A Clinicopathologic Study on the Feasibility of Direct Surgical Treatment of Occlusive Coronary Arterial Disease

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Atherosclerosis and occlusion of the coronary arteries is one of the leading causes of death at this time. The medical treatment of this condition is not satisfactory in a curative sense and, therefore, numerous surgical procedures have been devised in an attempt to improve the blood supply to the myocardium. The major procedures employed thus far include: (1) abrasion of the pericardium and poudrage with asbestos powder which may or may not be combined with partial ligation of the coronary sinus; (2) arterialization of the coronary sinus; (3) cardio-omentumopexy, cardiomyopexy, or cardiopneumopexy; (4) implantation of a systemic artery into the myocardium; (5) ligation of the internal mammary arteries, and (6) direct anastomosis of systemic arteries to the coronary arteries.1-3 Most cardiologists have shown little enthusiasm for these technics, and none of these procedures has been adopted widely.4-5 Recently, considerable interest has been exhibited in coronary endarterectomy for relief of occlusion. This approach is appealing, for it offers a direct attack on the offending lesions and, if successfully carried out, would provide the myocardium with a more nearly normal myocardial blood flow than previous methods.

Review of Literature

Absolon and co-workers6 performed operations on the coronary arteries in 10 cadaver hearts and concluded that coronary endarterectomy was a feasible procedure. Beck and associates7 studied cadaver hearts, and stated that coronary endarterectomy probably would not be successful because the involvement usually extends into the secondary arterial branches. Thal and colleagues8 reported that coronary arteriographic studies in man indicated that angina pectoris is a diffuse disease of the entire coronary arterial system and that success of direct operations on the coronary arteries was unlikely. Reports of coronary endarterectomy in man have been made by Bailey and associates,9,10 and Satinsky and associates.11 In another series reported by Longmire, Cannon, and Kattus12 operations were performed on 10 patients, five of whom survived.

Blumgart, Schlesinger, and Davis13 after studying 30 hearts with the aid of injection technics and dissection of the coronary arteries found that all patients with angina pectoris had an area of old complete occlusion in at least one of the major coronary arteries. Exceptions to this finding were patients with angina who had severe rheumatic heart disease or cor pulmonale.13 Schlesinger and Zoll14 in a study of complete occlusions of the coronary arteries found that 69 per cent of such occlusions were in the proximal 4 cm. of the main coronary arteries. Sixty-three per cent of the occlusive lesions were less than 5 mm. in length and 40 per cent were less than 3 mm. in length. Thirty-seven per cent of the lesions were 5 mm. or longer. They stated that markedly narrowed zones are functionally almost as inefficient in supplying blood dis-
tally as zones of complete occlusion are. Thal and co-workers\textsuperscript{15} stated that in a small percentage of cases the disease may be localized to a relatively short segment of a major arterial trunk and that this group presents the challenge for surgical correction.

Blumgart, Zoll, and Kurland\textsuperscript{16} in a discussion of the pathologic-anatomic problem listed the following features as favorable to direct coronary arterial surgery: (1) that at least 90 per cent of myocardial infarcts and episodes of angina pectoris are due to coronary atherosclerosis; (2) that these atherosclerotic lesions are localized and segmental, approximately 60 per cent being less than 4 mm. in length and 70 per cent occurring within 4 cm. of the coronary ostia; (3) that the lesions are mostly in epicardial arteries with more than half of them in the main stem arteries, and (4) that the frequent patency of the smaller coronary vessels favors maximal myocardial nutrition if the proximal obstructions can be relieved. They cited features that may pose difficulties to coronary endarterectomy which are as follows: (1) that a third of the occlusions of the main stem arteries are 6 to 75 mm. in length; (2) that in some instances, fibrosis and calcification may involve not only the intima but also the entire media of the arterial wall; (3) that multiple occlusions are frequent in angina pectoris, and (4) that the coronary arteries are sometimes small and are potentially subject to postoperative thrombosis and occlusion.

