Coronary Sinus Reflux
A Source of Error in the Measurement of Thermodilution Coronary Sinus Flow

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SUMMARY In seven patients thermodilution coronary sinus flow (TD-CSF) was higher (164 ± 21 ml/min) during ventricular pacing than during atrial pacing (119 ± 21 ml/min, P < 0.005) at identical heart rate, without an increase in the determinants of myocardial oxygen consumption. To assess the possibility of right atrial admixture in coronary sinus blood during ventricular pacing we compared electromagnetic coronary arterial blood flow (CBF) with TD-CSF in nine dogs during interventions that increased right atrial pressure. During ventricular pacing, rapid atrial pacing, pulmonary artery constriction and increased intrathoracic pressure, right atrial pressure increased and electromagnetic CBF was significantly less (41–166%) than TD-CSF. Marked reflux from the right atrium to the coronary sinus was also demonstrated by bolus injection of cold saline into the right atrium and continuous infusion of contrast material into coronary sinus. Caution needs to be exercised in interpreting TD-CSF in the presence of changing right atrial pressure.

THE MEASUREMENT OF CORONARY SINUS BLOOD FLOW by the thermodilution technique has been used by many investigators,3 4 because it is a safe, simple and inexpensive method which can be applied easily in man. Its main advantage is the rapidity with which changes in flow can be detected.

We applied this technique in patients to evaluate the effect of atrial and ventricular pacing at identical heart rate on myocardial blood flow, assuming that changes in thermodilution coronary sinus flow (TD-CSF) reliably reflect changes in myocardial blood flow. It was the surprising finding of this study that ventricular pacing produced an increase in TD-CSF, although there was a decrease in the determinants of myocardial oxygen consumption. To verify this observation we performed animal experiments, where in addition to TD-CSF we also measured coronary arterial blood flow (CBF) with electromagnetic flow transducers. The measurements were done during various interventions that are expected to cause a change in coronary blood flow, so that CBF and TD-CSF could be compared.

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Supported in part by NHLBI Program Project Grant HL 06285. Dr. Lekven is a recipient of the Fogarty International Research Fellowship (FO 5 TW 2371) of the USPHS. Dr. Tyberg is the recipient of a Research Career Development Award of the NIH (HL 00016), a Grant-in-Aid from the Bay Area Heart Research Committee, and a Grant-in-Aid from the American Heart Association.

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Received June 17, 1977; revision accepted November 7, 1977.
Methods

Patient Studies

Seven patients undergoing cardiac catheterization because of known or suspected coronary artery disease were studied. Their ages ranged from 38 to 81 years. The patients were premedicated with 10 mg oral diazepam and were in the fasting state. Informed consent was obtained after the nature and risk of the study had been explained to each patient; there were no complications from these studies. Five patients had significant coronary artery disease, and the remaining two patients had no obstructive coronary artery disease, and none had mitral regurgitation. Pulmonary capillary wedge pressure and right atrial pressure were recorded with a 7F Swan-Ganz catheter.\(^*\) Mean pulmonary capillary wedge pressure was regarded as representative of the left ventricular filling pressure in those patients in whom the left ventricular end-diastolic pressure was not measured directly. Cardiac output was determined by the thermodilution technique with the same catheter.\(^*\) Left ventricular or aortic pressures were measured via an 8F Judkins right coronary artery catheter. Peak left ventricular or aortic pressure will be referred to as peak left ventricular systolic pressure. Coronary sinus blood flow was determined by the constant infusion thermodilution technique using a pre-shaped coronary sinus catheter equipped with two thermistors and bipolar pacing electrodes (Wilton Webster Laboratories).\(^*\) The catheter was inserted from the left antecubital vein and placed in the coronary sinus in such a way that the external thermistor was 10 to 20 mm inside the coronary sinus. A stable catheter position was checked under fluoroscopy by injection of small amounts of contrast medium. The reproducibility of TD-CSF measurements was examined at identical heart rates by 17 repeat measurements in six patients. The correlation coefficient for repeat measurements was 0.90.\(^*\) Measurements were made during atrial and ventricular pacing at the same rate. Atrial pacing was performed from the thermodilution coronary sinus catheter, ventricular pacing through a 5F pacing catheter placed in the apex of the right ventricle. Atrial and ventricular electrodes were connected to a bifocal pacemaker (American Optical).

