cardiomyopathy. This technique complements the high resolution but limited field of view of the standard echocardiogram because it allows dynamic two-dimensional evaluation of the interventricular septum and left ventricle.

Acknowledgments

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References


Detection of Edema
Associated with Myocardial Ischemia
by Computerized Tomography
in Isolated, Arrested Canine Hearts

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SUMMARY This study was undertaken to determine if computerized tomography (CT scanning) with an EMI cranial scanner could detect edema associated with myocardial ischemia in canine hearts. A localized area of decreased density in the posterior papillary muscle and surrounding myocardium was detected on serial 8 mm CT scan slices of each heart after 60 min of circumflex artery occlusion and 45 min of reflow of blood. The wet/dry weight ratios and previous electron microscope studies of the ischemic posterior papillary muscles revealed edema accumulation. After 1 hour of arterial occlusion and 12 hours of reflow (which produces extensive necrosis and a decrease in the wet/dry ratio) lesions were still discernible but were less consistently as severe. Permanent ligation of the left anterior descending coronary artery and major collateral arteries for 6 hours also resulted in a lesion of decreased density in the distribution of the occluded arteries.

Thus, CT scanning can detect, and is a potential means for sequential noninvasive quantitation of myocardial edema associated with ischemia.

IT IS WELL ESTABLISHED that edema occurs as a result of acute, severe myocardial ischemia.1-4 Recently, it has been demonstrated that at least part of this edema is intracellular.3-4 The extent of intracellular edema which is present during early myocardial ischemia appears to correlate with the extent of eventual myocardial cell necrosis.3-4 With the development of myocardial necrosis, there is disruption of cell membranes and loss of intracellular edema.4 However, the cells which remain viable demonstrate persistent cell swelling.5

To date, there is no entirely satisfactory method to detect, localize and follow sequentially, the lesion of myocardial ischemia.6 Computerized tomography (CT scanning) can detect small differences in soft tissue density.6,7 the limits of which have been defined.6,7 This noninvasive technique has provided a precise tomographic means of localizing intracranial pathology based on differential densities. In view of the documented association of edema with ischemic myocardial...


dium, this technique should also be applicable to the evaluation of myocardial ischemia.

Therefore, the present studies were carried out to examine structural definition obtainable with CT scanning and to determine if regional ischemic lesions could be visualized using an in vitro canine heart preparation. An attempt was also made to determine if these lesions could be accurately localized and if their evolution could be assessed chronologically.

Because of the variability of the collateral circulation in the dog, the model used primarily in these experiments was that of ligation of the proximal circumflex artery followed by reflow of blood. This results in a reproducible lesion in the posterior papillary muscle, the histologic characteristics of which have been well established.1 4. 12

**Methods**

Computerized tomography scans were performed with an EMI cranial scanning unit (EMI Ltd., Hayes, Middlesex, England). The characteristics of this scanning unit have been described.5  7.  9.  10 Each point in the matrix (160 × 160) of a scan represents a block of tissue 1.5 × 1.5 × 6 mm and is projected with a ten level gray scale with black corresponding to the lowest density and white to the highest density. This gray scale can be adjusted to accentuate certain ranges of densities. Except where noted, all illustrations of scans were obtained with the same gray scale adjustment to allow comparisons among illustrations.

The distensible, rubber, fluid-filled dam in the scanning unit provided a firm but flexible coupling to a plastic boot-shaped container. The latter was designed to hold the isolated heart preparation for scanning. A wooden rack supporting the heart was fastened in the toe of the boot and the container was filled with lactated Ringer’s solution (McGaw Labs, Glendale, California) so that the entire heart was surrounded with fluid. Lactated Ringer’s solution was selected as the surrounding fluid because it would allow immersion of the specimen in a nearly isoosmotic medium. Thus, air was eliminated from the path of the X-ray beam, which is a requirement of the EMI CT cranial unit used in the present investigation but not of the recently developed CT scanning units.

Twenty-five arrested and two ejecting left heart preparations were scanned. Twenty-seven mongrel dogs of either sex weighing between 18 and 22 kg were anesthetized with intravenous sodium pentobarbital (30 mg/kg). Following anesthesia, the animals were intubated and respiration was maintained with 97% O2, 3% CO2 with a Harvard respirator. Each dog received 6000 units of intravenous heparin.

