Angiocardiographic Measurement of the Cardiac Segment of the Inferior Vena Cava in Health and in Cardiovascular Disease

By Edwin Ettinger, M.D., and Israel Steinberg, M.D.

Measurement of the inferior vena cava during life, has not to our knowledge, been previously reported. Review of a large series of intravenous angiocardiograms with reflux filling of the inferior vena cava forms the basis of this paper. In many of the angiocardiograms the diameters of the inferior vena cava and the superior vena cava could also be compared. This report establishes values for the diameter of the inferior vena cava in normal and diseased conditions.

Materials and Method

The material used in this publication comprised 392 angiocardiographic studies selected from examinations performed from 1946 to the present time. Films chosen for the study were of quality adequate to afford satisfactory measurement of the inferior vena cava. In 244 cases the superior and inferior vena cavae were visualized and measured in the same film. Measurements were made in the frontal, lateral, or oblique projection depending on the best delineation of the inferior vena cava. For technical reasons, because of the surrounding radioluency of the lungs, the lateral projection was preferred. Standard intravenous angiocardiographic technic, with suspended respiration in moderate inspiration at the time of exposure, was used in all examinations. The erect (rarely the supine) position in frontal, lateral, or oblique projection was utilized; examination during anesthesia was rare. The target film distance in most cases was 72 inches; in films taken at 48 inches, correction for distortion (estimated at 7 per cent) was not made because these few cases were scattered throughout the series. In 364 cases reflux opacification of the inferior vena cava from the right atrium allowed measurement of the vessel. In 28 instances, the inferior vena cava was opacified by direct injection of the saphenous or of the femoral vein. The films were not exposed during a selected phase of the cardiac cycle. It was considered that the large size of the series would balance the systolic and diastolic variations in caliber of the inferior vena cava. Measurements of both the inferior and superior vena cavae were made perpendicular to the axis of each vessel at selected points. The inferior vena cava was measured at the level of the diaphragmatic surface of the right atrium; the superior vena cava was measured at the level of the upper border of the right atrium (figs. 1 and 2).

After measurement, the cases were classified into groups according to the clinical and angiocardiographic data. Analysis was applied to five major groups: Group I, 54 normal subjects over the age of 15 in whom there was no cardiac or great vessel disease. In many of these studies there were peripherally located pulmonary or mediastinal lesions, but the cardiovascular structures were not involved. Group II, 115 patients over the age of 15 in whom acquired heart disease was present, with clinical and roentgen evidence of right heart failure. Cases of rheumatic heart disease, arteriosclerotic cardiac disease, pulmonary hypertension with or without pericardial effusion, and constrictive pericarditis comprised this group. Criteria for right heart failure were based on such clinical findings as increased venous pressure and circulation time, peripheral edema, and hepatomegaly. In these, there was enlargement of the right atrium, right ventricle, pulmonary artery, and pulmonary arterial system, demonstrated by angiocardiography. Group III, 40 patients over the age of 15 years in whom acquired heart disease was present, but without clinical and angiocardiographic evidence of right heart disease. Cases in this category included patients with rheumatic heart disease, syphilitic heart disease, and bronchogenic carcinoma involving the great vessels (mostly the superior vena cava and pulmonary arterial system). Group IV, 136 patients under the age of 15 years with congenital heart disease. Group V, 47 patients over the age of 15 with congenital heart disease. All patients with congenital heart

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Supported by the Health Research Council of the City of New York under contract U-1084.

Dr. Steinberg is an Investigator of the Health Research Council of the City of New York, under contract no. I-258.
Angiocardiograms in the erect position showing the normal frontal (A) and lateral (B) superior and inferior vena cavae. Upper arrows bracket the site of superior vena caval measurement; the lower arrows bracket the site of inferior vena caval measurement. RA, right atrium.

disease had evidence of right-sided cardiac enlargement. Uncomplicated cases of coarctation of the aorta and of aortic stenosis were not included in this classification because the right heart structures were normal. Too few normal subjects under 15 years of age were available to warrant analysis.

