

The Utility of Cardiac Apex Measurements In Upright Posteroanterior Chest Radiographs In Determining Ventricular Enlargement

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Background --- Displacement of the cardiac apex in the chest radiograph is one of the signs used in determining right or left ventricular enlargement. However, there is limited data regarding the objective assessment of the cardiac apex position for such purpose in the upright posteroanterior chest radiograph.

Objective --- This study was undertaken to determine the utility of measurements of cardiac apex position in the chest radiograph in detecting ventricular enlargement.

Methods --- This retrospective study included patients over the age of 18 years who had undergone echocardiography and chest radiography at the Philippine Heart Center between June 2007 and September 2007. Radiographic measurements of the cardiac apex position in upright posteroanterior chest films were compared with echocardiographic findings.

Results --- Chest radiographs of 306 patients who underwent echocardiography at the Philippine Heart Center were included in this study. Patients with normal ventricular dimensions by echocardiography (41%) have a mean cardiac apex – carinal vertex (AV) distance of 14.7 (\pm 1.3) cm, mean cardiac apex – diaphragm (AD) distance of 4.7 (\pm 1.4) cm, and mean cardiac apex – diaphragm / carinal vertex – diaphragm (AD/VD) ratio of 0.30 (\pm 0.05). Patients with right ventricular dilatation and normal-sized left ventricles (12%) have a mean AV distance of 15.7 (\pm 1.3) cm, mean AD distance of 5.6 (\pm 1.7) cm, and mean AD/VD ratio of 0.32 (\pm 0.08). Patients with dilated left ventricles and normal-sized right ventricles (38%) have a mean AV distance of 16.6 (\pm 2.1) cm, mean AD distance of 3.6 (\pm 1.3) cm, and mean AD/VD ratio of 0.22 (\pm 0.07). Patients with biventricular dilatation (9%) showed a mean AV distance of 17.9 (\pm 1.9) cm, mean AD distance of 4.3 (\pm 1.4) cm, and mean AD/VD ratio of 0.25 (\pm 0.07). All radiographic parameters between the groups showed significant overall mean differences in their values. Optimal cut-off points for each radiographic parameter were determined using receiver operating characteristic curves.

Conclusion --- Radiographic measurements of cardiac apex position may be useful tools to assist clinicians and radiologists in evaluating ventricular enlargement in patients. *Phil Heart Center J 2008; 14(1):42-47.*

Key Words: radiography ■ cardiac apex ■ ventricular enlargement

In these days of echocardiography, nuclear imaging, multi-slice computed tomography (CT), and cardiac magnetic resonance imaging (MRI), the conventional chest radiograph remains important in detection and monitoring of cardiac disease. Although its role has been undervalued, it provides the earliest opportunity in many instances for diagnosing all forms of cardiac disease.¹

The evaluation of the chest film in the cardiac patient involves sequential logical assessment and correlation of both anatomic and physiologic information available on the radiographs. Overall cardiac size as well as specific cardiac chamber enlargement can be identified

based on changes in cardiac contour.

Cardiac apex displacement in the posteroanterior chest radiograph is a frequently cited sign in determining ventricular enlargement. If the right ventricle is enlarged, there would be an uplifted cardiac apex in the chest film while left ventricular dilatation results in displacement of the apex of the heart inferiorly.^{1,2} Despite frequent citations in literature, for most clinicians, this subjective radiologic sign is quite vague since there is no definite cut-off point that would tell when the cardiac apex is displaced superiorly or inferiorly. Therefore, an objective radiologic assessment of cardiac apex position is needed.

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Ventricular evaluation, in the upright posteroanterior chest radiograph is difficult. The classic signs so often enumerated are unreliable.^{1,2} Danzer described the cardiothoracic ratio, which is still one of the most common measurements of overall heart size.³ This ratio was constructed to measure left ventricular dilatation. Because it measures the transverse heart diameter, the cardiothoracic ratio is usually normal when either the left atrium or the right ventricle is moderately enlarged, because neither of these two chambers is reflected in the transverse dimension. The left atrium and right ventricle become border-forming when they are severely enlarged. Rose and colleagues⁴ noted that changes in the left ventricular volume up to 66 % in excess of normal are needed for the cardiothoracic ratio to reliably detect enlargement of the left ventricle. A cardiothoracic ratio of more than 0.5 is found to be only 45% sensitive but 85% specific in detecting left ventricular dilatation. This means that many patients with left ventricular dilatation are not detected by the cardiothoracic ratio but when the ratio exceeds the normal value, the heart is clearly enlarged.

