Quantitative Angiocardiology

II. The Normal Left Atrial Volume in Man

By John A. Murray, M.D., J. Ward Kennedy, M.D.,
and Melvin M. Figley, M.D.

SUMMARY
Maximum and minimum volumes of the left atrium (LA) were calculated from the biplane angiocardigrams of 18 men and four women without significant heart disease. The mean LA maximum volume was 63 cc ± 16 cc; the mean LA minimum volume was 31 cc ± 10 cc, and their difference, LA cyclic volume change, was 33 cc ± 13 cc. Larger LA volumes were associated with greater cyclic volume changes. LA cyclic volume changes constituted 38% of LV stroke volume.

No significant correlation between LA volumes and age, sex, surface area, heart rate, LV end-diastolic volume, LV stroke volume, or cardiac output was found.

Volume data in normal subjects support the thesis that the LA serves mainly as a reservoir and conduit for blood destined for the left ventricle and that its contractile function is less important. The relation of LA volume change to LV stroke volume appears abnormal in chronic mitral regurgitation and constrictive pericarditis.

Additional Indexing Words:
Angiocardiology Left atrium Left atrial volume

The functions of the left atrium (LA) as studied by standard pressure and flow techniques have been shown to be (1) a reservoir for blood flowing from the pulmonary veins during LV systole; (2) a conduit for blood flowing from lung to heart during early LV filling; and (3) a contractile chamber for augmentation of left ventricular (LV) filling. Recent attention has been paid to changes in these functions associated with heart disease, particularly arrhythmia and valvular dysfunction,1-4 and it is apparent that an understanding of the pathological physiology in these circumstances is dependent upon an understanding of LA function. LA volume and its changes during the cardiac cycle are essential to this understanding, but few volume measurements have been recorded in persons without heart disease.

This paper reports LA volumes in 22 subjects, 18 male and four female, without significant heart disease, and relates them to sex, age, body surface area (BSA), heart rate, LV end-diastolic volume, LV stroke volume (LVSV), and LV-ejection fraction (LVSV/LV end-diastolic volume). Left atrial performance in normal and diseased states is discussed.

Methods
Twenty-two patients (table 1) were selected from radiological and catheterization records at the University of Washington and Seattle V. A. Hospitals. Records of those patients without histological or other evidence of significant heart disease and with adequate x-ray visualization of LA are reported. All patients were studied fasting, in an unanesthetized, resting, supine state. Forty to 80 cc of iodinated contrast material were injected over a 1- or 2-second period.

From the Departments of Medicine and Radiology, University of Washington School of Medicine and the Department of Medicine, U.S. Veterans Administration Hospital, Seattle, Washington.

Supported by Postgraduate Cardiovascular Training Grant HE 05281 from the National Heart Institute, U. S. Public Health Service to the University of Washington and the Washington State Heart Association.

Figure 1

Left atrium at end-systole shown in anteroposterior and lateral projections. Left atrial outline amputates pulmonary vein (PV) and atrial appendix (APX). LL is the longer of two major axes; SL is the shorter axis; Aap denotes planimetered area in AP projection and A lat denotes area in lateral projection.

into the pulmonary artery or the LA, in one instance. Filming was programmed to include six exposures per second during left heart opacification.

Atrial end-systolic (LA minimum) and atrial end-diastolic (LA maximum) films were selected, and calculation of angiocardiographic volumes was performed as described by Sauter and co-workers.\(^4\) In some instances it was possible to select maximum and minimum volumes from an LA volume-time curve plotted over several cardiac cycles.

This method assumes that the LA may be represented by an ellipsoid whose volume may be calculated by formula 1.

\[
V = \frac{4}{3} \pi \cdot \frac{a}{2} \cdot \frac{b}{2} \cdot \frac{c}{2}
\]

(1)

where \(V\) is volume; \(a\) is the major axis; \(b\) and \(c\) are the minor axes.

In practice, the LA outline is traced directly from the x-ray film with amputation of pulmonary veins, LA appendix, and LV inflow stream as indicated in figure 1. The greater length is measured; lateral and anteroposterior areas are planimetered; and these values are corrected for x-ray distortion as previously described.\(^5\) Simplification produces formula 2.

\[
LA = 0.848 \cdot (CF \ LL)^2 \cdot (CF SL) \cdot (Aap) \cdot (A lat) / (SL)
\]

(2)

where LA is atrial volume in cc; (CF LL) is the x-ray correction factor of the longer, AP or lateral, length; (CF SL) is the correction factor for the shorter length; (Aap) is the planimetered atrial area in the anteroposterior projection (cm\(^2\)); (A lat) is the area in the lateral projection (cm\(^2\)); and (SL) is the shorter of the two major axes (cm).

