A Large Whale Heart

By George J. Race, M.D., W. L. Jack Edwards, M.D., E. R. Halden, M.D., Hugh E. Wilson, M.D., and Francis J. Lubel, M.D.

The comparative cardiac anatomy and function of mammals larger than man has been the subject of several prior studies. However, the opportunity to secure the very large heart of an adult male sperm whale (Physeter catodon) weighing approximately 47,700 pounds and measuring 44 feet in length occurred during a visit to a whaling factory in Paita, Peru, in connection with a study of the cortex of the adrenal gland of large mammals. The whale was taken off the coast of Peru, latitude south 56 degrees 15 minutes, longitude west 81 degrees 32 minutes, in water of 21.2 degrees Centigrade, by a Peruvian whaling company.* The animal was dissected 18 hours after death, and the heart preserved by freezing in dry ice until formaldehyde injection and submersion could be accomplished.

General Considerations. The heart including 1 foot of proximal aorta weighed 256 pounds or 116 Kg. when removed. The animal's weight was calculated by multiplying length by diameter squared divided by 2, the usual method of the whaling company, and was 21,708 Kg.; length was 13.4 M. and the diameter was 1.8 M.

A second heart weighing 1,600 Gm. was obtained from a fetus in utero, with a length of 2.1 M., diameter of 0.45 M., and calculated weight of 212 Kg. The fetus was discovered in a female whale, accidentally killed, that measured 9.4 M. in length, 1.6 M. in diameter, and had a calculated weight of 12,032 Kg.

The whale heart is a large globular organ lying in the normal position for all mammals.

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*Cía. Ballenera del Norte, an affiliate of Archer-Daniels-Midland Co., Minneapolis, Minn.

Fig. 1 Top. Adult whale, right ventricle, and tricuspid valve, 15-inch ruler under moderator band.

Fig. 2 Middle. Adult whale, right main coronary artery distal end (15-inch ruler).

Fig. 3 Bottom. Adult whale aortic valve and opened aorta. Innominate artery folded back, not opened. Note ostium of left coronary in middlower part of photograph.
A LARGE WHALE HEART

Fig. 4 Top. Adult whale, diagram of coronary arterial system.

Fig. 5 Bottom. Adult whale, diagram of cardiac venous system.

In the fetal heart a bifid apex was noted, while the adult heart had a single apex as in the human. The pericardium measured 0.5 cm. in thickness. The epicardium was smooth; a minimal amount of fat was visible in the atrioventricular sulcus. Both hearts were opened in the usual manner. The adult right ventricle (fig. 1) contained an estimated 10 L. of blood. No evidence of atherosclerosis or other disease was noted in the coronary arteries (figs. 2 and 3). Table 1 shows the measurements and their comparison with average human values.

Coronary Artery and Venous Anatomy.

The distribution of coronary arteries and veins are illustrated in figures 4 and 5. The general similarities of whale and human circulatory anatomy can be noted, although there are several differences.

![Diagram of coronary arterial system](Image)