The protocol was as follows: Ventricular pacing was initiated at a heart rate which was 10 to 20 beats/min higher than the patient's resting heart rate. In three patients the atria were paced simultaneously, in two patients there was retrograde atrial depolarization. In these five patients, atrial cannon waves occurred regularly during ventricular pacing. In two other patients the atria continued to beat in sinus rhythm contributing randomly to left ventricular filling and irregular atrial cannon waves occurred. After five minutes, pressures, cardiac output and TD-CSF were measured. Then atrial pacing was started at the identical rate and measurements were repeated after another period of five minutes. Before determination of TD-CSF during atrial pacing at five minutes, and during ventricular pacing at identical heart rate, the temperatures of the coronary sinus blood (\(T_\beta\)) were recorded. \(T_\beta\) during ventricular pacing and atrial pacing before the infusion of the injectate did not vary significantly (ventricular pacing \(T_\beta\) 36.9 ± 0.081; atrial pacing \(T_\beta\) 37.0 ± 0.042). In three patients 10 ml of cold saline were injected as a bolus into the right atrium during atrial pacing as well as ventricular pacing and changes in coronary sinus and pulmonary artery blood temperatures were recorded. In four patients contrast medium (Renografin 76) was infused continuously into the coronary sinus through a 7F Lehman catheter at a rate of 40 ml/min. The distance the contrast medium traveled retrograde in the coronary sinus was observed from cineangiograms during atrial and ventricular pacing and also during Valsalva maneuver.

Animal Studies

Nine dogs weighing between 23 and 30 kg were studied. Anesthesia was induced with sodium thiopental (25 mg/kg, i.v.). The animals were intubated and ventilated. After cannulating the femoral vein, anesthesia was maintained by intravenous morphine sulfate (2 mg/kg initially, 0.5 mg/kg at two hour intervals thereafter). Succinylcholine (600 \(\mu\)g/kg) was continuously administered as a muscle relaxant. The heart was exposed by a left lateral thoracotomy. Arterial acid-base status was constantly monitored and pH maintained between 7.24 and 7.47. Central aortic pressure was measured with a Statham P23 Db pressure transducer, attached to a fluid-filled catheter. Electromagnetic flow transducers (Model 501, Carolina Medical Electronics) were placed around the origin of the left anterior descending coronary artery and circumflex coronary artery. Zero flow was ascertained by repeated mechanical occlusions. Right atrial pressure was measured with a high fidelity miniature pressure transducer (Konigsberg Model P-22), introduced through the right atrial appendage. Zero pressure was checked by matching the observed pressure with that obtained via a fluid-filled catheter and external transducer. A thermistor was placed in the main pulmonary artery to measure pulmonary artery blood temperature. Pacing electrodes were sutured to the right atrial appendage and right ventricular apex and connected to a pulse generator (Model S-88, Grass Instruments).

A TD-CSF catheter was introduced into the coronary sinus via the external jugular vein and advanced in the coronary sinus so that the tip of the catheter was palpable at the acute left margin of the heart (Position 1). The catheter was then labeled at its entry into the external jugular vein. After a first series of measurements had been obtained, the catheter was withdrawn so that the external thermistor was at least 10 mm inside the coronary sinus (Position II). The catheter was then labeled again at its entry into the external jugular vein and the distance between labels measured. The exact distance between the external thermistor in Position II and the coronary sinus ostium was measured postmortem. It ranged from 10 to 15 mm. This distance plus the distance between the two catheter labels was regarded as an approximate measurement of the distance between the external thermistor and the coronary sinus ostium when the catheter was in Position I. This distance ranged from 25 to 35 mm. Simultaneous measurements of right atrial and arterial pressure, electromagnetic coronary blood flow in the left anterior descending coronary artery (\(\text{CBF}_{\text{LAD}}\)) and in the left circumflex coronary artery (\(\text{CBF}_{\text{CFX}}\)) and TD-CSF were