Twenty-five arrested hearts were prepared as follows:

In five animals following thoracotomy and ligation of the great vessels, including the pulmonary arteries and veins, the hearts with their surrounding pericardium were removed from the chests. The pericardium, suspended from four posts of a wooden rack, formed a sling for each arrested heart. The rack containing the heart is shown on the left of figure 1.

In 16 animals following thoracotomy a reversible snare was placed around the proximal circumflex branch of the left coronary artery within two centimeters of its origin. Tightening of the snare produced total occlusion of the proximal circumflex artery for 60 min. In the dog, this model has been documented to provide complete and reproducible interruption of blood flow to the tip of the posterior papillary muscle.2  These 16 hearts, three were arrested at the end of 60 min of circumflex artery occlusion, seven were arrested following 60 min of arterial occlusion and 45 min of reflow of blood and six were arrested following 60 min of arterial occlusion and 12 hours of reflow of blood. The hearts were then removed and suspended in a pericardial sling as described above for the nonischemic hearts. In the arrested hearts, which had been subject to ischemia, contrast enhancement of the chambers was obtained by direct intracavitary injection, through a 20 gauge needle, of 30% meglumine diatrizoate (Reno-M-Dip, Squibb Laboratories.) This agent contains 143 mg of iodine/ml of solution. Between 0.4 to 1.2 ml of this iodinated contrast material was injected to achieve a dilution in blood of 1:100. Following injection, the heart on the rack was agitated to permit thorough intracavitary mixing of the contrast agent.

In four hearts, following thoracotomy, the left anterior descending coronary artery was ligated one third of the distance from its origin to the apex. In each heart four or five major collateral arteries to the distribution of the ligated left anterior descending artery were also ligated. After six hours of ligation, and without reflow of blood, the hearts were removed and suspended in a pericardial sling, as described for scanning.

Two ejecting heart preparations (fig. 1) were studied. Following thoracotomy and prior to removal of the heart from the chest of the dog, Tygon polyethylene tubing (internal diameter (ID): 7/16 inch) was placed in the left atrial appendage and secured with a purse string suture. The tip of a Versi catheter (FR 16) (National Catheter Corp., Argyle, New York) was placed in the right ventricle through the right atrial appendage. The tip of a second Versi catheter (FR 20) was placed into the ascending aorta through the left subclavian artery. With partial occlusion of the left subclavian artery catheter, the proximal portion of the descending aorta was cross-clamped and a wide bore polyethylene tubing (Tygon, ID: 7/16 inch), which was connected to an aortic overflow tubing, was inserted into the proximal aorta. Virtually simultaneously, the aortic overflow tubing was unclamped, the left subclavian artery tubing was clamped and the venous return tubing from a left atrial reservoir was opened, permitting completion of the ejecting left heart preparation. Opening the right ventricular drainage catheter allowed drainage of the coronary flow. The height of the left atrial return reservoir determined the left heart filling pressure. The height of the aortic overflow column determined the aortic root pressure. The aortic overflow and the coronary venous drainage were oxygenated with a Bentley Temptrol Oxygenator which was maintained at 30°C with a water bath and the blood from the oxygenator was pumped to the left atrial return reservoir.

A reversible snare was then placed around the proximal circumflex branch of the left coronary artery as was described above for the arrested hearts. The ejecting heart was then suspended in a pericardial sling in a wooden rack and placed in the toe of the boot-shaped container for scanning. Because of a length of fine bore polyethylene tubing around the snare between the proximal circumflex artery and the clamp, it was possible to snare remotely the cir-
Computerized Tomography of Ischemic Heart

The circumflex artery from outside the lactated Ringer’s bath. The snare was also released remotely, and reflow to the territory of the circumflex artery was allowed to occur following 60 min of interruption of blood flow. With the beating heart preparation, it was possible to obtain sequential scans before, during, and following interruption of circumflex artery blood flow. At the desired time of reflow of blood, meglumine diatrizoate was added to the oxygenator to achieve a dilution in blood of 1:100.