Another sign of left ventricular enlargement is an increase in length of the left heart border as measured from the lower margin of the pulmonary artery segment to the apex. This lengthening is due to the downward extension of the heart so that the apex often lies below the diaphragmatic curve.⁵

Right ventricular enlargement is difficult to assess in the posteroanterior chest film. The right ventricle should be significantly enlarged in order for it to be manifested in the said projection. If this chamber is significantly enlarged, the cardiac apex is usually described to be uplifted or the left cardiac border maybe round, resembling that seen in left ventricular enlargement, but the cardiac apex does not extend below dome of diaphragm.^{1,2,3,5,6,7,8}

What is the cardiac apex in the chest radiograph? There are different points in the cardiac shadow that were considered as apices. Most literature would mention that the cardiac apex is the lower end of the long diameter of the cardiac silhouette.^{1,2,3,5,6,7,8} In a study done by Walker and colleagues,⁹ the position of the clinical apex beat projected on chest radiographs was compared to different points on the cardiac outline which have been regarded as radiological apices. Good correlation was found between the clinical apex and the most lateral point of the left cardiac border, but not the lower end of the long diameter of the heart.

To date, there is paucity of published data regarding objective assessment of the position of the cardiac apex in the posteroanterior chest radiographs in distinguishing right and left ventricular enlargement. For

this reason, this study was conducted to determine the utility of measurements of cardiac apex position in the upright posteroanterior chest radiograph in detecting ventricular enlargement. Specifically, we determined the mean cardiac apex to carinal vertex (AV) distance, cardiac apex to diaphragm (AD) distance, and ratio of cardiac apex to diaphragm and carinal vertex to diaphragm (AD/VD) in patients with normal-sized ventricles; mean AV distance, AD distance, and AD/VD ratio in patients with right or left ventricular enlargement; mean AV distance, AD distance, and AD/VD ratio in patients with right and left ventricular (biventricular) enlargement; and the optimal cut-off points of AV distance, AD distance, and AD/VD ratio in distinguishing normal from enlarged ventricles.

Methods

We used a retrospective cross-sectional study to determine the utility of radiographic parameters for the cardiac apex position in the upright posteroanterior chest films in determining normal ventricular dimension, right and/or left ventricular dilatation using echocardiography as the gold standard.

All consecutive patients over the age of 18 years who had an upright posteroanterior chest radiograph and underwent echocardiography at a time difference of 3 months or less from June 2007 to September 2007 at the Philippine Heart Center were considered for this study. The chest radiographs were taken in true upright posteroanterior projection at the end of full inspiration with a tube-film distance of 72 inches.

Radiographs with any of the following were excluded in the study: (1) poor technique; (2) presence of pericardial effusion; and (3) presence of lung, pleural, or any thoracic pathology (i.e., consolidations, lobar atelectasis, pleural effusions, pulmonary hyperaeration, vertebral deformities) which may obscure or distort the cardiac silhouette and diaphragm.

Sample Size and Basis of Calculation

A trial study was done using 15 eligible subjects in order to compute for the sample size. At $\alpha = 0.05$, $\beta = 0.20$, and assumed difference in the cardiac apex – diaphragm (AD) / carinal vertex – diaphragm (VD) ratio between patients with and without left ventricular enlargement of 0.036 ± 0.018 , a sample size of equal to or greater than 68 was estimated with at least 17 patients per category.

Description of Data Collection

The chest radiographs were labeled randomly by number, obscuring any reference to patient name, age, or sex. Three radiologists, each of whom reviewed the

films independently without any clinical information about the patients. Each radiograph was determined by the radiologists to be of sufficient quality and appropriate exposure to allow interpretation. Radiologists recorded their findings on a standardized report form for each patient. For the purpose of this study, the most lateral point of the left cardiac border (Figure 1) is chosen as the radiologic cardiac apex. It is easier and more often seen in the chest radiograph and also shows better correlation with the clinical cardiac apex as compared with the lower end of the long diameter of the cardiac silhouette, which is also occasionally obscured by the diaphragm.⁹