Szilagyi, McDonald, and France\textsuperscript{17} in a study of applicability of angioplastic procedures in coronary atherosclerosis examined 190 human hearts obtained at necropsy by injection and dissection technics. At first all hearts obtained at routine necropsy were examined but later, because 40 per cent were normal, the study was limited to hearts of patients more than 50 years of age and patients who before death had clinically manifest arteriosclerotic heart disease. Only specimens in which necropsy confirmed this diagnosis were studied. They regarded luminal narrowing of 70 per cent or more as of 'clinical importance. This study suggested that the potential role of surgery in coronary arterial disease is not encouraging and that patients with clinical evidence of coronary atherosclerosis, as a rule, have advanced and diffuse forms of the occlusive process.

The selection of patients for coronary endarterectomy has been the subject of considerable interest, but definite criteria or uniformity of selection has not been established.\textsuperscript{18} In general, only severely incapacitated patients incapable of carrying out their usual work have been considered candidates for operations.\textsuperscript{12} Various authors have emphasized that above all the diagnosis must not be in doubt.

The present study was undertaken with two purposes in mind. The first was to obtain some ideas as to the feasibility of coronary endarterectomy by examination of necropsy specimens of hearts. The second was an attempt to determine whether those patients in whom the coronary arteries were found to have lesions theoretically amenable to direct surgery had presented any identifying features during life that would permit selection by any of the usual clinical methods.

**Methods**

Since this study was designed to elucidate clinical problems, the selection of cases was made after a review of the clinical records. We reviewed the case records of patients registered at the Mayo Clinic who had died during the 3-year period from January 1, 1955, through December 31, 1957, and in whom a diagnosis indicative of coronary arterial disease had been made. The most common diagnoses were coronary arterial disease, coronary insufficiency, angina pectoris, and myocardial infarction. Approximately 600 patients were included in this category. From this group, cases were selected for the present study (1) if the diagnosis indicative of coronary arterial disease had been made at least 3 months prior to death, (2) if necropsy had been performed in the Section of Pathologie Anatomy of the Mayo Clinic, and (3) if significant coronary arterial disease was found at necropsy. Four cases were excluded because the heart was not available for re-examination. One hundred twelve patients met these criteria and were included in the present study.

The preserved hearts in the 112 cases were re-examined and the coronary arteries were sectioned serially at intervals of 3 to 4 mm. throughout their length. The coronary-arteries
of all hearts had been serially sectioned, at least in part, at the time of necropsy. The degree of obstruction of the lumen in each 3- to 4-mm. section was estimated and graded. Grade 1 indicated that the lumen was narrowed 0 to 25 per cent, grade 2, narrowed 26 to 50 per cent, grade 3, 51 to 75 per cent, and grade 4, 76 to 100 per cent. The length of each lesion was recorded. Whenever the outside diameter of the main arteries was less than 3 mm., this was noted. The degree of luminal narrowing of the distal arterial branches was recorded. Tortuosity and calcification of the walls of the arteries were not recorded.

According to Poiseuille’s law, flow in a vessel is proportional to the square of the cross-sectional area of the vessel. Therefore, a vessel whose lumen is reduced by 50 per cent is able to carry a fourth the normal amount of blood, all other conditions remaining equal. For purposes of this study, it was decided that lesions that narrowed the coronary artery by more than 50 per cent of the original caliber would be considered.

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Table 1

Theoretic Operability of Individual Coronary Arteries by Given Criteria

<table>
<thead>
<tr>
<th>Coronary artery</th>
<th>Uninvolved, &gt;50 per cent patent</th>
<th>Operable</th>
<th>Inoperable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unoccluded for 2.0 cm. or less*</td>
<td>Occluded for 2.1-4.9 cm.</td>
<td>Occluded for 5.0 cm. or more</td>
</tr>
<tr>
<td>Men</td>
<td>3</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Left</td>
<td>7</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Right</td>
<td>12</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>Circumflex</td>
<td>1</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Women</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Left</td>
<td>8</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Right</td>
<td>1</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>57</td>
<td>67</td>
</tr>
</tbody>
</table>

*1 or 2 lesions.
†Small major artery or extensively diseased distal branches or both.

significant. Therefore lesions graded as 3 or 4 were recorded as causing significant stenosis of the involved vessel.