Following CT scanning, each of the hearts was sliced manually into 8 mm transverse sections corresponding to the plane of the tomographic scans. Each anatomic section of the heart was compared with the corresponding scan to verify structural identification. Since the circumflex artery occlusion model results in reproducible ischemia at the tip of the posterior papillary muscle, wet/dry weight ratios were determined for the tips of the ischemic posterior papillary muscles and of the control, nonischemic anterior papillary muscles of the arrested hearts. Following dissection of the tips of the papillary muscles, the chordae tendineae were trimmed away. In the four hearts which underwent ligation of the left anterior descending coronary artery and major collaterals, the ischemic area of the sliced specimen was identified from the scan and a corresponding transmural section of myocardium was obtained for wet weight/dry weight ratios. A control nonischemic area of myocardium was obtained from the opposite wall of the heart. Since the lesion did not occur in as well-defined anatomic areas as the tips of the papillary muscles, precise localization of the lesion in the cut specimen was more difficult in these hearts with left anterior descending coronary artery ligation. The muscle to be weighed was blotted on wax paper to remove excess blood, and the wet weights were determined in stoppered weighing bottles which had been previously cleaned, dried, and weighed. Following two days of desiccation in a Stabil-Therm gravity oven (Blue M Electric Company, Blue Island, Illinois) at 100° C with the stoppers removed, the stoppers were then replaced and the bottles reweighed to determine the dry weights. Statistical analysis of the wet weight/dry weight determinations was performed using Student’s t-test. Statistical significance was considered to occur at P < 0.05.

In one arrested heart, the aortic root was perfused with blood containing meglumine diatrizoate at a pressure of 60 mm Hg by means of a vertical overflow column to determine whether or not coronary arteries could be detectable by computerized tomography. After completion of the scanning with iodinated contrast material, warm paraffin was hand injected into the aortic root at a pressure sufficient to fill the major coronary arteries. The paraffin distended the coronary arteries. By this technique, because of the increase in size of the arteries and the very low density of the paraffin,
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Results

Scans of hearts, the cavities of which contained blood without the addition of iodinated contrast material, did not reveal structural definition (fig. 2). Injection of small amounts of iodinated contrast material into the ventricular cavities allowed definition of anatomic structures bordering the cavities (fig. 3).

Sixty minutes of proximal circumflex artery occlusion followed by 45 min of reflow resulted in a lesion of decreased density localized to the area of the posterior papillary muscle and surrounding myocardium. Figure 3 shows on the left, a transverse tomographic scan demonstrating such a lesion and on the right, the corresponding specimen of the heart. The observer is viewing the scan and the specimen of the heart from the apex looking toward the base. The large area of increased density seen on the scan is the left ventricular cavity; the smaller area of increased density on the left of the scan is the right ventricular cavity. The posterior papillary muscle can be seen protruding into the ventricular cavity from the bottom right of both the scan and the heart specimen. Note that the area of decreased density on the scan extends into the free wall of the ventricle and also into a portion of the intraventricular septum.

In each heart it was possible to detect the lesion and to assess visually the extent of the lesion on serial scans. Figure 4 is illustrative of serial tomographic scans obtained from a heart following 60 min of proximal circumflex artery occlusion and 45 min of reflow of blood. Note, as in the preceding figure, the area of decreased density in the region of the posterior papillary muscle in the two scans on the lower left. The lesion can be seen extending toward the apex of the heart in the scans on the lower right and toward the base of

FIGURE 2. Tomographic scan of a beating heart with a hematocrit of 36%. Note the definition of the outer border of the heart. This definition is obtained with myocardial-lactated Ringer's interface in vitro. The in vivo situation of a myocardial-air interface may result in some decrease in the definition of the outer border of the heart. At normal levels of hematocrit the cavities are vaguely, if at all, distinguishable.