Arteriosclerosis, in the absence of clinical or roentgen evidence of obvious disease, did not preclude admission of cases to group I. On the other hand, when patients with arteriosclerosis had associated or complicated heart disease, they were classified in the appropriate groups.

Results

Group I, Normal

The mean measurements of the inferior vena cava for all groups are presented in table 1. The relationship between age and caliber

<table>
<thead>
<tr>
<th>Group</th>
<th>Diagnosis</th>
<th>No. of cases</th>
<th>Mean age (range) (yr.)</th>
<th>Mean caliber ± SD (mm.)</th>
<th>Significance of difference between means: P</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal</td>
<td>54</td>
<td>44.5 (15-75)</td>
<td>23.9 ± 5.0</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>Acquired heart disease with right heart failure</td>
<td>115</td>
<td>45.6 (15-76)</td>
<td>30.5 ± 5.5</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>III</td>
<td>Acquired heart disease without right heart failure</td>
<td>40</td>
<td>48.3 (15-72)</td>
<td>23.4 ± 3.9</td>
<td>&gt; 0.5</td>
</tr>
<tr>
<td>IV</td>
<td>Congenital heart disease over 15 years</td>
<td>47</td>
<td>26.7 (16-55)</td>
<td>27.0 ± 6.7</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>V</td>
<td>Congenital heart disease under 15 years</td>
<td>136</td>
<td>5.1 (NB*-14)</td>
<td>17.1 ± 5.5</td>
<td></td>
</tr>
</tbody>
</table>

*NB=newborn.
is graphically represented in figure 3. The age distribution was subdivided into 20-year increments beginning with 15 years (fig. 4). Calculation and statistical analysis of the mean inferior vena caval diameter for each of the subdivisions showed no significant change in the caliber of the vessel between adjacent age groups (table 2). Although the line representing the mean diameter for each age grouping showed a slight increase with age, which was a reflection of the correlation coefficient noted above, the degree of change was not sufficiently large to enter into clinical evaluation.

In 25 normal studies the superior vena cava was also adequately visualized for measurement (table 3). The mean caliber corresponds to that presented by Dotter and Steinberg. For the same 25 patients the mean caliber of the inferior vena cava was 24.6 mm.

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**Table 2**

<table>
<thead>
<tr>
<th>Age Subdivisions</th>
<th>Statistic</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
<th>Group IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>23.6 ± 6.5</td>
<td>32.3 ± 6.5</td>
<td>22.3 ± 3.9</td>
<td>26.1 ± 5.0</td>
</tr>
<tr>
<td>15–34 years</td>
<td>Number of cases</td>
<td>16</td>
<td>23</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>95% Confidence range</td>
<td>26.8–20.4</td>
<td>29.5–35.1</td>
<td>19.1–25.5</td>
<td>24.1–28.1</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>23.5 ± 4.2</td>
<td>29.9 ± 6.7</td>
<td>24.3 ± 3.8</td>
<td>30.0 ± 8.8</td>
</tr>
<tr>
<td>25–54 years</td>
<td>Number of cases</td>
<td>21</td>
<td>61</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>95% Confidence range</td>
<td>25.4–21.6</td>
<td>28.2–31.6</td>
<td>22.4–26.2</td>
<td>24.2–35.8</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>24.2 ± 7.1</td>
<td>29.9 ± 5.8</td>
<td>22.8 ± 4.2</td>
<td></td>
</tr>
<tr>
<td>55–75 years</td>
<td>Number of cases</td>
<td>17</td>
<td>31</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95% Confidence range</td>
<td>27.8–20.6</td>
<td>27.8–32.0</td>
<td>20.4–25.2</td>
<td></td>
</tr>
</tbody>
</table>
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Figure 3
Group I-normal subjects (54 cases). Relation of inferior vena caval caliber (ordinate) to age (abscissa). The solid black line represents the mean caliber, calculated for 20-year increments, as a reflection of the correlation coefficient: \( r_{23} = 0.47; 0.01 > p > 0.001 \).