With regard to the size of the artery that might be potentially operable we noted that, in dogs with coronary arteries having outside diameters of 1 to 2 mm., it has been possible to produce a systemic to coronary arterial shunt.²⁰ Although many of these shunts have become occluded, some have remained patent. Thal and co-workers¹⁵ reported that anastomosis of small blood vessels was feasible when the internal diameter was 2 to 3 mm. It seemed reasonable, therefore, to consider a vessel as potentially operable if the outside diameter at the site of stenosis or occlusion was 3 mm. or more.

The distal epicardial branches of each of the three main coronary arteries were examined and an estimate was made of the amount of luminal narrowing. These branches were considered uninvolved if fewer than half were severely stenosed or if most branches showed less than 50 per cent luminal narrowing. If more than half of these branches were severely narrowed or if most branches showed more than 50 per cent luminal narrowing, these branches were considered as involved to a significant extent by the atherosclerotic process.

Each coronary artery examined was placed in one of three categories: not needing surgical relief, inoperable, and operable. The main coronary artery was classified as not needing surgical relief of stenosis if it contained no grade 3 or 4 lesions.

An artery was classified as inoperable (1) if the stenosis or occlusion was in the main vessel at a site where the outside diameter of the vessel was less than 3 mm., (2) if the distal arterial branches were significantly occluded, or (3) if the total length of the portion stenosed or occluded was 5.0 cm. or more.

A single artery was classified as operable if (1) there was stenosis or occlusion of the main coronary artery or primary branch, (2) outside diameter of the artery at the site of the lesion was 3 mm. or more, (3) distal arterial branches were not significantly occluded, and (4) the total length of the lesions was less than 5.0 cm.

The three main coronary arteries in each heart were then considered as a group. The heart was classified as pattern 1, when all arterial lesions in one, two, or three vessels were operable. In hearts of pattern 2 the coronary arteries appeared theoretically capable of deriving some relief of stenosis from surgical procedures and at least one of the major coronary arteries in these hearts was classified as operable and at least one was classified as inoperable. In hearts of pattern 3 the coronary arteries appeared theoretically inoperable with none of the three major arteries classified as operable.

Results

Ninety men and 22 women were represented in this series of 112 cases. At death, the men ranged in age from 40 to 86 years, with an average of 64.6 years. Figure 1 is an analysis of the hearts of the men classified by age groups and patterns of theoretic operability. The youngest patient whose heart exhibited pattern 1 was 54 years of age. Of the 26 men less than 60 years of age in the group, only two (8 per cent) had hearts in which the condition was classed as pattern 1,
Table 2

Patterns of Coronary Arteries in 112 Hearts Studied

<table>
<thead>
<tr>
<th>Pattern 1: operable</th>
<th>Pattern 2: subject to palliation</th>
<th>Pattern 3: inoperable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>13</td>
<td>48</td>
<td>29</td>
</tr>
<tr>
<td>Women</td>
<td>7</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>Per cent</td>
<td>18</td>
<td>32</td>
<td>30</td>
</tr>
</tbody>
</table>

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Figure 3
Patterns of theoretic operability in hearts of 90 men: correlation with various clinical features.

12 (46 per cent) as pattern 2 and 12 (46 per cent) as pattern 3. Each of the two hearts showing pattern 1 had two arteries classified as operable and one uninvolved artery.

Figure 2 presents an analysis of the hearts of the women using the same classification as for men. The women ranged in age at time of death from 55 to 87 years, with an average of 72.3 years. The youngest woman among the pattern 1 cases was 68 years of age. The cardiac lesions of none of the four women who were less than 65 years old were in pattern 1. Two (50 per cent) were in pattern 2 and two (50 per cent) were in pattern 3.

Figure 3 shows the relationship of the three patterns of theoretic operability of the coronary arteries in men with the presence or absence of angina pectoris, hypertension, diabetes mellitus, myocardial infarction more than 3 months prior to death, cardiomegaly by roentgenographic examination, and cause of death as determined at necropsy. Hypertension was considered to have been present if diastolic blood pressures of 100 mm. of mercury or more were recorded in the patient’s history. Diabetes mellitus was considered to have been present if this had been diagnosed clinically. The classification of previous myocardial infarction was determined by clinical history, not by pathologic examination. Only episodes of infarction diagnosed at least 3 months before death were included and those patients with only a terminal infarct were classified as “no previous infarction.” Cardiomegaly was based on the report by the roentgenologist who examined the roentgenogram of the thorax. Death was classified as due to cardiac or noncardiac causes from the opinion of the pathologist conducting the necropsy. Similar information to that just presented for men is presented for the 22 women in figure 4.

