that squeezes from the lateral to medial sides. Based on the catheter placement, P and R waveforms vary depending on the position. The patterns of negative R waves for birds were in striking opposition to those in mammals, demonstrating that the impulses are delivered from the surface of the heart toward the endocardium (flow along the Purkinje cells' fiber is reversed). To our knowledge, no previous report proves Harrison's electrophysiological ECG impulse conduction system.

From the standpoint of p waves, RR interval variations can be separated into RP and PR intervals. The RP interval includes the SA node, while the PR interval includes the AV node. Thus, the SA node involves both sympathetic and parasympathetic nerves, while the AV node involves neither. Visceral vessels are controlled by both sympathetic and parasympathetic nerves. While the peripheral vessels are clearly controlled by sympathetic nerves, whether peripheral vessels are controlled by parasympathetic nerves is unknown.

An esophageal catheter was implanted in a carrion crow, and then the bird was released from our hands, allowing it to flight off.

RR intervals before and after flight.

High-frequency respiratory variations and autonomic nerve variations were seen before the flight; once the crow was in flight, these variations were significantly suppressed (less than 1% CVRR). This RR interval control suggests flapping is achieved not only by motor nerves that control skeletal muscles but also by the contraction of vessels in the heart and entire body. In humans, this pattern of sympathetic nerve dominance is comparable to the physiological state generated by a 100-meter sprint. Birds are capable of maintaining this state of sympathetic nerve dominance. In our research, sympathetic and parasympathetic nerve control could be deduced by measuring RR intervals using an angular velocity sensor. In birds with avian influenza, inflammation causes mast cells to release chemical mediators, such as histamine, to elevate vascular permeability. Since autonomic nerve control is negatively affected from an early stage, the early screening of infected birds may be possible.

At present, the Ministry of Agriculture, Forestry and Fisheries of Japan takes action only when domestic fowls die and retroactively acts to stop transferring or destroying nearby domestic fowls. However if autonomic nerve abnormalities can be detected before the level of antibodies increases, suspected birds can be isolated early. If infected birds can be isolated early, herd infections can be prevented, and we believe that ICT can be a breakthrough technology for non-contact avian autonomic nerve monitoring.

5. Conclusion

This paper developed esophageal catheters for use with birds to record ECG and esophageal angular velocity as measured during anesthesia, while resting, or in flight. The ECG and angular velocity measurements made with these catheters had the characteristics listed below, suggesting that the catheters would be useful in screening for avian influenza:

1. Esophageal catheters offer topological advantages that eliminate the effects of EMG.
2. A strong correlation exists between blood pressure and angular velocity of the axial rotation of the esophageal catheter.
3. The impulse conduction pathway passing through the ventricle (Purkinje fibers) for birds is opposite to that for mammals.
4. The sympathetic nerves are overwhelmingly predominant for birds in flight, and RR interval variations are strongly suppressed.
5. ICT technology capable of monitoring autonomic nerve activity in birds may be useful in screening for avian influenza.

The electrophysiological data obtained by this study provided especially the state of avian autonomic nervous system activity, so the individual health condition of birds can be determined. If the change of the RR interval was small, then isolation from the group can prevent the pandemics of avian influenza. This catheter shall be useful for the analysis of avian autonomic systems, and also to perform screening, leading the way to put into place positive policies to control massive avian influenza infections.