Table 1.—Anatomic Measurements of Hearts and Calculated Weight Ratios

<table>
<thead>
<tr>
<th></th>
<th>Adult whale</th>
<th>Fetal whale</th>
<th>Average adult human</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (Kg.)</td>
<td>27,708</td>
<td>212</td>
<td>75</td>
</tr>
<tr>
<td>Height weight (Kg.)</td>
<td>116</td>
<td>1.6</td>
<td>0.325</td>
</tr>
<tr>
<td>Left ventricular thickness (em.)</td>
<td>6.3-12.5</td>
<td>2.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Right ventricular thickness (em.)</td>
<td>3.1</td>
<td>1.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Tricuspid circumference (em.)</td>
<td>75</td>
<td>15</td>
<td>12.3*</td>
</tr>
<tr>
<td>Pulmonary circumference (em.)</td>
<td>63</td>
<td>10</td>
<td>7.1*</td>
</tr>
<tr>
<td>Mitral circumference (em.)</td>
<td>68</td>
<td>9.5</td>
<td>11.0*</td>
</tr>
<tr>
<td>Aortic circumference (em.)</td>
<td>62</td>
<td>9</td>
<td>7.0*</td>
</tr>
<tr>
<td>Diameter coronary sinus (em.)</td>
<td>6.5</td>
<td>1.4</td>
<td>.8</td>
</tr>
<tr>
<td>Diameter left coronary ostium (em.)</td>
<td>4.6</td>
<td>0.25</td>
<td>.3</td>
</tr>
<tr>
<td>Diameter right coronary ostium (em.)</td>
<td>5.5</td>
<td>0.5</td>
<td>.4</td>
</tr>
<tr>
<td>Diameter aorta (em.)</td>
<td>20</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Average muscle fiber</td>
<td>11.0</td>
<td>6.0</td>
<td>10.7</td>
</tr>
<tr>
<td>(diameter in microns)</td>
<td>(Range 6.3-14.2)</td>
<td>(Range 5.5-7.9)</td>
<td>(Range 7.9-13.4)</td>
</tr>
<tr>
<td>Heart weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight Ratio</td>
<td>.47%</td>
<td>.61%</td>
<td>.43%</td>
</tr>
<tr>
<td>Cardiac output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight Ratio</td>
<td>2.1%</td>
<td>—</td>
<td>5.3%</td>
</tr>
</tbody>
</table>


The left circumflex artery gives off a branch, called a left marginal branch in figure 4, which is actually larger in diameter than the continuing left circumflex. This supplies the major portion of the lateral mass of the left ventricle. Another difference is in the manner of anastomosis between the left circumflex artery and distal right coronary artery posteriorly; in the whale these arteries communicate by multiple, very small branches (fig. 4). The anterolateral right ventricle is supplied by a branch of the right coronary artery, the right marginal artery, originating 9 cm. from the ostium; the diameter of this branch is equal in size to the posteriorly cours-
ing continuation of the right coronary. Multiple atrial branches, 1 cm. in size, from both coronary arteries were found.

There was no evidence of atherosclerosis or calcification in any arteries.

The fetal whale heart exhibited a disproportionately large right coronary artery, which directly anastomosed through a large artery with the left circumflex. The major ventricular myocardium branches of the left circumflex and right coronary arteries so prominent in the adult were relatively smaller in the fetal heart.

No major differences in venous return between whale and human heart were noted except for a large additional left ventricular branch (fig. 5).

Conduction System. By means of the method outlined by Widran and Lev, a specific conduction system could not be grossly or microscopically differentiated. Microscopic sections of tissue from the area in which the atrioventricular node and bundle was sought showed extensive autolysis.

Microscopic Anatomy. Microscopic study of the adult whale heart from better preserved areas showed syncytial, striated muscle with fibers averaging 11 μ in diameter (figs. 6 and 7 and table 1). It is of interest to note the small average diameter of the muscle fibers in the fetal whale heart (fig. 8). The human fetal heart is quite cellular, has small fibers, and enlarges by increase in fiber diameter after birth. The same mechanism would appear to be present in the whale, although there would also have to be an increase in total numbers of myocytes as well as in fiber size to obtain the total mass of the adult whale heart.

Histologic sections of the adult whale aorta showed extremely thick, interlacing bundles of elastic and fibrous tissue (figs. 9-11). Smooth muscle was not demonstrated by trichrome stains except in smaller arteries of approximately 1 to 2 cm. diameter. These arteries showed a mixture of smooth muscle and elastic tissue similar to the human aorta. Smaller arteries were predominantly muscular as is the case in other mammals. There was no microscopic evidence of atherosclerosis, intimal fibrosis, calcification, or arteriolosclerosis.

Estimated Cardiac Output and Comparisons. A comparison of ratios of heart weight to body weight of adult whale, whale fetus, and average human can be readily made from
table 1. Since these ratios in table 1 are relatively constant, the linear increase of heart weight with increasing body weight in mammalian species is suggested.

