Circulation of the Giraffe

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THE long neck of the giraffe presents a unique problem in the regulation of the systemic arterial blood pressure and in the maintenance of the cerebral circulation. In 1954, Goetz and Budtz-Olsen succeeded in measuring the arterial blood pressure in a standing, unanesthetized giraffe.1,2 In this animal, approximately 13 feet tall, the carotid arterial mean pressure was found to be 200 mm. Hg at the base of the brain. The present study was undertaken 2 years later as a sequel to this preliminary observation to provide detailed information concerning the circulation of the giraffe. Concomitant studies of respiratory function will be reported separately.

Method

In January, 1956, 4 wild giraffes, about 2 years of age, were captured and confined to a stockade on the Hans Merensky Farm, Northern Transvaal, Union of South Africa. The 3 largest animals were kept together; the fourth, the victim of multiple cutaneous tumors of low grade malignancy and of unknown identity, was penned separately. The animals were fed their usual herbivorous diet and, with the exception of the sick giraffe, appeared healthy. None of the animals became entirely tame. At the time of the study, in October, 1956, the 3 larger animals ranged in height from 12 to 13 feet, whereas the small one was only 9 feet tall.

For physiologic study, the giraffe was lured and driven into a narrow chute or “crush pen”. When the gate to the chute was closed, the animal could move neither forward nor backward. After a blindfold and a halter had been applied, the animal could be led into a latticework of 3-inch steel pipes firmly imbedded in the ground.3 The giraffe was secured in the standing position by hobbling the feet to the pipes and by placing a leather sling under the abdomen to prevent the animal from lying down. The head was controlled by 2 men positioned on the scaffolding at head level. The clamps which secured the pipes could be rapidly released so that the anesthetized animal could be rapidly lowered to the lateral decubitus.

Needle electrodes were inserted into the skin over the shoulders and a third into the neck for electrocardiographic monitoring.

The jugular vein and the carotid artery were exposed through a generous incision made along the lateral border of the sternohyoid muscle about 50 cm. above the jugular. Xylocain (lidocaine) was used for local anesthesia. Since the skin is about 1.5 cm. thick in this region, a linoleum cutter was required to effect the cutdown. At this level in the neck the jugular vein was found to be about 2.5 cm. in diameter and in a state of collapse; the diameter of the carotid artery was about 1.2 cm. Bleeding from tiny arteries was difficult to control because of the high intraluminal pressure.

In each animal an extra-long woven nylon catheter (240 cm.) was passed centrally through the isolated jugular vein. The pulmonary artery could be catheterized in 2 animals by blindly advancing the catheter. In the other 2 animals the catheter tip could not be passed beyond the right ventricle. A cannula was inserted into the carotid artery for blood samplings. Intravascular pressures were measured from this cannula or from nos. 90 or 60 polyethylene tubing attached to Statham P23D or P23G strain gages placed in most cases at the level of the incision.

In each animal venous catheterization was effected both with a single and a double lumen catheter, 1 lumen of which carried at its tip a modified Wetterer miniature manometer.4 The use of this type of manometer permitted direct measurement of pressures at heart level. In 2 animals, a catheter of this latter type was also passed from the carotid artery into the aorta and into
the left ventricle without incident. Pressures and electrocardiograms were recorded simultaneously on a Sanborn M-150 direct-writing polyoscillograph or optically with Heiland Type G galvanometers and a camera housed in a light-tight prefabricated shack.

The pressures recorded at heart level were corrected to brain level by subtracting a hydrostatic correction calculated with the assumption that the specific gravity of giraffe blood is not significantly different from man:

\[
\text{Hydrostatic correction} = 1.055 \times \text{cm. elevation} \div 1.36
\]

The cardiac output was measured, utilizing the Fick principle and the indicator-dilution method, in all animals using T-1824.7,8 The dye was injected through the cardiac catheter. Arterial blood samples were collected in heparinized tubes at 1-second intervals. Subsequently at intervals up to 30 minutes blood samples were obtained for estimation of the general blood volume. The dye concentration of the plasma was read on a Coleman Junior spectrophotometer. The mean dye concentration, the mean circulation time, the cardiac output and the central blood volume were obtained from the time-concentration dye curve and the hematocrit reading and the total blood volume by extrapolating the dye disappearance curve back to zero. The high environmental temperature caused hemolysis in a number of the blood samples.

