MORPHOLOGIC STUDIES

Right Ventricular Infarction: Frequency, Size and Topography in Coronary Heart Disease: A Prospective Study Comprising 107 Consecutive Autopsies From a Coronary Care Unit

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During a 14 month period autopsies were performed on 107 patients with coronary heart disease and the results were evaluated prospectively with special reference to right ventricular infarction. A total of 214 regional infarcts were found, 107 (50%) of which involved the right ventricle. Right ventricular infarction was found in 90 hearts (84%), but only three isolated right ventricular infarcts were seen. Right ventricular involvement was found with equal frequency in anterior and posterior infarction (64 versus 66%), but posterior right ventricular infarcts were much larger (15% of the right ventricle was infarcted versus 1%). Proximal right coronary artery occlusion caused larger right ventricular infarction than did distal occlusion (15 versus 5 g). Right ventricular infarct size was not influenced by coronary artery disease (evaluated angiographically) in noninfarct-related vessels.

Since the initial autopsy report (1) on infarction of the right ventricle, pathologic studies (2–20) have reported conflicting results on incidence, size and distribution of right ventricular involvement in acute myocardial infarction. The incidence rate varies between 1 (5) and 85% (11), and the amount of involvement ranges from 2 to 91% of the right ventricle (11). These discrepancies reflect differences in study design, autopsy techniques and study groups. The study design most frequently applied has been retrospective evaluation of right ventricular involvement in selected autopsies showing acute or healed left ventricular myocardial infarction (2–4,8,13,14), in which the autopsy procedure was not primarily designed for the detection of right ventricular infarction. There are very few prospective studies (12,17) dealing with right ventricular involvement in acute myocardial infarction verified by postmortem examination.

The aim of the present study was to evaluate prospectively right ventricular infarction in patients admitted with coronary heart disease documented by pathologic observations in a consecutive autopsy series from a coronary care unit.

Methods

Study patients. The coronary care unit of Aalborg Sygehus (1,200 beds) serves a community of approximately 155,000 persons. During the 14 month study period (November 1984 to January 1986), 1,331 patients were admitted with known or suspected coronary heart disease, and the diagnosis was established clinically in 1,082. A total of 574 acute myocardial infarcts according to World Health Organization (WHO) criteria (22) were diagnosed in 505 patients. Of the 1,082 patients diagnosed as having coronary heart disease, 235 died before discharge from the coronary care unit, and autopsy was
Figure 1. Photographs of 1 cm thick transventricular sections with corresponding coronary angiograms illustrating acute myocardial infarction (AMI) with corresponding poor contrast filling in the myocardium perfused by thrombosed arteries ("risk areas"). A and B, Occluded (ocl.) left anterior descending (LAD) artery with anterior myocardial infarction involving a small portion of the right ventricle. C to F, Thrombosed right (R) coronary artery with extensive right ventricular infarction associated with a small (C and D) and large (E and F) posterior left ventricular infarct. G and H, Thrombosed circumflex (CX) artery with lateral/posterior infarction involving the posterior right ventricular wall.
performed on 107. Autopsy was requested and, if not prohibited, performed on all included patients who died in the hospital. It was not performed on patients who died in another hospital, outside the hospital or in the emergency room before arrival in the coronary care unit. There were 72 men (mean age 66.8 years, range 40 to 88) and 35 women (mean age 69.8 years, range 54 to 84) with coronary heart disease. A similar sex and age distribution was found in the 128 patients who did not undergo autopsy.

Autopsy Procedure

The heart was removed and weighed. 

Coronary arteries. Postmortem coronary angiography was performed with a barium-gelatin mixture injected gently through a catheter into the ascending aorta. Angiograms were taken in different projections. After fixation, the coronary arteries were dissected from the myocardium and decalcified and X-ray films were made with the arteries placed directly on the radiographic film (Kodak X-Omat MA). From these angiograms, coronary artery lesions were identified and stenosis was graded visually as a diameter reduction of 50 to 74%, 75 to 89%, or 90 to 99%, nearly complete occlusion (just passable for angiographic medium) or complete occlusion.