\(^*\) \(y = 1.01 \times -2.24 \text{ ml/min}, \text{ where } y \text{ and } x \text{ are first and second measurement, respectively, } \text{SE intercept} = 4.08; \text{ SE slope} = 0.04.\)
performed during the following interventions: atrial pacing, synchronous atrioventricular pacing, pulmonary artery constriction and increased intrathoracic pressure. After the thorax had been closed and externally supported by a binding, intrathoracic pressure was raised transiently by occlusion of the expiratory tube and simultaneous compression of an anesthesia bag. During atrial and ventricular pacing measurements were made in both Positions I and II. During pulmonary artery constriction and increased intrathoracic pressure, recordings were made only in Position II. Each intervention was repeated once or twice in each animal. Heart rate was kept constant during the intervention and its control state. Bolus injections of 5 ml of cold saline into the inferior vena cava were performed during each intervention and the resultant changes in coronary sinus and pulmonary artery blood temperatures were recorded. In one dog, complete atrioventricular block was produced by injections of 0.1 ml of formalin into the atrioventricular node to allow more independent control of the sequence of atrioventricular conduction, thus to study the effect of different right atrial pressure on CBF LAD, CBF CFX and TD-CSF. In another dog, an electromagnetic flow transducer was placed on the proximal coronary sinus allowing comparison of CBF, electromagnetic coronary sinus flow and TD-CSF.

**Calculations**

\[
\text{TD-CSF} = \left[ \frac{T_b - T_i}{T_b - T_m} - 1 \right] \times (1.08 \times F_i)
\]

where \( F_i \) is the infusion rate of the indicator, 1.08 is a factor based on the densities and specific heat of blood and indicator when normal saline or 5% dextrose in water is used. \( T_b, T_i \) and \( T_m \) are the temperatures of the blood, indicator and mixture, respectively, in degrees centigrade. \( F_i \) in patients was 46 ml/min, in animals 33 ml/min. A paired \( t \)-test was performed to determine statistical significance. \( P < 0.05 \) was considered significant.

**Results**

Table 1 shows comparative TD-CSF and hemodynamic data during ventricular pacing and atrial pacing at identical heart rate. In each patient, TD-CSF was higher during ventricular pacing than atrial pacing. Average TD-CSF during atrial pacing was 119 ± 21 ml/min; during ventricular pacing, however, TD-CSF was 164 ± 21 ml/min (\( P < 0.01 \)). This higher TD-CSF during ventricular pacing was observed despite the fact that the determinants of myocardial oxygen consumption were less during ventricular pacing. Peak left ventricular systolic pressure was less during ventricular pacing (123 ± 5 mm Hg) than during atrial pacing (132 ± 5 mm Hg, \( P < 0.001 \)). Maximum dp/dt was lower during ventricular pacing (1049 ± 469 mm Hg/sec) than during atrial pacing (1740 ± 165 mm Hg/sec) (\( P < 0.001 \)). Left ventricular filling pressure was less during ventricular pacing (10 ± 1 mm Hg) than during atrial pacing (12 ± 1 mm Hg, \( P < 0.05 \)). Cardiac index was also less during ventricular pacing (2.2 ± 0.3 L/min/m²) than during atrial pacing (2.8 ± 0.3 L/min/m², \( P < 0.02 \)). Due to atrial cannon waves during ventricular pacing, mean right atrial pressure was higher (6 ± 1 mm Hg) than during atrial pacing (4 ± 1 mm Hg, \( P < 0.001 \)). An illustrative recording in an individual patient (patient 7, table 1) is shown in figure 1. In this patient TD-CSF during ventricular pacing was 232 ml/min, while during atrial pacing it was only 159 ml/min.