Abbreviations: LLL = left lower lobe; SVC = superior vena cava.

The accuracy of this method as applied to barium-filled, postmortem specimens has been reported by Sauter and co-workers to be ± 6.80 cc.\(^4\)

The difference between LA maximum volume and LA minimum volume was defined as left atrial cyclic-volume change (LAVC).

Results

Results as shown in table 2 indicate that the mean maximum LA volume was 63 cc ± 16 cc; the mean minimum LA volume was 31 cc ± 10 cc; and their difference, LA cyclic-volume change, was 33 cc ± 13 cc.

Maximum LA volumes correlated only with LA cyclic-volume change. Those subjects with the largest LA volumes had the greatest atrial volume change during the cardiac cycle (fig. 2).

No significant correlation was found between left atrial volumes and age, sex, BSA,
Table 2
Quantitative Data on Volume of the Left Atrium in Normal Subjects

<table>
<thead>
<tr>
<th>Patient, sex</th>
<th>BSA (m²)</th>
<th>LA max (cc)</th>
<th>LA min (cc)</th>
<th>LAVC (cc)</th>
<th>LVSV (cc)</th>
<th>LAVC/LVSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M</td>
<td>1.72</td>
<td>42</td>
<td>24</td>
<td>31</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>2 M</td>
<td>1.73</td>
<td>85</td>
<td>49</td>
<td>40</td>
<td>23</td>
<td>45</td>
</tr>
<tr>
<td>3 M</td>
<td>1.75</td>
<td>88</td>
<td>50</td>
<td>43</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>4 M</td>
<td>1.75</td>
<td>65</td>
<td>37</td>
<td>49</td>
<td>28</td>
<td>16</td>
</tr>
<tr>
<td>5 M</td>
<td>1.78</td>
<td>66</td>
<td>37</td>
<td>21</td>
<td>12</td>
<td>45</td>
</tr>
<tr>
<td>6 M</td>
<td>1.81</td>
<td>79</td>
<td>44</td>
<td>45</td>
<td>25</td>
<td>34</td>
</tr>
<tr>
<td>7 M</td>
<td>1.82</td>
<td>77</td>
<td>42</td>
<td>49</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>8 M</td>
<td>1.82</td>
<td>71</td>
<td>39</td>
<td>32</td>
<td>18</td>
<td>39</td>
</tr>
<tr>
<td>9 M</td>
<td>1.84</td>
<td>52</td>
<td>28</td>
<td>27</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>10 M</td>
<td>1.86</td>
<td>87</td>
<td>47</td>
<td>32</td>
<td>17</td>
<td>55</td>
</tr>
<tr>
<td>11 M</td>
<td>1.89</td>
<td>51</td>
<td>27</td>
<td>28</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>12 M</td>
<td>1.93</td>
<td>76</td>
<td>39</td>
<td>30</td>
<td>16</td>
<td>46</td>
</tr>
<tr>
<td>13 M</td>
<td>1.94</td>
<td>49</td>
<td>25</td>
<td>33</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>14 M</td>
<td>1.95</td>
<td>81</td>
<td>42</td>
<td>39</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>15 M</td>
<td>1.95</td>
<td>81</td>
<td>42</td>
<td>39</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>16 M</td>
<td>1.97</td>
<td>63</td>
<td>32</td>
<td>22</td>
<td>11</td>
<td>41</td>
</tr>
<tr>
<td>17 M</td>
<td>2.03</td>
<td>46</td>
<td>23</td>
<td>30</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>18 M</td>
<td>2.08</td>
<td>46</td>
<td>22</td>
<td>35</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>19 F</td>
<td>1.56</td>
<td>47</td>
<td>30</td>
<td>23</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>20 F</td>
<td>1.56</td>
<td>49</td>
<td>31</td>
<td>11</td>
<td>7</td>
<td>38</td>
</tr>
<tr>
<td>21 F</td>
<td>1.60</td>
<td>43</td>
<td>29</td>
<td>17</td>
<td>11</td>
<td>36</td>
</tr>
<tr>
<td>22 F</td>
<td>1.94</td>
<td>73</td>
<td>38</td>
<td>21</td>
<td>11</td>
<td>52</td>
</tr>
<tr>
<td>Mean</td>
<td>1.83</td>
<td>63</td>
<td>35</td>
<td>31</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>± 1 sd</td>
<td>0.14</td>
<td>16</td>
<td>8.7</td>
<td>10</td>
<td>5.8</td>
<td>13</td>
</tr>
</tbody>
</table>

BSA = body surface area; LA max = left atrial maximum volume; LA min = left atrial minimum volume; LAVC = left atrial volume change; LVSV = left ventricular stroke volume.