Arterial and venous blood samples were collected anaerobically for the measurement of oxygen content by a modified Haldane method, for direct oxygen and carbon dioxide tensions and for blood pH with the Beckman Model G pH-meter. Expired gas samples were analyzed for \( \text{O}_2 \) and \( \text{CO}_2 \) concentration with the Scholander Microgasanalyzer. Oxygen consumption was measured by the open-circuit method. Expired gas was collected with a specially constructed mask for periods of 2 to 3 minutes. Pulmonary blood flow (cardiac output) was calculated from the oxygen consumption and the arterio-mixed venous blood oxygen difference.

After initial observations general anesthesia was induced in the fourth animal by injecting sodium thal-barbital (Kemithal) through the cardiac catheter. Prior to this the animal had been given 500 mg. chlorpromazine intravenously in an unsuccessful effort to reduce struggling.

**Results**

Once confined in the steel scaffolding the giraffe remained quiet and apparently calm for periods as long as 10 or 15 minutes. The animal would then, for a moment and at irregular intervals, buck and thrash about. The first and largest animal was immobilized only with great difficulty; the dissection was long and difficult; the day was extremely hot, and the animal bucked repeatedly and violently, each time apparently aggravating a severe angulation of the neck. After 4 hours the animal began to show signs of respiratory distress, the muzzle became pale, and during the injection of T-1824 dye, it suddenly collapsed and died. The dye samples were visually evaluated because of the small volume of individual blood samples. The times from onset and from midpoint of the dye injection to the peak concentration were 4 to 6 seconds, respectively. This rapid circulation rate suggested that the animal's hypotension resulted from vasodilatation rather than from inadequate cardiac action. It is, therefore, possible that the animal developed orthostatic syncope, irreversible because of its immobilization in the standing position. At autopsy the total weight of the disarticulated limbs, neck and body was 570 Kg.

**Carotid Arterial Pressure**

Technically satisfactory pressure tracings were obtained both with the miniature manometer and the Statham transducer using PE 90 polyethylene tubing. The pulse contour was essentially the same. In each animal, except giraffe no. 3, a tall high-frequency spike was recorded during the early ejection phase followed by a domelike plateau preceding the incisura (fig. 1). With the rise in systolic blood pressure during struggling this initial spike decreased in height in animal no. 1 and completely disappeared in animal no. 2.

The intravascular pressure measurements (at heart level) are summarized in table 1. As it was felt that the initial spike contributed little to the mean pressures, the pressures are recorded by 3 readings. The first refers to the initial spike, the second to the plateau or dome following the spike and the third to the end diastolic pressure (fig. 1). In all 4 animals the arterial pressure was extraordinarily high as judged by human standards. Even in the smallest animal which was not quite 9 feet tall the arterial pressure...
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Figure 1
Catheterization of right heart in the standing nonanesthetized giraffe with miniature manometer. Pressures in right atrium (A) and right ventricle (B) simultaneously recorded with arterial pressure in carotid artery and electrocardiogram. (C) Changes in carotid artery and right ventricular pressure on lowering the head for 150 cm. Note the increase in the short initial spike and the lowering of the mean pressure in the carotid artery.

was not much lower than in the larger animals. The highest systolic pressure recorded in a quiet animal was 353 mm. Hg and the highest diastolic pressure 303 mm. Hg. Except for the pressure taken before the syncope in giraffe no. 1, the lowest recorded pressures in a standing healthy animal were 260 mm. Hg systolic and 158 mm. Hg diastolic. In the calm, standing animal, the pressures varied relatively little, but on struggling, both the systolic and diastolic pressures often rose by more than 100 mm. Hg. The arterial blood pressure in 1 anesthetized giraffe in the lateral decubitus was 262/225/188 mm. Hg.