The cardiac apex – carinal vertex (AV) distance was measured in centimeters from the point of tracheal bifurcation to the radiologic cardiac apex (Figure 2). The cardiac apex – diaphragm (AD) distance was measured in centimeters by drawing a horizontal line at the level of the left costophrenic sulcus and measuring perpendicularly to the point of the radiologic cardiac apex (Figure 3). The cardiac apex – diaphragm (AD) / carinal vertex – diaphragm (VD) ratio was calculated by dividing the AD distance with the perpendicular distance of the carinal vertex from the horizontal line drawn at the level of the left costophrenic sulcus (Figure 4). The resulting quotient was rounded to the nearest hundredths. The averages of the three radiologists' measurements (AV distance; AD; and AD/VD ratio) were computed and used as basis for correlation with the echocardiographic findings. Patients were divided into the following categories according to the echocardiographic findings:

Group A - those with normal-sized chambers (right and left ventricles)

Group B - those with dilated right ventricle but normal left ventricle

Group C - those with dilated left ventricle but normal right ventricle

Group D - those with right and left ventricular dilatation.

A left ventricular end-diastolic dimension of more than 5.0 cm and right ventricular dimension of more than 4.0 cm are the echocardiographic criteria used for ventricular dilatation.^{10,11} The mean (\pm SD) and optimal cut-off points of the radiologist's measurements per category were determined.

Statistical Analysis

A pre-study estimate of the reproducibility of the radiographic measurements (AV distance; AD; and AD/VD ratio) was done using chest radiographs of 10 subjects. The intra- and inter-reader correlation coefficients were

obtained from a random effect analysis of variance. Data gathered for this study was presented as frequencies and percent distribution. Descriptive analysis using means and standard deviation were computed for the radiographic parameters. Comparisons of mean values of the different parameters were carried out using independent t-test. Different cut-off points were established for each radiographic parameter. The sensitivity, specificity, positive and negative predictive values of these cut-off points were computed. Kappa (κ) statistics was used to evaluate agreement. Receiver operating characteristic (ROC) curves were constructed to determine the best cut-off points. For all statistics, p-values less than 0.05 were considered significant.

Results

Using chest radiographs of 10 subjects, the intrareader and inter-reader correlation coefficients were obtained and are summarized in Tables 1 and 2. For the AV distance, intrareader correlation coefficients ranges from 0.922 to 0.989 ($p < 0.000$) while that of the inter-reader ranges from 0.692 to 0.980 ($p = 0.000$ to 0.019). AD distance intrareader correlation coefficients ranges from 0.759 to 0.991 ($p = 0.000$ to 0.011) while AD distance inter-reader correlation coefficients ranges from 0.888 to 0.998 ($p = 0.000$ to 0.001). The intrareader and inter-reader correlation coefficients for AD/VD ratio were 0.956 to 0.980 ($p = 0.000$ to 0.001) and 0.727 to 0.992 ($p = 0.000$ to 0.019), respectively. Overall values indicate strong positive correlations between readings.

Chest radiographs of 306 patients who underwent echocardiography at the Philippine Heart Center were included in this study. Patients were either normal or diagnosed to have rheumatic heart disease, cardiomyopathy, or congenital heart disease. Out of the 306 subjects, 127 (41%) had normal-sized right and left ventricles by echocardiography (Group A). Right ventricular dilatation is seen in 36 (12%) of the subjects (Group B) while 116 (38%) showed dilated left ventricles (Group C). The remaining 27 (9%) had dilated right and left ventricles in their echocardiography reports (Group D).

As shown in Table 3, patients with normal ventricular dimensions by echocardiography have a mean (\pm SD) AV distance of 14.7 (\pm 1.3) cm, mean (\pm SD) AD distance of 4.7 (\pm 1.4) cm, and mean (\pm SD) AD/VD ratio of 0.30 (\pm 0.05). Patients with dilated right ventricles and normal-sized left ventricles have a mean (\pm SD) AV distance of 15.7 (\pm 1.3) cm, mean (\pm SD) AD distance of 5.6 (\pm 1.7) cm, and mean (\pm SD) AD/VD ratio of 0.32 (\pm 0.08). Patients with dilated left ventricles and normal-sized right ventricles have a mean (\pm SD) AV distance of 16.6 (\pm 2.1) cm, mean (\pm SD) AD distance of 3.6 (\pm 1.3) cm, and mean (\pm SD) AD/VD

ratio of 0.22 (\pm 0.07). Patients with biventricular dilatation showed a mean (\pm SD) AV distance of 17.9 (\pm 1.9) cm, mean (\pm SD) AD distance of 4.3 (\pm 1.4) cm, and mean (\pm SD) AD/VD ratio of 0.25 (\pm 0.07). Using ANOVA, all radiographic parameters (AV distance, AD distance, and AD/VD ratio) between the groups showed significant overall differences in their values ($p = 0.000$).