To clarify whether acute thrombosis was present, doubtful lesions were cut transversely and, if doubt persisted, studied by microscopy. The epicardial coronary arteries investigated were the left main stem, the left anterior descending artery with major diagonal and septal branches, the left circumflex artery with its marginal (obtuse) branch and the right coronary artery with its marginal (acute) branch. The pattern of coronary artery distribution was noted with special reference to the origin of the posterior descending artery and the vascular supply of the posterior left ventricular wall.

Myocardium. After chilling of the heart, the ventricular portion was cut into 1 cm thick slices parallel to the atrioventricular groove with an electric meat slicer. The slices were photographed (Kodak Ektachrome) and X-ray films were made with the slices placed directly on the radiographic film (Fig. 1). After incubation in a nitro blue tetrazolium solution to visualize reduced dehydrogenase activity (nitro BT test for demarcation of early infarction [23,24]), the basal surface of each slice was photographed again, and 13 x 19 cm color prints were prepared for planimetry (Fig. 2). Myocardial infarction was identified distal to coronary artery obstruction, and the demarcation of each infarct was drawn on the color prints on the basis of a combined evaluation of 1) myocardium with poor contrast filling distal to thrombosed arteries ("risk area"), 2) gross changes, 3) reduced dehydrogenase activity regionally, and 4) microscopic changes (Fig. 1 and 2). Histologic sections were prepared from myocardial "risk areas" if infarction was not identified by gross examination.

Figure 2. Photographs of a transventricular section before (A) and after (B) nitro blue tetrazolium (NBT) test with corresponding coronary angiogram (C). The left ventricle was divided into equiangular thirds for classification of infarct site (anterior, lateral posterior), and each ventricle and septum was measured by planimetry separately using boundaries as illustrated in B. Obviously, the acute myocardial infarction (AMI) is more clearly demarcated after the NBT test (as a result of dehydrogenase depletion) (B), in agreement with the "hypoperfused" area (C). RV = right ventricle.
Table 1. Intraobserver Variation in Estimating Infarct Size in 10 Patchy Fibrotic Infarcts Measured Twice Within an Interval of 3 Months

<table>
<thead>
<tr>
<th>Infarct No.</th>
<th>First Measurement (g)</th>
<th>Second Measurement (g)</th>
<th>Difference (d) (g)</th>
<th>(d^2) (g²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.8</td>
<td>10.0</td>
<td>0.8</td>
<td>0.64</td>
</tr>
<tr>
<td>2</td>
<td>5.3</td>
<td>5.3</td>
<td>0.0</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>31.0</td>
<td>28.7</td>
<td>2.3</td>
<td>5.29</td>
</tr>
<tr>
<td>4</td>
<td>3.2</td>
<td>3.4</td>
<td>0.2</td>
<td>0.04</td>
</tr>
<tr>
<td>5</td>
<td>12.7</td>
<td>12.3</td>
<td>0.4</td>
<td>0.16</td>
</tr>
<tr>
<td>6</td>
<td>4.5</td>
<td>6.3</td>
<td>1.8</td>
<td>3.24</td>
</tr>
<tr>
<td>7</td>
<td>10.2</td>
<td>11.2</td>
<td>1.0</td>
<td>1.00</td>
</tr>
<tr>
<td>8</td>
<td>21.0</td>
<td>24.5</td>
<td>3.5</td>
<td>12.25</td>
</tr>
<tr>
<td>9</td>
<td>4.4</td>
<td>4.3</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>10</td>
<td>23.8</td>
<td>22.7</td>
<td>1.1</td>
<td>1.21</td>
</tr>
<tr>
<td>Mean</td>
<td>(\bar{X}_1 = 12.7)</td>
<td>(\bar{X}_2 = 12.9)</td>
<td>(\Sigma d^2 = 23.84)</td>
<td></td>
</tr>
</tbody>
</table>