Group II, Patients with Acquired Heart Disease and Right Heart Failure

The angiocardiograms of 115 patients in this group were measured (table 1). Figure 5 shows the relationship between age and caliber. The mean caliber for this group is significantly different from the normal. Figure 4 expressed the mean caliber at 20-year increments for group II as a curvilinear relationship; however, this curvilinear trend is a nonsignificant one (\( r_{115} = 0.13; p > 0.1 \)).

The superior vena cava was measured in 87 cases (table 3). The ratio of the diameter of the superior and inferior venae cavae was 0.62, greater than normal.

Group III, Patients with Acquired Heart Disease Without Right Heart Failure

This group comprised 40 cases (table 1). The standard error of the mean caliber was calculated at \( \pm 0.58 \). The age to caliber relationship is shown in figure 6. The mean calibers calculated for each 20-year subdivision did not differ significantly (\( r_{38} = 0.43; 0.01 > p > 0.001 \)) from each other (table 2 and fig. 4).

In 27 of these cases the superior vena cava was also measured (table 3). For these patients the ratio of the mean caliber of the superior and inferior vena cava was 0.64.

Group IV, Patients over 15 Years with Congenital Heart Disease

The angiocardiograms of 47 patients were included in this group. The standard error of the mean caliber was \( \pm 0.98 \) (table 1). The mean caliber for this group was significantly different from the normal (0.05 \( p > 0.02 \), table 1). Mean inferior vena cava caliber increased with age as shown in figure 7. However, the trend of this line as judged by the correlation coefficient (\( r_{15} = 0.266; 0.1 > p > 0.05 \)) was of borderline significance.

Group V, Patients under 15 Years with Congenital Heart Disease

The angiocardiograms of 136 patients were included in group V (table 1). The standard error of the calculated mean diameter was \( \pm 0.44 \). Figure 8 shows the relationship of the inferior vena caval measurements to age. The correlation coefficient calculated for group V (\( r_{134} = 0.288; 0.01 > p > 0.001 \)) showed the significance of the relationship.

Since the curvilinear relationship for groups IV and V showed a pronounced change

*Subscript for each "r" equals the number of cases minus two, \( n - 2 \), which is equivalent to degrees of freedom.

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with age, the method of "least squares" was applied to derive a formula for predicted inferior vena caval caliber (caliber = 7.7 log10 age − 16.5); the resultant curve for these groups is shown in figure 4. Thus, it is predicted that the inferior vena cava of a 5-year-old patient with congenital heart disease should be 21.5 mm. in caliber; that of a 20-year-old patient, 26.5 mm. It is recognized that the predictions are useful for order of magnitude rather than for absolute individual application.

The superior vena cava was measured in 71 of these cases. The standard error of the mean caliber was ± 0.38. The superior-to-inferior vena caval ratio was 0.66 (table 3).

Discussion
Analyses of the measurements of the inferior vena cava permit certain generalizations

Table 3

<table>
<thead>
<tr>
<th>Group</th>
<th>Diagnosis</th>
<th>No. of cases</th>
<th>SVC mean age ± SD (yr.)</th>
<th>SVC mean caliber ± SD (mm.)</th>
<th>IVC caliber (mm.)</th>
<th>SVC:IVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal</td>
<td>25</td>
<td>43.9 (15-75)</td>
<td>12.0 ± 2.6</td>
<td>24.6</td>
<td>0.49</td>
</tr>
<tr>
<td>II</td>
<td>Acquired heart disease with right heart failure</td>
<td>87</td>
<td>45.8 (18-76)</td>
<td>19.1 ± 5.5</td>
<td>30.7</td>
<td>0.62</td>
</tr>
<tr>
<td>III</td>
<td>Acquired heart disease without right heart failure</td>
<td>27</td>
<td>46.2 (15-72)</td>
<td>14.9 ± 4.6</td>
<td>23.3</td>
<td>0.64</td>
</tr>
<tr>
<td>IV</td>
<td>Congenital heart disease over 15 years</td>
<td>34</td>
<td>28.2 (16-55)</td>
<td>17.1 ± 4.3</td>
<td>26.5</td>
<td>0.65</td>
</tr>
<tr>
<td>V</td>
<td>Congenital heart disease under 15 years</td>
<td>71</td>
<td>5.5 (NB-13)</td>
<td>11.7 ± 3.2</td>
<td>17.8</td>
<td>0.66</td>
</tr>
</tbody>
</table>

SVC, superior vena cava; IVC, inferior vena cava; NB, newborn.

