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Dolphin hearts have the same characteristics as human

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【Abstract】

Previous studies of dolphin electrocardiograms showed that they are mainly composed of increased negative waves similar to ungulates.

The electrocardiogram waveform is determined by the distribution of the location of the Purkinje fibers.

Based on the waveform of the dolphin electrocardiogram, Hamlin predicted that the distribution of

Purkinje fibers would be within the ventricular muscle, as in ungulates.

In this study, bottlenose dolphin heart were observed both visually and histologically, and the effects

of Purkinje fiber distribution and cardiac morphology on electrocardiogram waveforms were

considered.

This study showed that the Purkinje fibers of dolphins run just below the endocardium as in humans,

dogs, and cats, whose electrocardiograms show mainly positive waves.

When the cardiac morphology of dolphins was observed carefully again, the right ventricle was

extremely dilated compared to terrestrial mammals.

In human recreational divers, right ventricular dilatation is induced by diving.

We hypothesized that the dolphin's heart is in a similar state to that of right heart dilatation in terrestrial

animals.

21 The dolphin electrocardiogram waveform is considered to be due to right axis deviation.

22 Based on the above, we concluded that the dolphin electrocardiogram waveform was due to its living

23 in water.

24 We found that the dolphin is genetically related to the ungulates, especially the hippopotamus, but that

25 their hearts have evolved differently.

26 **【Introduction】**

27 There are no reports of circulatory physiological studies of small cetaceans.

28 Previous studies of dolphin electrocardiograms showed that they are mainly composed of increased

29 negative waves similar to ungulates ^{1,2}.

30 Purkinje fibers in ungulates are distributed from the endocardium into the myocardium.

31 The stimulation impulse emitted from the sinus node, atrioventricular node, and his bundle to the

32 Purkinje fibers in the myocardium.

33 Then, the stimulation impulse emitted from the end of the Purkinje fibers to the cardiomyocytes.

34 The impulses that reach the cardiomyocytes gradually spread throughout the ventricle via gap junctions

35 between cardiomyocytes.

36 In the case of ungulates, stimulation impulses emitted from the periphery of Purkinje fibers in the

37 ventricular myocardium propagate to the endocardial side of the heart's center.

38 Therefore, in the case of ungulates, the vector of stimulation impulses goes from the apex side to the

39 base side of the heart.

40 Considering the whole heart, the vector of stimulation impulses is from the apex to the base of the
41 heart.

42 That is, the vector indicates the cranial direction.

43 A-B (apex-base) induction is used in electrocardiography of large animals.

44 This method measures stimulation impulses from the acromion on the longitudinal extension of the
45 heart to the sternum.

46 However, since the direction of the ungulate vector is the opposite from the sternal side to the acromion
47 direction, the electrocardiogram waveform shows mainly negative waves.

48 Thus, the electrocardiogram waveform is determined by the distribution of the location of the Purkinje
49 fibers.

50 Based on the waveform of the dolphin electrocardiogram, Hamlin predicted that the distribution of
51 Purkinje fibers would be within the ventricular muscle, as in ungulates ¹.

52 There are few reports of histological studies of the cardiac conduction system , which is the cause of
53 the small cetacean electrocardiogram waveform.

54 Scanning electron microscope (SEM) examination has enabled visualization of the three-dimensional
55 network of Purkinje fiber in whales, seals, primates, and rodents.

56 Purkinje fibers of whales and dolphins consisting of 2-8 oval cells form some minute networks,
57 but the intramyocardial distribution of Purkinje fibers has not been clearly demonstrated ³.

58 There has been no definitive report of the relationship between Purkinje fiber distribution and the

59 electrocardiogram waveform in small cetaceans.

60 In this study, bottlenose dolphin ventricles were observed both visually and histologically, and the
61 effects of Purkinje fiber distribution and cardiac morphology on electrocardiogram waveforms were
62 considered.

63 **【Material and Method】**

64 In this study, we used the hearts of three bottlenose dolphins (Fig.1).

65 These dolphins died in domestic aquariums due to causes other than heart disease (No. 1-3).

66 Each heart was formalin fixed.

67

68

69 Fig.1 Heart of Bottlenose Dolphin: Section at the lower part of the aortic valve.

70 The heart was amputated at the transverse short axis at the lower aortic valve.

71 The thickness of both ventricular walls and the diameter of both ventricular cavities were measured.

72 In order to compare the heart morphology of terrestrial mammals, the same site was measured in pig

73 hearts (No. 4 - 6).