Nitro BT test. After death the bodies were kept at 12°C for 6 to 12 hours and then refrigerated until necropsy. The death to necropsy interval was <100 hours in all but one case (median 23 hours), and the test was performed a few hours later. All myocardial slices were tested in the majority of cases, otherwise every second slice. The slices were incubated for 30 minutes (turned after 15 minutes) at 37°C in a 0.5% nitro BT solution in phosphate buffer (pH 7.4). Alternating myocardial slices were tested with or without added exogenous substrate (0.1 M succinate, or 0.1 M lactate with coenzyme nicotine adenine dinucleotide [NAD]) to evaluate the effect of postmortem autolysis. Adding substrate/coenzyme should "eliminate" the effect of even long-lasting autolysis, but reduces the sensitivity of the test (23,24). Nitro BT stains normal muscle dark blue, and necrotic muscle without enzymes, coenzymes or substrates remains pale (Fig. 2).

Age of infarction. 1) "Risk area": myocardium with poor contrast filling distal to thrombosed arteries without gross, "enzymatic" or histologic necrosis. In these cases,
demarcations were drawn using the X-ray images of the myocardial slices. 2) Acute infarction: grossly yellow necrosis, clearly reduced dehydrogenase activity regionally or microscopic coagulation necrosis with polymorphonuclear leukocytic infiltration. An acute infarct was considered 100% necrotic within its demarcations even though areas of apparently surviving cells were intermingled. Subendocardial enzyme depletion outside the perfusion area of the thrombosed artery was not considered part of the primary infarct, and right ventricular necrosis limited to the papillary muscle was disregarded. 3) Infarct fibrosis: Healed infarct without acute necrosis. The extent of fibrosis within patchy infarcts was estimated to the nearest 10%. Correction was made for wall thinning due to loss of infarct mass during healing.

**Site of infarction.** The left ventricle was divided into equiangular thirds (Fig. 2A) (25), and infarcts were classified as anterior, lateral or posterior (electrocardiographically usually referred to as inferior or inferior/posterior) according to which third of the left ventricle contained the largest amount of infarct as determined by planimetry.

**Measurements.** Planimetric measurements were made on color prints of each myocardial slide with a Hewlett-Packard 9864A digitizer/9810A calculator (Hewlett Packard Products) (26). Each slice was regarded as cylindric, and the myocardial volume of the septum and left and right ventricles was calculated using boundaries as illustrated in Figure 2B (25). Infarcts within each part were measured separately. The total volume of each part of the heart, of each infarct and of infarcts within each part were calculated and expressed in cubic centimeters and grams (1 cc = 1.05 g) (25). The right ventricle was divided into an apical, middle and basal third along the apex-base axis, and total tissue volume and infarcted myocardial volume were calculated for each third.

**Reliability of measurements.** All the autopsies were performed by the pathologist (E. F.). Classification of coronary artery lesions and demarcation of infarcts were performed by two investigators jointly (H.R.A. and E.F.). Planimetric measurements and computer calculations were performed by one investigator (H.R.A.). Infarct measurements and computer calculations were performed with one decimal rounded to the nearest whole number for presentation.

The resolution of the digitizer system in length measurements is 0.08 mm, giving an accuracy of ±0.08 mm (26). The intrinsic error of the digitizer equipment in area measurements is calculated to <0.03 mm². The intraobserver variation in planimetric measurements was checked by measuring the same area 10 times and by performing 10 repeated measurements of the same infarct. The coefficient of variation was 0.3% for the first measurement and 1.3% for the second measurement. To estimate the intraobserver variation in classifying extent of fibrosis within patchy infarcts, 10 different patchy infarcts were evaluated blindly.

**Figure 3.** Right ventricular (RV) infarct fibrosis was as frequently found as right ventricular acute myocardial infarction (MI). **A,** Occluded left anterior descending artery with anterior infarct fibrosis involving a small part of the right ventricle. **B,** Occluded right marginal branch with isolated right ventricular infarct fibrosis (confirmed microscopically). Additionally, the left anterior descending coronary artery was occluded, with anterior infarct fibrosis involving a very small part of the right ventricle. **C,** Occluded right coronary artery (proximal occlusion) with extensive right ventricular infarct fibrosis (confirmed microscopically) as part of an old posterior infarct.
twice within an interval of 3 months (Table 1). The coefficient of variation was 8.5%.