Pulse Wave Velocity
The velocity of the arterial pulse wave was calculated in 1 standing and 1 anesthetized recumbent animal from a pressure recording made during the withdrawal of the miniature manometer for a measured distance from the left ventricle to the carotid artery, using the electrocardiogram as a reference point (fig. 2). In the standing giraffe the pulse wave velocity was about 5 M/second whereas in the anesthetized and recumbent animal it measured 4.0 M/second.

Changes in Arterial Pressure Pattern
The changes in the arterial pressure pattern recorded with the miniature manometer during withdrawal from the left ventricle into the carotid artery are illustrated in figure 3. The R waves of the electrocardiogram have been superimposed on the corresponding pressure pulses. An initial spike in the left ventricular pressure contour is noted. It is also recorded in the arterial blood pressure in 1 anesthetized giraffe in the lateral decubitus 262/225/188 mm. Hg.
Withdrawal of miniature manometer from the left ventricle via aorta and for 70 cm. along the carotid artery in a standing unanesthetized giraffe. Pressure simultaneously recorded with electrocardiogram. The electrocardiogram has been erased but for the R wave, as in the original record it was superimposed over the pressure tracing. Time = 0.1 second. A, B, C and D refer to the pulses reproduced in figure 3.

(A) coincides with a small presystolic dip in (C) and the systolic dip following the initial spike in (A) with the early systolic peak in (D).

The drop in diastolic pressure during withdrawal of the miniature manometer is practically linear and uneventful.

Ventricular Pressures
The left ventricular pressure was measured in 1 standing and in 1 recumbent giraffe by retrograde arterial catheterization with the miniature manometer. Atrial premature beats occurred regularly when the catheter traversed the aortic valve. In the standing animal the left ventricular systolic pressure varied between 260 to 286 mm. Hg and the end diastolic pressure between 10 to 18 mm. Hg (fig. 4). The maximal rate of left ventricular pressure ascent was about 6,000 mm. Hg/sec. In the recumbent anesthetized small animal (no. 4) the left ventricular pressure was 170/0 mm. Hg.

Right ventricular pressures were recorded in all 4 animals with the Statham transducer and in 2 with the miniature manometer. The right ventricular systolic pressures varied between 40 and 75 mm. Hg and the end diastolic pressures between 5 and 20 mm. Hg (figs. 1 and 4). Large fluctuations were produced by respiration. The maximal rate of pressure ascent in the right ventricle was 1,200 mm. Hg per second.

The right ventricular pressure was also recorded with the miniature manometer as the head was lowered in 1 giraffe (fig. 1). There was a marked increase in the respiratory fluctuations with a maximum systolic fluctuation of 20 mm. Hg during inspiration. The end-diastolic pressure remained essentially the same.

Pulmonary Arterial Pressure
The pulmonary arterial pressure recorded in giraffe no. 3 varied between 38/13 mm. Hg and 48/22 mm. Hg. In this animal, it was possible to catheterize the right ventricle with the miniature manometer and then advance the catheter well into the pulmonary artery. There was a drop in pressure as the catheter passed through the valve, the gradient between systolic pressures in the 2 areas being 10 mm. Hg. In giraffe no. 2 the same procedure was followed, but the catheter tip lodged in the region of the pulmonic valve and the gradient and the pulmonic pressures, although apparently of comparable magnitude to those found in giraffe no. 3, could not be determined with precision. Convincing pulmonary capillary venous pressures could not be obtained in any of the animals.