FIGURE 3. Arrested heart after one hour of circumflex artery occlusion and a 45 min reflow. The observer is viewing the scan and the corresponding specimen of the heart from the apex looking toward the base. Both the left ventricular cavity (large area of white toward the center of the scan) and the right ventricular cavity (area of white on the lower left of the scan) contain small amounts of iodinated contrast material resulting in an increased density. A posterior papillary muscle can be seen protruding into the left ventricular cavity on both the scan (white arrow) and the heart specimen. Note that the ischemic area of decreased density involves the posterior papillary muscle and the free wall of the ventricle and also a portion of the intraventricular septum. The anterior papillary muscle projects into the ventricular cavity from the upper right of the scan and the specimen.
FIGURE 4. Serial scans of an arrested heart after one hour of circumflex artery occlusion and 45 min of reflow. The posterior papillary muscle can be seen on the lower left scans (white arrows). Note that the ischemic area of decreased density can be followed serially on each of the tomographic scans of this heart. In the scans on the upper right, the anterior papillary muscle can be seen projecting into the left ventricular cavity from the top.

the heart in the scans shown along the top of the figure. In the top three scans on the right, the uninvolved anterior papillary muscle can be seen protruding into the left ventricular cavity from the top.

A lesion of decreased density in the tip of the posterior papillary muscle was a consistent finding in all seven hearts subjected to one hour of proximal circumflex artery occlusion followed by 45 min of reflow of blood. A tomographic scan from each of the seven hearts at the level of the tip of the posterior papillary muscle is illustrated in figure 5. Note that there is a consistent lesion in the region of the posterior papillary muscle but that the extent of the lesion in the left ventricular wall and septum is variable from heart to heart. Wet weight/dry weight determinations of the tips of the papillary muscles were performed in the four hearts illustrated at the top of the figure following 45 min of reflow of blood. These values are given in table 1. Each pair of values in table 1A corresponds in order to each of the scans in the top of figure 5. The mean wet weight/dry weight ratios of the ischemic posterior papillary muscles and the control anterior papillary muscles were 5.9 ± 0.1 (SEM) and 4.7 ± 0.1, respectively (P < 0.01).

In two ejecting heart preparations a lesion of decreased density developed in the region of the posterior papillary muscle at approximately 30 and 40 min of reflow of blood respectively. Figure 6 is illustrative of the tomographic scans obtained in one of these hearts. On the upper left (panel A) is shown a scan of the heart prior to circumflex artery ligation. In the top center (panel B) is a scan of the same heart following 60 min of arterial occlusion but prior to reflow. On the

FIGURE 5. Tomographic scans from each of seven arrested hearts obtained following 60 min of circumflex artery occlusion and 45 min of reflow of blood. The scan for each heart is at the level of the tip of the posterior papillary muscle. Note that there is a consistent lesion in the region of the posterior papillary muscle and that the extent of the lesion in the left ventricular wall and septum is variable from heart to heart. In the scan on the lower left, the three round white densities at the periphery of the heart represent polyethylene tubing sutured to the outside of the heart for orientation purposes.
TABLE 1. Wet/Dry Weight Ratio Data 17 Dog Hearts Subjected to Four Different Ischemic/Reflow Protocols

<table>
<thead>
<tr>
<th>Dog #</th>
<th>APM</th>
<th>PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) 60 min circumflex artery occlusion, 45 min reflow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.38</td>
<td>6.07</td>
</tr>
<tr>
<td>2</td>
<td>4.82</td>
<td>5.47</td>
</tr>
<tr>
<td>3</td>
<td>4.84</td>
<td>6.00</td>
</tr>
<tr>
<td>4</td>
<td>4.79</td>
<td>6.06</td>
</tr>
<tr>
<td>Mean</td>
<td>4.71</td>
<td>5.88**</td>
</tr>
<tr>
<td>± SEM</td>
<td>0.11</td>
<td>0.14</td>
</tr>
<tr>
<td>B) 60 min circumflex artery occlusion, no reflow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.61</td>
<td>4.90</td>
</tr>
<tr>
<td>6</td>
<td>4.64</td>
<td>4.57</td>
</tr>
<tr>
<td>7</td>
<td>4.64</td>
<td>4.62</td>
</tr>
<tr>
<td>Mean</td>
<td>4.63</td>
<td>4.69</td>
</tr>
<tr>
<td>± SEM</td>
<td>0.01</td>
<td>0.10</td>
</tr>
<tr>
<td>C) 60 min circumflex artery occlusion, 12 hr reflow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4.96</td>
<td>4.98</td>
</tr>
<tr>
<td>9</td>
<td>5.09</td>
<td>5.20</td>
</tr>
<tr>
<td>10</td>
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<td>5.06</td>
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<tr>
<td>11</td>
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<tr>
<td>12</td>
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</tr>
<tr>
<td>13</td>
<td>4.44</td>
<td>5.10</td>
</tr>
<tr>
<td>Mean</td>
<td>4.72</td>
<td>5.21*</td>
</tr>
<tr>
<td>± SEM</td>
<td>0.11</td>
<td>0.01</td>
</tr>
<tr>
<td>D) 6 hr after left anterior descending coronary artery and its collaterals ligation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ant Wall</td>
<td>Post Wall</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>4.99</td>
<td>4.87</td>
</tr>
<tr>
<td>15</td>
<td>5.12</td>
<td>4.96</td>
</tr>
<tr>
<td>16</td>
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<tr>
<td>Mean</td>
<td>5.14</td>
<td>4.78*</td>
</tr>
<tr>
<td>± SEM</td>
<td>0.06</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*P < 0.05.  **P < 0.01.