Table 4 shows multiple comparisons of the different radiographic measurements between the groups. For the AV distance, measurements done on chest radiographs of patients belonging to groups B and C show statistically insignificant mean difference. The rest of the groups show statistically significant intergroup mean differences in their AV distance measurements. AD measurements done between groups A and B, A and C, B and D, and between groups B and C show statistically significant mean differences while those between groups A and D and between groups C and D are not. The mean differences of AD/VD ratios between groups A and C, A and D, B and C, and between group B and D are also statistically significant. Intergroup comparisons between groups A and B and between groups C and D show statistically insignificant mean differences in their AD/VD ratios.

The different cut-off points of the different radiographic measurements with their corresponding sensitivities and specificities are shown in Tables 5 to 13. Receiver operating characteristic (ROC) curves constructed based on the tabulated data show the optimal cut-off points for each radiographic parameter in detecting specific ventricular enlargement. Most measurements made from the chest films have poor agreement with ventricular size from quantitative echocardiographic measurements.

For the AV distance, the optimal cut-off point is 16.0 cm. A measurement of less than 16.0 cm may suggest right ventricular enlargement (sensitivity of 44.1% and specificity of 41.9%). A measurement equal to or more than 16.0 cm may be indicative of left ventricular enlargement with a sensitivity of 60.3% and specificity of 66.8%. A measurement of 17.0 cm or more may suggest biventricular enlargement (sensitivity of 77.8% and specificity of 78.9%).

An AD distance of 4.0 cm or more is 75% sensitive and 44.8% specific in telling us that the patient may have right ventricular enlargement based on the radiograph (75% sensitivity and 44.8% specificity). If the AD distance measures less than 4.0 cm, left ventricular enlargement (with 62.9% sensitivity and 70.0% specificity) or combined right and left ventricular enlargement (with 44.4% sensitivity and 57.7% specificity) may be considered.

AD/VD ratios of less than 0.25 are usually seen in patients with left ventricular (68.1% sensitivity and 72.1% specificity) and biventricular (70.4% sensitivity and 58.5% specificity) enlargement. Right ventricular enlargement may be detected if the ratio is 0.30 or more with a sensitivity of 52.8% and specificity of 71.1%.

Discussion

The chest radiograph is often the first imaging modality requested when heart disease is suspected, and, more commonly, it is used to assess and follow the severity of cardiac disease. Because the chest film form images by projection, this technique detects only those cardiopulmonary abnormalities that change the shape of the heart, mediastinum, and lungs.^{1,2,3,5} Following the assessment of cardiac size, the contour of the heart should be evaluated for signs of specific chamber enlargement. Specific chamber enlargement indicates an earlier stage of disease than general cardiac enlargement.^{7,10} Furthermore, it suggests the site and nature of underlying structural changes. Individual cardiac chambers may be enlarged with or without accompanying cardiomegaly but as each chamber of the heart enlarges, the cardiac contour is altered in a logical and predictable fashion based on their location within the heart.^{1,7} The cardiac apex is regarded as one of the anatomic landmark used in assessing changes in the cardiac silhouette. In normal individuals, the apex is located posterior to the left 5th intercostal space in adults, 7 to 9 cm from the median plane, and just left of the midclavicular line. The apex beat is an impulse imparted by the heart; it is its point of maximal pulsation or the lowest, most lateral point at which pulsation can be felt. The radiologic cardiac apex used in this study corresponds approximately to the apex beat. The true cardiac apex is actually further inferolaterally and does not contact the thoracic wall in systole.⁹ When the ventricles of the heart enlarge, the radiologic cardiac apex is expected to displace superiorly or inferiorly depending on the enlarged chamber. Because the right ventricle is the most anterior of the cardiac chambers, right ventricular enlargement is initially detected on the lateral view and often does not cause overt cardiomegaly. As the right ventricle becomes more dilated, cardiomegaly ensues. There is displacement of the left ventricle posteriorly and rotation of the heart to the left as the right ventricle forms the left heart border. As a result, on the posteroanterior film, the axis of the heart becomes relatively horizontal in its orientation and the cardiac apex displaced in a higher position. Sometimes, the left cardiac border is round, resembling that seen in left ventricular enlargement, but cardiac apex does not extend below dome of diaphragm.^{1,2,3,5} In extreme

instances the entire left heart border may be the right ventricle. In tetralogy of Fallot when the right ventricle is usually hypertrophied and the fat pad is absent in the left cardiophrenic angle, the heart have an uplifted cardiac apex, which has been called the “boot-shaped heart” or the *cœur en sabot*.^{1,3,5}