Figure 2 illustrates the effect of bolus injections of cold saline into the right atrium on coronary sinus blood temperature. During atrial pacing almost no change in coronary sinus blood temperature was noted; during ventricular pacing in the presence of atrial cannon waves a marked decrease in coronary sinus temperature was seen. In this particular patient the external thermistor was about 15 mm inside the coronary sinus. The simultaneous deflection of coronary sinus and pulmonary artery blood temperatures indicates that the decrease in coronary sinus blood temperature was not due to recirculation of the cold indicator. Similar results were obtained in the two other patients in whom such bolus injections of cold dextrose solution were made in the inferior vena cava. In two patients contrast medium was infused into the coronary sinus during atrial and ventricular pacing and during Valsalva maneuver. During atrial pacing, phasic reflux of contrast medium with each atrial contraction was seen 1-2 cm distal to the tip of the catheter (fig. 3, upper panel). During ventricular pacing and Valsalva maneuver, however, the contrast medium traveled 4-6 cm upstream to the origin of the great cardiac vein.

### Table 1. Effect of Ventricular Pacing in Individual Patients

<table>
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<tr>
<th>Patient</th>
<th>HR (min⁻¹)</th>
<th>Peak PLVS (mm Hg)</th>
<th>max dp/dt (mm Hg/sec)</th>
<th>PLVS (mm Hg)</th>
<th>CI (L/min/m²)</th>
<th>TD-CSF (ml/min)</th>
<th>mean Pm (mm Hg)</th>
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<td>( P )</td>
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**Abbreviations:** HR = heart rate; AP = atrial pacing; VP = ventricular pacing; peak PLVS = peak left ventricular or systolic pressure; PLVS = left ventricular filling pressure; CI = cardiac index; TD-CSF = thermodilution coronary sinus flow; Pm = right atrial pressure; SEM = standard error of mean.
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Animal Experiments

The mean response of various interventions that produce increased right atrial pressure and decreased arterial pressure on simultaneously measured TD-CSF and CBF$_{LAD+CX}$ are summarized in table 2. Each of these interventions was evaluated when the external thermistor of the TD-CSF catheter was 10 to 15 mm inside the coronary sinus (Position II). The effect of ventricular pacing was also evaluated when the external thermistor was 25 to 35 mm inside the coronary sinus (Position I). In Position II, the change of pacing from atrial to ventricular mode resulted in a decrease in CBF$_{LAD+CX}$ from 116 ± 19 to 103 ± 15 ml/min ($P < 0.01$), but an increase in TD-CSF from 118 ± 13 to 176 ± 28 ml/min ($P < 0.001$). At the same time mean right atrial pressure and peak a-wave amplitude increased significantly ($P < 0.001$). A typical recording is shown in figure 4. During ventricular pacing arterial pressure fell and correspondingly CBF$_{LAD+CX}$ decreased; however, TD-CSF increased significantly. The bottom tracing shows the appearance of atrial cannon waves during ventricular pac-

<table>
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<tr>
<th>Intervetion</th>
<th>No. of animals</th>
<th>No. of observations</th>
<th>Mean HR (min$^{-1}$)</th>
<th>Peak LVS (mm Hg)</th>
<th>CBF$_{LAD+CX}$ (ml/min)</th>
<th>TD-CSF (ml/min)</th>
<th>Mean P$_{a}$ (mm Hg)</th>
<th>s-amplitude</th>
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<td>AP ext. th. 10-15 mm</td>
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<td>28</td>
<td>134 ± 12</td>
<td>132 ± 7</td>
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<td>VP inside CS</td>
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<td>28</td>
<td>134 ± 12</td>
<td>117 ± 7</td>
<td>103 ± 15</td>
<td>176 ± 28</td>
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<td>AP ext. th. 25-35 mm</td>
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<td>113 ± 16</td>
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<td>Intrathoracic pressure</td>
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<td>152 ± 12</td>
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<td>312 ± 28</td>
<td>9.3 ± 1.3</td>
<td>12.3 ± 1.6</td>
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</table>