Abbreviations: APM = anterior papillary muscle; PPM = posterior papillary muscle; Ant = anterior; Post = posterior.

Note that the density in the tip of the posterior papillary muscle appears comparable to that of the anterior myocardium in each scan. Two of the three scans (right and left), however, show patchy areas of decreased density in the subendocardium adjacent to the area of the posterior papillary muscle. The associated wet weight/dry weight data for these experiments are given in table 1B.

In six hearts in which reflow of blood was allowed to occur for 12 hours following 60 min of total interruption of blood flow, lesions of variable density were apparent in the region of the posterior papillary muscles. Figure 8 shows a scan from each of these six hearts. Note that in each of the top three tomographic scans there is a minimal decrease in density in the posterior papillary muscle. However, in the remaining three hearts distinct lesions can be appreciated. Table 1C gives the wet weight/dry weight ratios of the tips of the posterior papillary muscles and the tips of the corresponding anterior papillary muscles for each heart. The positions of the numerical values correspond to those of the scans in figure 6. As can be seen by comparison of figure 8 and table 1C, there is a visual relationship between the density of the posterior papillary muscle and the wet weight/dry weight ratio for each of the hearts. The mean wet weight/dry weight ratio of the posterior papillary muscles and the control anterior papillary muscles in these hearts were 5.2 ± 0.1 and 4.7 ± 0.1, respectively (P < 0.05). Comparing the results from the short reflow and long reflow experiments the difference in the wet weight/dry weight ratios between the anterior and the posterior papillary muscles was significantly less in the long reflow experiments (P < 0.05).

In each of the four hearts which underwent six hours of ligation of the left anterior descending coronary artery and its major collateral arteries, a lesion of decreased density was consistently seen in the distribution of the occluded left anterior descending coronary artery. A scan from each of the four hearts is shown in figure 9, and the wet weight/dry weight ratios of the region of decreased density seen on the scan and the uninvolved opposite ventricular wall are given in table 1D. Note that there was a consistent increase in the wet weight/dry weight ratio of the region of myocardium corresponding to the lesion seen on scan.

In one arrested heart, in which the aortic root was perfused with blood containing meglumine diatrizoate, the major proximal coronary arteries were visualized. Scanning of this heart from the base toward the apex revealed a vertical linear area of increased density (white arrow in the upper left panel of figure 10). The adjacent tomographic scan of the heart revealed an area of linear density extending toward the left of the heart (white arrow in the upper right panel of figure 10). A subsequent perfusion with paraffin of the aortic root of this same heart revealed similarly located linear areas of decreased density corresponding to the left anterior descending coronary artery, its major branches, and the circumflex artery (bottom two panels of figure 10). Thus, it was possible to discern major coronary arteries in a canine heart by computerized tomography giving an indication of the structural definition which is achievable under ideal, in vitro conditions.

Discussion

The data indicate that computerized tomography (CT) has potential as a noninvasive technique for cardiac...
diagnosis with a relatively high degree of resolution. Computerized tomography can detect edema associated with myocardial ischemia. It is possible with this technique to localize this region of edema within the myocardium. In addition, computerized tomography offers the potential of sequentially following the development and evolution of ischemia-induced edema.

Computerized tomography detects differences in density of as little as 0.5%. However, because of the similarity of attenuation coefficients of various tissues including blood and myocardium and the variation in attenuation coefficient within a single organ, it was not possible in the present experiments without the use of iodinated contrast material to distinguish intraventricular structures. The addition of small amounts of contrast material did allow structural definition which was sufficient to define various cardiac structures.