An estimate of cardiac output in the adult whale was obtained in the following manner. The length of the left ventricular cavity before fixation from base to apex was 49 cm., and the ventricular cavity radius at the base was 21 cm. By means of the formula for a hemi-ellipsoid, \( V = \frac{4}{3}abc \), the left ventricular volume of the adult whale was found to be 45.3 L. White et al.\(^{8-10}\) have reported that the heart rate of a small Alaskan Beluga whale, estimated to weigh 1,136 Kg., varied from 12 to 24 beats per minute after harpooning. Assuming that the sperm whale has a slightly slower cardiac rate because of its much greater size (21,708 Kg.) a figure of 10 beats per minute was chosen arbitrarily, since the actual heart beat was not measured. At this assumed rate, the cardiac output would be a staggering 453 L per minute with assumed complete ventricular emptying at each stroke. Similar calculation for the cardiac output of the fetal whale was not attempted because of the unknown factor of the fetal cardiac rate.

A comparison of ratios of cardiac output to body weight of whale and average man also shows a remarkable similarity as seen in table 1.

**Summary**

A large whale heart weighing 256 pounds (116 Kg.) was dissected. The coronary arteries had extremely large right and left marginal branches, which supplied the major lateral mass of the right and left ventricles. The venous system was similar to other mammals. Crude ventricular volume and cardiac output was calculated to be 453 L per minute based on a rate of 10 per minute. The size of the cardiac muscle fiber was similar to the human myocardium except in a fetal whale heart (wt. 1,600 Gm.) in which very small fibers were found. The aorta was found to be 20 cm. in diameter and the wall to consist of very large interwoven bundles of elastic tissue and fibrous tissue apparently devoid of muscle. There was no evidence of arteriosclerosis. Comparative estimated cardiac output/body weight ratios and heart weight/body weight ratios were made between the whale and the human.

**Summario in Interlingua**

Un grande corde de balena de un peso de 256 libras (116 kg) esseva disseccate. Le arterias coronari habeva extrememente grande braneas dextero- e sinistro-marginal le quales
provisionava le major massa lateral del ventriculos dextere e sinistre. Le sistema venose esseva simile a illo de altere mammiferos. Le volumine ventricular e le rendimento cardiac esseva calculate crudemente a 453 litros per minuta (super le base de un frequentia cardiac de 10 per minuta). Le dimensiones del fibras myocardial esseva simile a illos in humanos. (Sed in un fetal corde de balena—de un peso de 1,600 g—micrissime fibras esseva incontrate.) Esseva constata te que a aorta habeva un diametro de 20 cm e que su pariete consistert de grandissime fases intertextite de histo elastic e histo fibrose, apparentemente sin musculo. Nulle signos de arteriosclerosis esseva notate. Comparative estimationes inter balena e homine esseva facite pro le proportion de rendimento cardiac a peso corporee e pro le proportion de peso cardiac a peso corporee.

REFERENCES


Primary retention of water and secondary hyponatremia were illustrated in metabolic studies of 3 subjects with rheumatic heart disease and congestive heart failure on a low-sodium intake in whom an imbalance between cardiac output and body needs was acutely intensified. In 1 case, this resulted from an escape from digitalization, in another from a severe respiratory infection and in the third from digitalis sensitivity due to potassium depletion. In each patient, an acute antidiuretic mechanism was invoked leading to retention of water in excess of sodium. Continued fluid intake during oliguria resulted in weight gain, increasing edema, azotemia, hyponatremia, and hypochloremia. These events were attributed to sustained production of antidiuretic hormone invoked by extrarosmocceptor mechanism when cardiac output became inadequate. Therapy should be directed toward increase of cardiac output by adequate digitalization or decreasing metabolic demands through treatment of infection. Misguided efforts to correct the assumed sodium deficit by intravenous administration of concentrated salt solution may further aggravate the condition.
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