Statistical methods. Assessment of variance in double determinations was performed by calculating the pooled standard deviation (PSD) according to the formula:

\[
PSD^2 = \frac{1}{2K} \sum_{i=1}^{K} d_i^2,
\]

where \(d\) = the difference between two double determinations and \(K\) = the number of samples. The coefficient of variation (CV%) in double determinations was calculated as:

\[
CV\% = \frac{PSD}{(X_1 + X_2) / 2} \times 100,
\]

where \(X_1\) and \(X_2\) are the mean values of measurements 1 and 2, respectively. In the tables, median values and range are presented. The Mann-Whitney rank test was used to test for differences in median values. A significance level of \(p < 0.05\) was chosen, and two-sided tests were used.

Results

Frequency of right ventricular infarction. In 107 hearts, a total of 214 regional infarcts was found (Table 2). In three hearts, three areas of isolated right ventricular infarct fibrosis were found (2.8%), all due to occlusion of a right marginal (acute) branch supplying the right ventricle only (Fig. 3B). Isolated acute right ventricular infarction was not seen. Combined left and right ventricular infarcts were found in 90 hearts (84%), and left ventricular infarcts alone were found in 17 hearts (16%). Eighty-five anterior infarcts, 56 lateral infarcts and 70 posterior left ventricular infarcts were found. The frequency of right ventricular infarction associated with these different sites of left ventricular infarction is presented in Table 3. Right ventricular infarction accompanied anterior and posterior left ventricular infarction with equal frequency, but rarely accompanied lateral infarction.

Size of right ventricular infarction. The site, size and distribution of acute infarction in 31 hearts from patients who died from a first infarct are presented in Table 4. Total infarct size was equal (measured as grams of infarcted myocardium) in acute anterior and posterior infarcts, but posterior infarcts were associated with significantly larger right ventricular infarction. Among all acute infarcts, more than one-fourth of infarcted myocardium was located in the right ventricle in 11 of 23 posterior infarcts, whereas none of 38 acute anterior infarcts had such extensive right ventricular involvement. A greater part of the left ventricle was intact after posterior than after anterior acute infarction (Table 4). Right ventricular infarct fibrosis (Fig. 3) was found in 13 hearts from 24 patients dying with only one left ventricular infarct fibrosis (acute infarction, if present, was disregarded) (Table 5).

Table 3. Frequency and Size of Right Ventricular Infarct Accompanying 211 Regional Left Ventricular Infarcts in 107 Patients

<table>
<thead>
<tr>
<th>Site</th>
<th>Frequency* (%)</th>
<th>Size† (g%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>64</td>
<td>1</td>
</tr>
<tr>
<td>Lateral</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>66</td>
<td>15</td>
</tr>
</tbody>
</table>

*Percent left ventricular infarcts accompanied by right ventricular infarction. †Gram percent of the right ventricle infarcted.

Table 4. Site, Size and Distribution of 27 Acute Infarcts in Hearts Without Infarct Fibrosis

<table>
<thead>
<tr>
<th>Acute Infarction</th>
<th>Anterior (n = 17)</th>
<th>Posterior (n = 10)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total infarct size (g)</td>
<td>41(19 to 97)</td>
<td>42(26 to 113)</td>
<td>NS</td>
</tr>
<tr>
<td>Right ventricular infarct size (g)</td>
<td>20(0 to 13)</td>
<td>15(5 to 32)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Percent of right ventricle infarcted</td>
<td>11(0 to 40)</td>
<td>50(12 to 76)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Percent of total infarct located in the right ventricle</td>
<td>7(0 to 17)</td>
<td>28(9 to 79)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Intact (noninfarcted) left ventricle (%)</td>
<td>64(16 to 87)</td>
<td>79(49 to 93)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Infarcts with right ventricular involvement (n)</td>
<td>16</td>
<td>10</td>
<td>NS</td>
</tr>
</tbody>
</table>

In four patients who died from a first lateral infarct (not listed), only one infarct was accompanied by right ventricular infarction.
Proximal versus distal occlusion and right ventricular infarct size. In posterior right ventricular infarction due to right coronary artery occlusion, infarct size was much greater when the occlusion was proximal rather than distal to the origin of the marginal (acute) branch (Table 6). In anterior infarction, no significant difference in right ventricular infarct size was seen as a function of the location of the occlusion in the left anterior descending artery.