Eighteen patients in this series of 112 had angina pectoris without hypertension, diabetes mellitus, previous myocardial infarction or cardiomegaly. Of these 18, one (6 per cent) was placed in pattern 1, nine (50 per cent) in pattern 2 and eight (44 per cent) in pattern 3.

Table 1 presents an analysis concerning operability of the individual coronary arteries. A total of 336 vessels was examined. The involved vessels were classified into four categories: (1) those that had one or two lesions with a total length of 2.0 cm. or less, and were considered “ideal” vessels for operation; (2) those that were theoretically operable but the lesions were 2.1 to 4.9 cm. in total length; (3) those that were theoretically inoperable because the lesions involved 5.0 cm. or more of a vessel; (4) those that were theoretically inoperable because of small-sized major arteries or extensively diseased distal branches, or both.

Figure 5 presents an analysis of disease of the three major coronary arteries and their distal branches. The patterns of the coronary arteries in the entire series of 112 hearts are given in table 2. The ages of the patients and the number of arteries involved in the pattern 1 hearts are summarized in table 3.
Patterns of theoretic operability in hearts of 22 women: correlation with various clinical features.

Discussion

This study was designed to be as nearly applicable to the situation in a living subject as was possible in a pathologic-anatomic study. The cases were selected on clinical criteria, and in all a diagnosis of coronary arterial disease or its equivalent had been made at least 3 months prior to death. This time limit was selected to exclude patients whose condition was diagnosed because of a recent acute myocardial infarction and those diagnosed in a terminal state. Hearts in which coronary arterial disease was not found at necropsy were excluded, as it seemed of no value to examine these few hearts. An ideal series for this type of study probably would be a group of cases diagnosed as coronary arterial disease in which the patient died of noncardiac causes. In the present series death was due to noncardiac causes in 21 of the 112 cases. The possibility of surgical alleviation of the arterial disease did not seem to be influenced to any great extent by the type of terminal events in the present series.

The present study is a theoretic and anatomic appraisal of operability of the coronary arteries alone. The state of the myocardium and other clinical considerations were ignored in classifying these cases as pattern 1, pattern 2, or pattern 3. In a pathologic-anatomic study of this type, most of the specimens examined may show an advanced stage of the disease process when death is due to the disease under consideration. Therefore, no final statement can be made of the pattern of the disease at earlier stages in the process. Table 3 is a summary of the pattern 1 hearts.

Szilagyi, McDonald, and France\textsuperscript{17} reported that the lesions in 21 per cent of their cases were curable, in 35 per cent were receptive of palliation, and in 44 per cent were inoperable. Our results (table 2) compare well with those of Szilagyi and associates with respect to the lesions suitable for operation and reasonably well with respect to the other groups of lesions. Their study also was directed at the specific problem of coronary endarterectomy and was similar to the present study. Szilagyi and co-workers used somewhat different criteria for operability, and selection of cases was based on findings at necropsy. The study of Schlesinger and Zoll,\textsuperscript{14} which is often quoted as indicating anatomic conditions of the coronary arteries favorable to direct surgery, is not directly comparable to this series or to the study of Szilagyi and associates as the Schlesinger and Zoll study was concerned with complete occlusions only and lesser degrees of narrowing of the arteries were not recorded.