The results indicate that during early ischemia (60 min of occlusion and 45 min of reflow) there is consistently an area of decreased density in the posterior papillary muscle and surrounding myocardium detected by CT scanning. This decreased density is most likely related to edema accumulation as indicated by the wet weight/dry weight data which showed pronounced increases in the water content of the posterior papillary muscles.

FIGURE 6. Sequential scans of an ejecting heart obtained before, during, and after 60 min of circumflex artery occlusion. Scans A, B, C, and D were obtained prior to the peripheral administration of Reno-M-Dip and scans E and F were obtained following the peripheral administration of this iodinated contrast agent. A) Scan of the heart prior to circumflex artery ligation. B) Scan immediately prior to the release of the one hour occlusion, showing no change in density in the expected position of the posterior papillary muscle, presumably because of no net gain of water in this area. C) Scan obtained 20 min after the release of the circumflex artery occlusion. There is a suggestion of an area of decreased density in the lower right of the heart (arrow). D) Scan obtained following 40 min of the release of occlusion; there is a more definite area of decreased density seen on the lower right of the scan. E) Scan obtained following the peripheral administration of Reno-M-Dip 60 min after the release of the circumflex artery occlusion. Note that there is some ventricular cavity definition and note the increased density of the myocardium due to perfusion with the iodinated contrast material. The increased density of the ventricular wall adjacent to the posterior papillary muscle (arrow) probably represents areas of reactive hyperemia. Note that there is a persistent decrease in density in the region of the posterior papillary muscle, indicating decreased perfusion. F) Scan following arrest of the beating heart.

In this series of illustrations the gray level settings were readjusted to demonstrate optimally the density differences of interest.

FIGURE 7. Tomographic scans from each of the three arrested hearts at the end of 60 min of circumflex artery occlusion but in which reflow of blood did not occur. Note that the density in the region of the tip of the posterior papillary muscle appears comparable to that of the anterior myocardium.
Furthermore, the data suggest that there is a relationship between the water content of ischemic myocardium and the degree of density change in the ischemic lesion by computerized tomography. Comparison of the results from the three protocols of circumflex artery occlusion (60 min of ligation and no reflow, 60 min of ligation and 45 min of reflow, and 60 min of ligation and 12 hours of reflow) suggests that the greater the water content of the ischemic posterior papillary muscle, the less the density of this area on CT scanning. The 60 min of ligation and no reflow model provides an hour of ischemia to the posterior papillary muscle but since there is little to no collateral blood flow to this area, there is little to no net gain in water. With 45 min of reflow, the posterior papillary muscle gains water, at least part of which is intracellular and associated with extensive cell swelling. With prolonged (12 hours) reflow following circumflex artery occlusion there is, with this model, extensive cell necrosis, but the few remaining viable cells have persistent intracellular edema.

It is likely that the edematous lesion which is detectable by CT scanning is of prognostic importance. The number of swollen cells in the tip of the posterior papillary muscle following short periods of reflow correlates closely with the number of cells which are eventually necrotic. When cell swelling is reduced with appropriate therapeutic maneuvers, the extent of eventual necrosis is reduced in parallel. While the lesion which is detectable by CT scanning in the present experiments may be composed of both intracellular and extracellular edema, it is likely that the majority of the increase in total water content is intracellular.

It follows from the above discussion, as well as from the data obtained in the ejecting heart experiments, that CT scanning also has potential value in monitoring chronologically the extent of ischemia-associated myocardial edema. The lesion can be seen to develop early during the period of...
reflow of blood. Then, in some instances, it is diminished after prolonged reflow of blood and the eventual development of necrosis.

The "no-flow followed by reflow" model has been employed primarily in the present study. The scans from the four hearts obtained after permanent occlusion of the left anterior descending coronary artery and major collaterals indicate that it is likely that CT scanning will provide a useful means of following sequentially the development of an edematous lesion produced by a "low flow" state. Ligature of the major collateral vessels to the region of the occluded left anterior descending coronary artery diminishes but does not abolish collateral blood flow. Recently, results were reported in which four dog hearts were arrested two days after permanent occlusion of the left anterior descending coronary artery without ligation of collateral vessels. The hearts were scanned using an EMI scanning unit. These investigators found in two of their four in vitro heart preparations, an area of decreased X-ray attenuation in the distribution of the occluded artery.