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Figure 7

Group IV-congenital heart disease over 15 years of age (47 cases). Relation of inferior vena caval caliber (ordinate) to age (abscissa). The solid black line represents the mean caliber as a reflection of the correlation coefficient: r = 0.27; 0.1 > p > 0.05.

Figure 8

Group V-congenital heart disease under 15 years of age (136 cases). Relation of inferior vena caval caliber (ordinate) to age (abscissa). Correlation coefficient: r = 0.29; 0.01 > p > 0.001. The solid black line represents the predicted caliber of the inferior vena cava (caliber = 7.7 log10 age -16.5).

regarding the caliber. Table I shows that the mean ages for groups I through III fall in the mid forties. Therefore, the 54 normal patients serve as a control for the other adult groups. The mean caliber for the normal group, 23.9 mm., remained essentially unchanged as age advanced to 75 years. A direct relationship between the caliber of the aorta and the age of the patient has been reported and was attributed to atherosclerosis and to the aging process. The failure to demonstrate this positive finding in inferior vena caval measurements is attributed to the absence of atherosclerosis in the venous circulation. In the presence of right heart failure or enlargement, whether due to acquired or congenital heart disease, there was significant enlargement of the inferior vena cava (table I, fig. 4). A positive relationship of caliber to age was not clinically evident. In contrast, in the presence of organic heart disease but without right heart failure and enlargement as determined by the criteria (increased venous pressure, circulation time, peripheral edema, and hepatomegaly as well as angiocardiographic demonstration of enlarged right atrium, ventricle, and pulmonary arterial tree) used for this study, the mean caliber of the inferior vena cava was not significantly different from the normal mean. Although a control group of normal subjects under the age of 15 was not available for comparison (because angiocardiography is rarely performed in the absence of disease), a mean caliber of 17.1 mm. was calculated for children with congenital heart disease and right heart failure. Other data obtained from this group of measurements showed a positive relationship between increasing age and caliber (figs. 4 and 8). Since this finding was made during the period of rapid growth and development, it may be anticipated that a similar curve would be present among normal subjects; however, an appropriate series of measurements is required to establish it. It was significant that, in the congenital heart disease groups, this positive relationship presented a continuum beyond the fifteenth year and appeared to level off in the caliber range of adult patients with right heart failure at age 42.

The normal inferior vena cava was twice the diameter of the normal superior vena cava (table 3), and therefore the blood volume in the former was four times greater at a given pressure, \( V = \frac{P}{R} \) where volume = pressure/resistance.

The calculated superior-to-inferior vena cava
ratios for the heart failure groups (II, IV, and V) demonstrated a relatively greater increase in the caliber of the superior vena cava. Physiologically, this may represent the phenomenon that, in the presence of heart failure, the renal and splanchnic blood flows are reduced, whereas the cerebral circulation tends to be maintained. Table 3 showed that the mean inferior vena caval diameters for patients in whom both cava could be measured corresponded closely to the calibers shown in table 1 in which the entire groups were considered. The superior-to-inferior vena caval relationship for group III was close to those calculated for the heart failure and enlargement groups, even though the mean inferior vena caval diameter corresponded to the normal group. This suggests, contrary to the clinical and roentgenographic criteria for right heart failure or enlargement, the existence of undetected right heart hemodynamic changes concerned with pressure and flow. The majority of patients in this group had rheumatic heart disease with mitral stenosis, a lesion resulting in hemodynamic alterations in the right heart; it appears then, the parameters used clinically to establish the presence of right heart failure in this study were not sufficiently precise to assess accurately the circulatory dynamics.

Inferior vena cava measurements related to body surface area would have made the mean measurements more meaningful for comparison with other cases; however, such data were not available. Although no distinct variation was evident between the sexes, a body surface area relationship may have brought this out.