Potential collateral flow and right ventricular infarct size. To evaluate the significance of disease in noninfarct-related vessels in relation to infarct size, acute right ventricular infarct size with or without stenosis in vessels other than the infarct-related vessel was compared (Table 7). Significant coronary artery disease was defined as angiographic diameter stenosis ≥ 75% seen in 1) the circumflex artery or its left marginal branch, 2) the left anterior descending artery or its largest diagonal branches, and 3) the right coronary artery or its right marginal branch. No connection between right ventricular infarct size and the presence or absence of significant coronary artery stenosis in noninfarct-related vessels was found. In fact, the largest right ventricular infarct was found in a heart with only one vessel disease.

Coronary artery distribution and right ventricular infarct site. The posterior descending artery originated from the right coronary artery in 95 hearts (89%), from the left circumflex artery in 11 hearts (10%) and from both (two descending arteries) in 1 heart (1%). Accordingly, 21 (91%) of 23 acute posterior right ventricular infarcts were caused by disease in the right coronary artery (Fig. 1C to F), whereas 2 (9%) of 23 were caused by circumflex artery occlusion (Fig. 1G and H). All anterior right ventricular infaracts were caused by disease in the left anterior descending artery (Fig. 1A and B).

Topography of right ventricular infarction. Right ventricular involvement was quite different in anterior and posterior infarction (Fig. 4). Posterior infarcts had triangular-shaped involvement with a broad base in the most basal part of the right ventricle and the infarct apex pointing toward the apical part of the heart. Anterior infarcts had triangular right ventricular involvement with a broad base in the apical third of the ventricle, and the infarct apex pointing toward the basal part of the heart. In posterior infarction, 40% of right ventricular infarct weight was located in the basal third of the right ventricle and only 16% in the apical third. In anterior infarction, only 9% of the right ventricular infarct weight was located in the basal third and 45% was located in the apical third. Posterior infarcts rarely had a 100% circumferential involvement, because the most anteroseptal right ventricular wall was always supplied by the left anterior descending artery and the conus artery. Anterior infarcts had their largest circumferential involvement in the apical third, where they were 100% circumferential in hearts with a left anterior descending artery bending around the apex of the heart, thus supplying the whole apical region (Fig. 4 and 5). However, 100% right ventricular circumferential involvement was never found in the middle...
or the basal third in anterior infarcts. In contrast to left ventricular infarction, right ventricular infarction seemed to have no predilection for the subendocardial myocardium.

**Discussion**

Right ventricular infarction may easily be missed at postmortem examination. The autopsy technique used in this study was very time consuming, but it showed right ventricular infarction in a sizable proportion of patients who died in a coronary care unit. Because fatal cases of infarction may differ from nonfatal cases, it should be emphasized that infarct fibrosis (nonfatal infarction) was found as frequently as necrosis. Even extensive right ventricular infarct fibrosis was seen (Fig. 3C), and one patient had a well demarcated right ventricular fibrotic aneurysm.

**Incidence and size.** The overall incidence of right ventricular infarction was 84%. In 31 patients who died from a first myocardial infarct, the incidence of right ventricular involvement in posterior infarction was 100%, in anterior infarction 94% and in lateral infarction 25%. It has been claimed (13,14) that right ventricular necrosis occurs only if posterior transmural left ventricular infarction is present. Ratliff and Hackel (14) examined 102 hearts from patients who died in a coronary care unit and found no right ventricular infarction in any heart with an anterior infarct; however, these workers disregarded right ventricular involvement extending < 1 cm into the right ventricle. In our prospective study comprising consecutive autopsies from a coronary care unit, all right ventricular infarcts were recorded regardless of size, and this may partly explain the different incidence rates of anterior right ventricular infarction in these two studies. In any case, right ventricular involvement is much smaller in anterior than in posterior infarction.