Central Venous Pressures
The right atrial pressure in 3 animals was essentially atmospheric but varied greatly with the phase of respiration (fig. 1). For
Systemic Arterial Blood Pressure and Heart Rate in Four Conscious Standing Giraffes

<table>
<thead>
<tr>
<th>Animal</th>
<th>Pressure at heart level (mm Hg)</th>
<th>Brain level Mean pressure at mm Hg</th>
<th>Heart rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Psp/Ps/Pd</td>
<td>Pm</td>
<td>Psp/Ps/Pd</td>
</tr>
<tr>
<td>No. 1</td>
<td>282/240/158</td>
<td>210</td>
<td>322/310/250</td>
</tr>
<tr>
<td>No. 2</td>
<td>340/285/220</td>
<td>265</td>
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<td>No. 3</td>
<td>333/315/240</td>
<td>285</td>
<td>350/385/300</td>
</tr>
<tr>
<td>No. 4</td>
<td>315/285/200</td>
<td>245</td>
<td>320/350/300</td>
</tr>
</tbody>
</table>

*With exception of animal no. 4, column 2.
†Highest and lowest readings are given of spike (Psp), systolic (Ps), end-diastolic pressures (Pd) and Pm = mean pressure determined by planimetry.

technical reasons it was impossible to measure the jugular venous pressure at head level. In the standing animal this vessel appears collapsed. From the rapid filling on compression it appears possible that the lumen still had an appreciable open cross section. However, the existence of an open lumen in a truly collapsible external jugular vein is unlikely to produce a negative venous pressure at the base of the skull. As a syphon effect may still be produced through the deep non-collapsible venous channels, it is believed that at head level the venous pressure is probably subatmospheric.

Cardiac Output

The data are summarized in table 2. The indicator-dilution procedure in giraffes nos. 2 and 3 were technically satisfactory. The cardiac output in these 2 animals compares well with similar determinations in dairy cows of about the same weight. From the dye curves the circulation time and the general and central blood volume were also available (table 2). The values for general blood volume, when related to estimated body weight, are very much the same as in the cow.

Cardiac output determinations, utilizing the Fick principle, were obtained in animals nos. 2, 3 and 4. The agreement between dye and Fick outputs in animal no. 3 was quite good but poor in the second animal due to the time differences in blood, expired gas and dye sampling. It should be noted that in animal no. 3 the mixed venous blood sample was believed to have been obtained from the right atrium. It is, therefore, possible that this sample contained a relatively high proportion of coronary sinus blood, which would have produced a falsely high mixed venous-systemic arterial oxygen difference and a falsely low cardiac output. There was a striking fall in cardiac output in animal no. 4 with change from the upright unanesthetized to the recumbent anesthetized condition. Both of the Fick determinations were done with good correspondence of gas and blood sampling times and the results are regarded with confidence.

Heart Rate

Considering the size of the animal the heart rates were high in all animals. They varied greatly, increasing rapidly whenever the animal showed signs of restlessness. When the animal appeared calm, the rate was about 60. The experimental conditions in blindfolding and restraint must obviously be considered when interpreting these data.

Circulatory Effects of Changes in Posture

In 1 giraffe the arterial pressure was continuously recorded while the head was force-
Changes in the arterial pressure pattern recorded during withdrawal of miniature manometer from left ventricle along the carotid artery in a standing nonanesthetised giraffe (Spr. no. 2). At V the manometer was lying within the left ventricle.

Figure 3

Changes in the arterial pressure pattern recorded during withdrawal of miniature manometer from left ventricle along the carotid artery in a standing nonanesthetised giraffe (Spr. no. 2). At V the manometer was lying within the left ventricle.

ably lowered by 150 cm. (fig. 5). As the head went down there occurred a marked increase in the pulse pressure resulting from a rise in the systolic and a conspicuous fall in the diastolic pressures (fig. 1). The mean arterial pressure at heart level fell approximately 50 mm. Hg. There was a concomitant rise in heart rate from 65 to 105 beats per minute.

Of particular interest was the response of the aortic pressure in the anesthetized recumbent animal when the head was passively raised a distance of 150 cm. above heart level as the miniature manometer lay in the ascending aorta. As is shown in figure 6, there was an immediate rise of 50 mm. Hg in systolic and of 60 mm. Hg in diastolic pressure. The pulse pressure, therefore, decreased. This pressure response was the exact opposite of that observed when the head was lowered but the change in heart rate was in the same direction, i.e. there was an increase in heart rate with elevation of the head. The observed rise in pressure of only 50 mm. Hg obviously did not suffice to keep the pressure at brain level constant since the calculated hydrostatic increase in pressure at the root of the aorta must have amounted to approximately 110 mm. Hg.