Reflux filling of the inferior vena cava, in many of the cases, may have reflected the performance of the Valsalva maneuver despite instructions to avoid it. However, Campeti et al. showed that peripheral injection of contrast agent produces a 1 or 2 mm. Hg rise in atrial pressure which, even in normal cases, may be sufficient to produce reflux into the inferior vena cava. They postulate that reciprocal caval reflux is a balancing mechanism to prevent right atrial overload. Opacification of the inferior vena cava via injections of the leg or groin veins, and avoidance of the Valsalva maneuver (such as occurs in deep anesthesia), would have eliminated the Valsalva variation. Caliber variations owing to position (erect or supine), projection, target film distance, and cardiac cycle (systole or diastole) were other uncontrolled factors. However, the large number of cases in the series and their random scatter tend to minimize these effects.

**Summary and Conclusions**

Angiocardiographic measurement of the inferior vena cava revealed the normal mean caliber to be 23.9 mm. (SE ± 0.68). In cardiovascular disease with right heart failure or enlargement, the mean caliber increased to 30.5 mm. (SE ± 0.51). In children with congenital heart disease, the mean caliber is 17.1 mm. (SE ± 0.44). The caliber of the inferior vena cava in the presence of congenital heart disease with right heart failure or enlargement may be roughly predicted from the following formula: caliber = 7.7 log₁₀ age - 16.5. This formula is not applicable to the adult groups, either normal or with acquired heart disease, because the caliber does not significantly increase with age.

Measurement of both cavae in the same angiocardiogram demonstrates that the caliber of the normal superior vena cava is half that of the inferior vena cava. With cardiovascular disease this ratio increases to 0.6 to 0.7. In an arbitrarily selected group of patients with acquired heart disease without clinical, roentgen, or angiocardiographic signs of right heart failure or enlargement, the superior-to-inferior vena cavae ratio was 0.64. This suggests that even in the absence of manifest right heart failure, hemodynamic changes exist.

Application of these measurements to individual cases is somewhat inaccurate because of failure to correlate the inferior vena caval measurements with body surface area and other variables such as insufficient number of normal cases in childhood, reflux opacification
from the right atrium rather than directly through the inferior vena cava, variations owing to the phases of the cardiac cycle, and variations in projection and position. However, in the absence of previously reported inferior vena caval measurements during life, the data herein presented are useful.

Acknowledgment
The authors are grateful for the statistical assistance provided by Dr. Melvin S. Schwartz, Assistant Professor of Biometrics in Public Health at Cornell University Medical College.

References

Galvani and the Electrophysiology of Muscular Contraction
It was in the course of studying the effects of electricity in bright daylight that Galvani made his most valuable discovery. The description of this experiment in one of his Manuscripts is worthy of quotation. "Accordingly, on an evening early in September 1786, we placed some frogs horizontally on a parapet, prepared in the usual manner by piercing and suspending their spinal cords with iron hooks. The hooks touched an iron plate; behold! a variety of not infrequent spontaneous movements in the frog. If, when they were quiescent, the hook was pressed with the finger against the iron surface, the frogs became excited almost as often as this type of pressure was applied."

At the beginning of the Third Part of the Commentary (the most important part) it is interesting to note that while the manuscript said that the hook piercing the spinal cord of the frog was made of iron (of the same metal as the railing on which the animal was placed), in the printed copy the small instrument is described as being made of copper. Galvani noted that the response was more readily obtained with a bimetallic arc than when using a single metal. Subsequently, in the Commentary, he stressed the greater efficacy of heterogeneous over homogeneous arcs, which are the basis of what later came to be called Galvanism and is today called electrodynamics.—Giulio Pupilli, Commentary on the Effect of Electricity on Muscular Motion. By Luigi Galvani. Translated by Robert Montraville Green, M.D., Cambridge, Massachusetts, Elizabeth Licht, Publisher, 1953, p. xi.
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Circulation. 1962;26:508-515
doi: 10.1161/01.CIR.26.4.508

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