Discussion

The LA volumes found in these 22 patients agree with those reported by other workers (table 3),3, 6-9 and are of the same order of magnitude as those reported in a recent post-mortem study.10 Quantitation of LA size is helpful in evaluation of the atrial contribution to cardiac function. Figure 3 demonstrates the relationship of simultaneous LA and LV volume changes in a normal subject during successive cardiac cycles.

The phases of left atrial function may be designated as follows: 1. The reservoir phase that begins with mitral valve closure and continues through ventricular systole. During this phase, blood under propulsion from the right ventricle returns through the pulmonary veins and is stored in the left atrium. The left atrial maximum volume is reached at ventricular...
### Table 3

#### Normal Left Atrial Angiocardiographic Volumes

<table>
<thead>
<tr>
<th>Author</th>
<th>Number of patients</th>
<th>Method of calculation</th>
<th>LA max (cc)</th>
<th>LA min (cc)</th>
<th>LAVC (cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soloff et al.6</td>
<td>1</td>
<td>Estimate</td>
<td>100</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Grant et al.7</td>
<td>2</td>
<td>Arvidsson1</td>
<td>—</td>
<td>—</td>
<td>20</td>
</tr>
<tr>
<td>Bjork &amp; Lodins8</td>
<td>4</td>
<td>Arvidsson1</td>
<td>66</td>
<td>16</td>
<td>50</td>
</tr>
<tr>
<td>Preger et al.9</td>
<td>9</td>
<td>Arvidsson1</td>
<td>53</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>Hawley et al.3</td>
<td>2</td>
<td>Sauter et al.4</td>
<td>58</td>
<td>—</td>
<td>21</td>
</tr>
<tr>
<td>Murray et al.</td>
<td>22</td>
<td>Sauter et al.4</td>
<td>63</td>
<td>31</td>
<td>33</td>
</tr>
</tbody>
</table>

LA max = left atrial maximum volume; LA min = left atrial minimum volume; LAVC = left atrial cyclic volume change.

---

3. The contraction phase that begins with atrial systole and continues through mitral valve closure. During this phase, further reduction in atrial volume occurs until the minimum size is reached, but in normal subjects, volume changes in this phase are less than those during the conductive phase.

It is of interest that various forms of heart disease may alter the phases disproportionately. It appears that the reservoir function is expanded by chronic mitral regurgitation and decreased in constrictive pericarditis. The conduit function should be selectively augmented by high-output states but restricted by mitral stenosis. Similarly, the contribution of contractile function appears greatest in aortic stenosis but negligible in atrial fibrillation.

In normal subjects and in patients with mitral stenosis, aortic valvular disease and bivalvular lesions, the LAVC-LV stroke volume relationship is consistent as shown in

---

**Figure 3**

Simultaneous left atrial and left ventricular volume determinations in a normal subject.

---

**Figure 4**

Left atrial volume change in normal subjects and in several types of heart disease. Means and ranges are shown.
This relationship appears deranged in two circumstances, chronic mitral regurgitation\(^3\) and constrictive pericarditis.\(^9\) In chronic mitral regurgitation, LAVC is increased but LA pressures may or may not be increased.\(^4\) This suggests a change in the elastic properties of the atrial wall and pulmonary veins. These changes in chronic mitral regurgitation may be differentiated from the LA volume changes found in acute mitral insufficiency associated with ruptured chordae tendineae, as reported by Kennedy and co-workers.\(^11\)

Marked reduction in LAVC has been reported in a small number of patients with constrictive pericarditis. In these patients, quantitative observation of restrictions in LAVC was thought to be helpful in selection between medical and surgical therapy.

Quantitative angiocardiography, applied to the left atrium and left ventricle\(^12\) in normal subjects, provides a reference point for understanding altered anatomy and function in disease.

References

Quantitative Angiocardiography: II. The Normal Left Atrial Volume in Man
JOHN A. MURRAY, J. WARD KENNEDY and MELVIN M. FIGLEY

Circulation. 1968;37:800-804
doi: 10.1161/01.CIR.37.5.800
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1968 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/37/5/800

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/