Discussion

The observations reported here must be viewed in the light of the prevailing experimental conditions. Facilities were limited compared with an established laboratory, being 300 miles from the nearest city, and transportation facilities were slow and irregular. Furthermore, the experiments were restricted to the 4 animals available, although studies on a larger series of animals clearly would have been desirable.

The systemic arterial pressure of the giraffe is the highest of any animal thus far studied. Even the lowest pressure recorded in these animals, with the exception of the presyncopal pressure in 1, would be adequate

A, B, C and D refer to the respective pulses in figure 2. The arrows indicate the R wave of the electrocardiogram. Time = 0.1 seconds.

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to maintain perfusion of the brain without recourse to any auxiliary mechanisms. The blood pressure showed a minimal tendency to fall, even over the longest periods during which the animal was quiet and not subjected to manipulation. Recent observations on more tractable domestic cattle have demonstrated considerable fluctuations in vascular functions related to environmental conditions. Of possible relevance to the question of the effect of environmental influences is the recording in 1 animal of almost identical diastolic pressures before and after general anesthesia. Indeed, the hydrostatic situation would probably not permit a significant fall in peripheral resistance and in arterial pressure if an adequate cerebral perfusion pressure were to be maintained. In this respect the anatomical structure of the large vessels is perhaps of considerable significance, with the arteries below heart level showing greater muscularity and smaller lumens.

The values obtained for cardiac output (table 2), while variable, are similar to those obtained in domestic cattle of about the same weight. Despite technical difficulties, some confidence is gained for the output values by the dye technic, in the case of animals nos. 2 and 3, by the reasonable values obtained for blood volume. Based on an estimated weight of 1,100 pounds (500 Kg.) for animal no. 2 and 1,000 pounds (455 Kg.) for animal no. 3, the blood volumes of these animals represented, respectively, 73 and 78 ml./Kg. body weight. The cardiac output values for animal no. 4 are also viewed with considerable confidence, taking into account the temporal closeness of the blood and expired gas samples, and the approximate agreement of the values for arteriovenous oxygen difference with those obtained in cattle.

Our data do not permit a precise analysis of the elastic state of the arterial system, but certain phenomena provide a basis for speculation. The pressure contours in the left ventricle and in the carotid artery display a
Left ventricular, ascending aorta and right ventricular pressures simultaneously recorded with the electrocardiogram in a standing nonanesthetized giraffe (Spr. no. 2). Time = 0.1 seconds.

high initial spike. This was recorded both by the miniature manometer and the Statham transducer. Records obtained during withdrawal of the miniature manometer from the left ventricle through the carotid artery were remarkable for the change in pulse pressure pattern which suggested the presence of a standing wave the node of which is located in the region of B in figure 2. However, definite proof of a standing wave is made difficult because the pulses used for the analysis were not taken strictly simultaneously at distant points. Attempts to catheterize the abdominal aorta failed.

An alternative explanation of the pressure contour would consider the initial spike of the arterial pulse pressure contour as a water hammer effect or acceleration transient similar to that described by Wiggers in states of shock and is believed to be caused by an explosive discharge of the stroke volume into a "lax" arterial system.

On first consideration, it is difficult to accept as appropriate the term "lax" when applied to an arterial system with such high intraluminal pressure. It is less difficult to visualize the situation as one in which the prevailing pressure, although high, may lie on a relatively flat portion of the arterial pressure-volume curve, beyond which considerable distensibility remains. The pulse wave velocity of 5 meters/sec. and the low pulse pressure at dome of contour minus diastolic pressure are in keeping with this concept.