Images obtained before and after the peripheral administration of small amounts of iodinated contrast material may allow a nearly simultaneous comparison of the extent of edema and the extent of the perfusion impairment. In cranial scanning the use of iodinated contrast material has not only enhanced structural definition but has also been postulated to provide an index of perfusion. Iodinated contrast material has been used in the diagnosis and localization of areas of cerebral infarction. The capability of comparing the perfusion defect with the edematous ischemic lesion would enhance the ability to assess the natural history of a myocardial infarction. Clinically, it is possible that a severely ischemic zone in the center of an infarction without any blood flow may be unable to accumulate edema fluid and hence not be detectable by CT scanning. In this instance, assessment of the perfusion defect with contrast material will assist in definition. The doses of iodinated contrast material which were used in our experiments to provide enhancement with CT scanning were small and of the order of magnitude of those administered in clinical intravenous pyelography. This small dose requirement will at least minimize, if not eliminate, the osmotic effect of these agents on the lesion of ischemia-induced swelling. It will also, particularly in patients with compromised cardiac function due to acute infarction, minimize the direct depressant effect of iodinated contrast materials on myocardial contractility.

Other techniques which have been used to assess the presence and extent of acute myocardial ischemia and infarction have certain limitations. For example, nuclear imaging with technetium pyrophosphate enables, through the use of nuclear scanning, a lesion to be seen in patients with established myocardial infarctions. While it was initially thought that this technique documented the presence of necrotic myocardial cells, it is now believed that patients with unstable angina, without definite evidence of an established myocardial infarction, have positive scans. Thus, it is not clear why technetium pyrophosphate localizes in areas of acute ischemia and/or infarction. Work has also been done with perfusion scans and recent interest has focused on the use of thallium. To date, however, the specificity of such radionuclide studies for the detection of perfusion or ischemia has not been established. However, a recent radionuclide technique which involves monitoring of the inflammatory response during an acute infarction is based on assessment of a known localized tissue response to ischemia. Emission tomography which involves radionuclide emission imaging utilizes the reconstruction principles of CT scanning. This technique has been applied to the heart and appears to offer a distinct improvement in nuclear medicine imaging. In the future, comparative studies of CT scanning with nuclear imaging will need to be done to determine the relative merits and applications of the various techniques.

Other methods currently employed to assess the extent of acute ischemia and infarction involve the use of sequential creatine phosphokinase (CPK) analysis and the use of precordial ST-segment mapping. Sequential CPK analysis requires at least 6 to 7 hours for baseline levels of CPK to be obtained before an intervention can be employed. In addi-
tion, there are certain other limitations to this method.22 The technique of sequential precordial ST-segment mapping has been employed to assess the extent of myocardial ischemia — particularly in patients with anterior myocardial infarctions.23 This technique is not as applicable to infarctions in other locations within the heart and factors other than the severity of ischemia may influence the extent of ST-segment elevation.

The clinical applicability of computerized tomography remains to be documented. Although the use of the occlusion-reflow canine model in the present study has allowed a correlation with known histological features, neither of the two canine models employed in this study exactly mimicks the situation of a patient with an acute myocardial infarction. It should also be emphasized that the lesion of decreased density, which is detected by CT scanning during acute myocardial ischemia, represents accumulated edema. As pointed out in the present study and in our previous histologic studies,4, 4 this edema may diminish as the acute ischemic lesion progresses over time to necrosis. Clinically, the quantitation of the effects of therapeutic maneuvers designed to diminish the extent of ischemia-associated edema must, of course, take into consideration this natural evolution of the lesion.

The present animal study indicates that CT scanning can assess a pathophysiologic event which has implications as to future prognosis. With this technique, quantitative data may be obtained in rapid sequential fashion. This technique may provide a relatively precise evaluation of the effects of various therapeutic interventions on myocardial ischemia. Thus, CT scanning has potential value in diagnosis, quantitation, follow-up, and assessment of therapy in acute myocardial ischemia.

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