74 Three healthy adult female micro-mini pig weighing between 25 ~ 30 kg hearts were purchased

75 from Fuji Micra, Inc. Shizuoka, Japan.

76 The hearts used in this study was obtained from pigs euthanized for other purposes.

77 Histological observations were performed focusing on the interventricular septum and the free wall of

78 the left ventricle.

79 Paraffin embedding, slicing, and Masson's trichrome staining were performed.

80 We followed the ARRIVE guidelines (<https://arriveguidelines.org/>) for all our methods.

81 **【Result】**

82 Macroscopic observation : In dolphin hearts, the right ventricular cavities was extremely dilated

83 compared to pig hearts (Fig.2) (Fig.3) (Table.1).

84 Fig.2 Dolphin heart.

Fig.3 Pig heart.

85

86

Table.1

87

The thickness of both ventricular walls and the diameter of both ventricular cavities were measured in the transverse short axis plane. (mm)

88

	①Right ventricular free wall	②Right ventricular cavity	③Ventricular septum	④Left ventricular cavity	⑤Left ventricular free wall
Dolphin	10	43	22	40	17
Swine(n=3)	10.6	9.6	7.3	21.6	13.3

89

Histological observation: In dolphins, Purkinje fibers ran just below the endocardium, and no Purkinje

90

fibers were found in the myocardium and on the epicardial side (Fig.4).

91

In pigs, Purkinje fibers ran just below the endocardium and in the myocardium.

92

93

Purkinje(P)
Endocardium(E)
Cardiac ordinary muscle(M)

94

Fig.4 Purkinje fibers run just below the endocardium in the dolphin heart.

【Discussion】

Ungulates show a negative S wave because Purkinje fibers are distributed deep in the ventricular muscles⁴.

Previous studies have shown that dolphin electrocardiograms are mainly composed of large negative S waves, similar to ungulates^{1,2}.

Therefore, Hamlin hypothesized that Purkinje fibers of dolphin are distributed in the myocardium¹.

However, the present study showed that the Purkinje fibers of dolphins run just below the endocardium as in humans, dogs, and cats, whose electrocardiograms show mainly positive waves.

The mean electrical axis of humans, dogs and cats is in the caudal direction; therefore, the electrocardiogram waveform is mainly a positive wave^{5,6,7}.

On the other hand, the electrical axis of the ungulates is in the cranial direction; therefore negative waves predominate in the electrocardiogram waveform (Fig.5) (Fig.6).

Fig.5 Differences in Purkinje fiber running between species

Fig.6 ECG Comparison

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109 The Purkinje fibers of dolphins were found to run just the endocardium, but the electrocardiogram
110 waveform showed a negative downward wave.

111 The results of this histological observation are inconsistent with previous reports.

112 When the cardiac morphology of dolphins was observed carefully again, the right ventricle was
113 extremely dilated compared to terrestrial mammals.

114 In human recreational divers, right ventricular dilatation is induced by diving.

115 It has been reported that changes in right ventricle morphology cause right axis deviation on the
116 electrocardiogram ⁸.

117 As described above, the water pressure due to diving causes right ventricular overload ⁹.

118 In humans, dogs, and cats with Purkinje fibers distributed just below the endocardium, when right
119 ventricular dilatation occurs due to right heart disease, the electrocardiographic axis shifts to the right
120 axis, and negative waves predominate ¹⁰.

121 As an aquatic animal, dolphins are always exposed to water pressure, which tends to cause blood

122 retention in the right ventricular system.

123 Therefore, we predicted that right ventricular overload causes dilation of the right ventricular cavity.

124 We hypothesized that the dolphin's heart is in a similar state to that of right heart diseases in terrestrial
125 animals. The dolphin electrocardiogram waveform is considered to be due to right axis deviation. This
126 is caused by dilation of the right ventricle due to water pressure.

127 Based on the above, we concluded that the dolphin electrocardiogram waveform was due to its living
128 in water.

129 We found that the dolphin is genetically related to the ungulates, especially the hippopotamus, but that
130 their hearts have evolved differently ¹¹.

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