**Coronary artery distribution.** As stated by Farrer-Brown (27) and confirmed by this study, extensive right ventricular infarction is not to be expected in anterior infarction because only a small part of the anterior right ventricular wall is supplied by the left anterior descending artery (Fig. 1B). Occlusion of the left circumflex artery was usually associated with lateral or posterior left ventricular infarction, or both, but only rarely did this artery supply the posterior right ventricular wall. Accordingly, we found only few and small right ventricular infarcts accompanying lateral left ventricular infarction (Fig. 1G and H). Thus, significant right ventricular infarction was always associated with right coronary artery disease and usually accompanied by infarction of the left ventricular posterior (inferior) wall (Fig. 1C to F and 2).

**Proximal versus distal occlusion.** Occlusion of the right coronary artery proximal to the origin of the right marginal branch was associated with much greater right ventricular infarct size than was distal occlusion. However, there was
no significant difference in right ventricular infarct size associated with proximal or distal occlusion of the left anterior descending artery.

Compromised collateral flow. Haupt et al. (28) examined posterior infarcts due to proximal right coronary artery occlusion, and they found a positive connection between right ventricular infarct size and severity of stenosis (evaluated angiographically) in the left anterior descending artery with potentially compromised collateral flow through the moderator band artery. These observations were not confirmed in our study because we found no connection between right ventricular infarct size and potentially compromised collateral flow as determined by significant stenosis in noninfarct-related vessels. However, this result does not necessarily exclude a beneficial effect of collateral vessels on right ventricular infarction, because stenosis severity evaluated by coronary angiograms may be unreliable (29).

Topography. Anterior right ventricular infarcts were small, involving predominantly the apical third of the ventricle (to the left of the sternum), whereas posterior infarcts usually were much larger, involving predominantly the basal and posterior part of the right ventricle near the atrioventricular groove (to the right of the sternum). This may explain why right chest electrocardiographic (ECG) recordings usually miss anterior right ventricular infarction (19). Furthermore, because right chest ECG changes seem to be correlated with the degree of right ventricular circumferential involvement in posterior infarction (18,19), a poor correlation should be expected in anterior infarction, where even small right ventricular infarcts are often 100% circumferential near the apex of the heart. On the other hand, even large posterior right ventricular infarcts are seldom 100% circumferential because of the coronary artery distribution.

Clinical estimation of infarct size. Total infarct size was found to be equal in acute anterior and posterior infarction. This agrees with clinical estimation of infarct size (30,31) using plasma enzyme values but it is at some variance with ECG estimation of infarct size (32). The reported poor correlation between enzymatic and ECG estimates of infarct size in inferior infarction could be due to right ventricular infarction leaking cardiac enzymes without affecting the ECG score (which predominantly reflects the left ventricle).

Accordingly, our study demonstrates that more left ventricular myocardium is intact after a posterior infarct than

Figure 5. Thrombotic occlusion (arrow in A) of the left anterior descending (LAD) artery with anterior infarction involving the whole apex of the heart including the posterior ventricular walls. The left anterior descending artery is empty (without contrast medium) distal to the occlusion (arrowheads in A) and the empty vessel is bending around the apex of the heart ascending into the posterior interventricular groove (small arrow in C) supplying the whole apex apart from small lateral areas perfused by the circumflex (CX) artery and the right marginal (RM) branch (B). R = right coronary artery; L = left main stem; LV = left ventricle.

13. Isner JM, Roberts WC. Right ventricular infarction complicating left ventricular infarction secondary to coronary heart disease: frequency, location, associated findings and significance from analysis of 236 necropsy patients with acute or healed myocardial infarction. Am J Cardiol 1978;42:885–94.