Since most patients with overt clinical coronary arterial disease in this study appeared unsuitable for coronary endarterectomy, is it possible to select the most favorable cases on the basis of clinical examination? The results

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
Pattern 1 operable & & & & & & \\
\hline
Arteries involved & & & & & & \\
\hline
Age, yr. & Total cases & Cases & 1 & 2 & 3 & \\
\hline
40-44 & 3 & 0 & & & & \\
45-49 & 5 & 0 & & & & \\
50-54 & 12 & 1 & 1 & & & \\
55-59 & 9 & 1 & 1 & & & \\
60-64 & 20 & 3 & 1 & 1 & & \\
65-69 & 17 & 5 & 2 & 2 & 1 & \\
70-74 & 20 & 4 & & & 1 & 3 & \\
75-79 & 13 & 5 & 1 & 3 & 1 & \\
80-84 & 11 & 1 & 1 & & & \\
85-89 & 2 & & & & & 0 & \\
\hline
Total & 112 & 20 & 8 & 7 & & & \\
\hline
\end{tabular}
\caption{Pattern 1 Hearts by Age Groups and Number of Involved Arteries}
\end{table}
as shown in figures 3 and 4 indicate a negative answer.

How then are cases to be selected for surgery? It has been stated in the literature that the preferred patient would be young and vigorous, with marked angina pectoris but without evidence of myocardial infarction. It has been suggested that the upper age limit for surgical candidates be 60 years. It is worthy of note that in the present series the condition of only two of the 26 men less than age 60 was classed as pattern 1, that of 12 was placed in pattern 2, and of 12 in pattern 3. Of the four women less than age 65 years, two had conditions classed as pattern 2 and two as pattern 3. In this study of the coronary arteries, it was the distinct impression that generally the most diffuse and severe coronary arterial disease was seen in the younger men and that the ideal candidates for surgery, that is, those whose arteries had short, focal lesions with patent distal branches, were most often patients of advanced age.

From this study it would appear that some method other than the usual clinical examination is a necessity for selecting patients for direct surgical attack, for coronary disease usually is well advanced before clinical recognition.

Of major importance among the problems of a direct surgical attack on the diseased coronary arteries are (1) the generally diffuse and severe nature of the occlusive process in patients with clinical manifestations of coronary arterial disease, (2) the finding in this study of severe coronary atherosclerosis in young men, (3) the frequency of arteries too small for surgical procedures, (4) the not uncommon involvement of the distal branches by the disease process, and (5) the difficulty of selection of patients by clinical means whose occlusive coronary arterial disease may be amenable to direct surgical attack. This study has taken as optimistic an approach as possible to the role of direct surgical attack on coronary arteries in atherosclerotic occlusive disease, but the results are not encouraging. We agree with Szilagyi and associates that the patients with clinical evidence of coronary atherosclerosis as a rule have advanced and diffuse forms of the occlusive process.17 This was the usual pattern seen in the coronary arteries studied and the artery with a short focal lesion potentially amenable to surgical procedures was definitely not common. However, perhaps surgical advances in the future will make some of the lesions now classified as inoperable amenable to some form of surgical therapy.

**Summary**

The coronary arteries of 112 patients with an antemortem diagnosis of coronary arterial disease were studied at necropsy with regard to the feasibility of coronary endarterectomy for direct relief of the luminal narrowing. The patients ranged in age at the time of death from 40 to 87 years. The condition of the coronary arteries in 20 cases (18 per cent) was classed as pattern 1 (theoretically operable), in 58 cases (52 per cent) as pattern 2 (theoretically capable of palliation), and in 34 cases (30 per cent) as pattern 3 (theoretically inoperable). The youngest man who had a pattern 1 condition was 54 years of age, and of 26 men studied who were less than age

![Figure 5](http://circ.ahajournals.org/)

**Figure 5**

Correlation of disease of the major coronary arteries and their distal branches in 112 hearts studied.
60 years, two had pattern 1 conditions, 12, pattern 2, and 12 pattern 3. Of the four women less than 65 years of age, none had pattern 1 conditions, two had pattern 2, and two had pattern 3.

An impression gained from this study was that in general the most severe and diffuse lesions observed at necropsy are seen in the younger men who give clinical evidence of coronary arterial disease. Certain clinical features were analyzed in an attempt to find a correlation between these factors and the anatomic state of the coronary arteries. No clearly defined correlation could be discovered in this series.

The role of direct surgical attack on the coronary arteries for relief of atherosclerosis does not appear to be an encouraging one from this study of clinical features and the final pathologic anatomy.

References
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