If it is assumed that one-half of the stroke volume of approximately 700 ml. is stored in the arterial Windkessel, then the end-systolic (approximately mean systolic) pressure rise of 60 mm. Hg in 1 animal permits the calculation by Frank's formula of the volume elasticity co-efficient \[ \frac{\Delta P}{\Delta V} \] of 230 dynes cm.\(^{-5}\).

This figure, about one-third the value in man, emphasizes the elasticity of the arterial system but should be interpreted in the light of differences in body size of the giraffe and man. It is evident that, with increasing animal size, stroke volume tends to increase to a greater degree than pressure rise during systole.

The head of a full-grown giraffe may transverse a vertical distance of 16 to 20 feet between a succulent bough and a pool of water. In the present study, it was possible to lower the head of 1 unanesthetized giraffe to heart level, and in a recumbent anesthetized animal to raise the head 5 feet above heart level. In the latter instance, the manometer was lying near the aortic valve and recorded a pressure increase of only one-half the calculated change in hydrostatic pressure at head level. Despite the fact that the arterial mean pressure in both procedures changed in opposite directions, the reaction of the heart rate was directionally the same in both, namely an increase. The blood pressure response to lowering of the head in the present study was the same as in a previous experiment, but the heart rate response was differ-
In the giraffe, there is a relatively great difference between the right ventricular and left ventricular maximal rates of pressure ascent, the left ventricular rate of ascent being 5 times that calculated for the right ventricle. This reflects a number of factors, of which the enormous thickness of the left ventricular musculature previously reported is probably the main one, besides differences in the resistances of the 2 major vascular beds.

It is regrettable that the jugular venous pressure at head level could not have been measured simultaneously with arterial pressure. On theoretical grounds it appears probable that when the head is moved between heart and ground level, cerebral perfusion pressure remains relatively constant. With a distended venous system changes in venous and arterial pressure at brain level with change in head position should be of similar magnitude. On the other hand, the situation may be somewhat different in the case of head positions between heart level and the "normal" high position of the head. In man, when the body position is changed from horizontal to upright, the average fall in venous pressure in the jugular bulb is only 0.38 \times the fall in arterial pressure at the same level. This is believed to be due to partial collapse of the veins with a corresponding increase in resistance to blood flow. In the giraffe the same mechanism would be expected to operate, probably in exaggerated degree.

**Summary**

Observations on the circulatory functions of 4 giraffes are recorded. Both the right and the left heart were catheterized under local anesthesia with a miniature manometer.
Cardiac output was determined by employing both indicator dilution method and the Fick principle. Other parameters, such as the circulation time, blood volume, velocity, right and left ventricular pressure ascent as well as the changes in blood pressure occurring with changes in the posture of the head were recorded. The difficulties of the experiments created certain limitations in their interpretation. The arterial blood pressure is high by human standards and adequate to maintain cerebral perfusion without other means of support. The arterial pressure pulse contour suggests a relatively lax vascular bed with considerable reserve distensibility. Values for cardiac output and blood volume were roughly comparable to those recorded in domestic cattle of the same approximate weight.

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Summario in Interlingua

Es registrate observationes relative al functiones circulatori in 4 girafas. Le corde dextere e le corde sinistre esseva catheterisate sub anestesia local per medio de un manometro micro-dimensional. Le rendimento cardine esseva determinate per le principio de Fick. Le aliter parametri quas esseva registrate include le tempore de circulation, le volumine de sanguine, le velocite del fluxo, le ascendentia del tension dextero- e sinistro-ventricular, et etiam le alterationes in le tension sanguine que occurre con alterationes in le posturam del capite. Le difficilitates del experimentes creavava certa limitationes del interpretation de lor resultatos. Le tension de sanguine arterial ess alta in comparation con standards human. Illo suffice a mantenir le perfusion cerebral sin altere medios do supporto. Le contorno del pulse de tension arterial suggero le existentia de un relativamente laxa vasculatura con considerabile reserves de distensibilitate. Le valores pro le rendimento cardine e le volumine de sanguine esseva grossiereamente comparabile al valores registrato in border domestic de aproximativamente le mesma statura.

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