It was expected that in right ventricular enlargement the cardiac apex would be in a higher location and will give us a shorter AV distance, longer AD distance, and higher values for AD/VD ratio. But the measurements in this study were not those as expected (Table 3). The results were not so predictive of right ventricle enlargement. The location of the right ventricle, being the most anterior chamber, is most likely the reason for the results. This would explain why subtle enlargement of the right ventricle is missed in posteroanterior chest radiographs. When the right ventricle enlarges, the cardiac apex does not directly displace upwards due to rotation of the heart to the left. Since the right ventricle is limited anteriorly by the sternum, it pushes the left ventricle posteriorly into the left hemithorax where there is least resistance causing the heart to rotate in a clockwise direction as viewed from below. This behavior of the heart in right ventricular enlargement is likely the reason why we do not see much upward displacement of the cardiac apex.

The left ventricle, based on its location, enlarges inferiorly and posteriorly. Simple left ventricle hypertrophy usually does not affect the overall cardiac size sufficiently to be detectable on the chest film, unless there is also concomitant cardiac decompensation. Left ventricular dilatation, however, results in displacement of the apex of the heart inferiorly. The cardiac axis clearly points downward in most cases of the left ventricular enlargement, unlike the transverse or horizontal axis seen in isolated right ventricular enlargement. Left ventricular enlargement exists if the left heart border is displaced leftward or inferiorly. Inferior displacement may invert the diaphragm and cause this border to appear in the gastric bubble. The chest film cannot reliably distinguish between left ventricular dilatation and hypertrophy. With hypertrophy, the apex has a pronounced rounding and a decrease in its radius of curvature. The elderly normal heart also has this shape. When massive hypertrophy is present, the left ventricular shape is large and appears similar to one that is only dilated.^{1,5,7}

As compared to individuals with normal ventricular sizes, patients with left ventricular enlargement may have chest radiographs with longer AV distance, shorter AD distance, and lower values for AD/VD ratio (Table 3). The cut-off points of the for AV distance (≥ 16.0 cm), AD distance (< 4.0 cm), and AD/VD ratio (< 0.25)

showed better sensitivities and agreement in detecting left ventricular enlargement.

In some instances, distinguishing right and left ventricular enlargement in chest radiographs is very difficult. The left ventricle can enlarge, pushing the right ventricle up and forward, filling in the retrosternal space, a classic sign of right ventricular enlargement. The right ventricle can enlarge, pushing the left ventricle down into the gastric air shadow and back against the spine (a classic sign of left ventricular enlargement).^{3,9} Frequently in right ventricular enlargement, the normal left ventricle may falsely appear enlarged on both posteroanterior and lateral chest radiographs because the entire heart is displaced posteriorly. If the right ventricle is dilated, the diagnosis of left ventricular enlargement may not be possible in the chest film (Dinsmore’s principle).³ Therefore, you should assess the size of the right ventricle on the lateral film before you judge the left ventricle.

Identifying biventricular enlargement in posteroanterior chest radiographs is also difficult and is frequently indistinguishable with signs of left ventricular enlargement. The findings would also depend on the more abnormal chamber, but usually the cardiac apex is displaced inferiorly as shown by the radiographic parameters (Table 3). If the right and left ventricles are enlarged, the cut-off points for AD distance and AD/VD ratio are the same with isolated left ventricular enlargement. Although these measurements may serve as useful tools in distinguishing ventricular enlargement, they should still be complemented with other radiographic evidences in the posteroanterior chest film.

Conclusion

Measurements of the cardiac apex position (AV distance, AD distance, and AD/VD ratio) may be useful tools to assist clinicians and radiologists in evaluating ventricular enlargement using posteroanterior chest radiographs. The mean values of each radiographic parameter were determined in patients with and without ventricular enlargement. The optimal cut-off points of these measurements were established increasing the sensitivity of chest radiography in distinguishing enlarged ventricles. In the majority of cases these measurements should provide additional support for assessing the severity of cardiac disease. However, these measurements can never be used as the sole criteria for diagnosis. We stress that history and clinical findings remain the paramount arms in decision-making. These radiographic measurements should therefore be used to complement other evidence of ventricular enlargement when echocardiography is not readily available. Further study would be useful to assess the true accuracy

of these measurements. Therefore, the measurements of specific chamber diameters, volumes, and wall thickness should still be made from techniques that show the chamber cavities (e.g., echocardiography, angiography, CT, and MRI).

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