**$P < 0.05$  
***$P < 0.01$  
****$P < 0.001$

Abbreviations: No. = number; HR = heart rate; peak P$_{a}$ = peak aortic pressure; CBF$_{LAD+CX}$ = left anterior descending and circumflex coronary arterial blood flow; TD-CSF = thermodilution coronary sinus flow; ext.th. = external thermistor of TD-CSF catheter; CS = coronary sinus; P$_{a}$ = right atrial pressure; AP = atrial pacing; VP = ventricular pacing; PA constriction = pulmonary artery constriction.
ing. This marked discrepancy between CBF_{LAD+CFX} and TD-CSF was not transient, but persisted to the same extent during 15 min of ventricular pacing. The relationship between percent change in CBF_{LAD+CFX} and percent change in TD-CSF during ventricular pacing (Position II) is illustrated in figure 5. There was no correlation between the changes in flow measured by the two methods; most values deviated from the line of identity by more than 50%. Figure 6 illustrates changes in coronary sinus blood temperature during bolus injections of cold saline into the inferior vena cava. There was an immediate decrease in coronary sinus blood temperature during ventricular pacing. Oscillation of the coronary sinus thermodilution curve indicates a phasic appearance of the cold indicator at the external thermistor. During atrial pacing the change in coronary sinus blood temperature was less pronounced compared to that during ventricular pacing (table 2). When the TD-CSF catheter was advanced farther so that the external thermistor was 25–35 mm inside the coronary sinus (Position I) (table 2, fig. 5), a weak linear relationship between percent change in CBF_{LAD+CFX} was noted (y = 0.36x + 7.69, r = 0.62). Despite this relationship there was a rather wide scatter of individual measurements. Slope and intercept were significantly different from those of the line of identity.

Atrial cannon waves also occur during rapid atrial pacing. Due to shortening of the RR interval and prolonged atrioventricular conduction, atrial contraction begins before the preceding ventricular systole has ended. An example is given in figure 7. In this experiment, shortening of the RR interval from 300 to 230 msec resulted in atrial cannon waves, decreased arterial pressure and markedly reduced CBF_{LAD+CFX}, with little change in TD-CSF. Figure 8 illustrates the effect of rapid atrial pacing in such experiments. There was a linear relationship between TD-CSF and CBF up to the RR interval where atrial cannon waves occurred. Beyond this point there was no change or a decrease in CBF, but an increase in TD-CSF (fig. 8). The effects of pulmonary artery constriction were similar to those of ventricular pacing (table 2). CBF_{LAD+CFX} decreased from 124 ± 20 to 94 ± 23 ml/min (P < 0.01), whereas TD-CSF increased from 148 ± 20 to 178 ± 29 ml/min (P < 0.05). A typical recording is shown in figure 9. There was a marked increase in TD-CSF, despite a slight decrease in CBF_{LAD+CFX} and TD-CSF during pulmonary artery constriction (fig. 5).
Increased intrathoracic pressure also produced discrepancy between CBF$_{LAD+CFX}$ and TD-CSF (table 2, fig. 5). CBF$_{LAD+CFX}$ decreased from 146 ± 18 to 117 ± 9 ml/min ($P < 0.001$), whereas TD-CSF increased from 200 ± 11 to 312 ± 28 ml/min ($P < 0.01$). Arterial pressure fell and right atrial pressure rose significantly. A representative experiment is shown in figure 10. During the period of increased intrathoracic pressure CBF$_{LAD+CFX}$ decreased 17% as arterial pressure also decreased. TD-CSF, however, increased 27%. Peak amplitude of right atrial 'a' wave was 3 mm Hg higher during the intervention. In order to quantitate the relationship between the amplitude of right atrial 'a' wave and the discrepancy between CBF$_{LAD+CFX}$ and TD-CSF, we determined the ratio of TD-CSF/LAD+CFX at different levels of right atrial 'a' wave amplitude. Changes in right atrial pressure were produced by varying the PR interval over a wide range during atrioventricular sequential pacing in a dog with complete atrioventricular block. As apparent from figure 11 (upper panel), changes in the 'a' wave amplitude paralleled those in TD-CSF/CBF$_{LAD+CFX}$. At a PR interval of 100 msec this ratio approached 1, while at PR = 0 and PR > 200 msec TD-CSF exceeded CBF$_{LAD+CFX}$ by about 50%. When TD-CSF/CBF$_{LAD+CFX}$ is plotted against changes in right atrial 'a' wave amplitude, a linear relationship was found ($y = 0.1x + 1.07, r = 0.82$). At 0 mm Hg, TD-CSF/CBF$_{LAD+CFX}$ were almost identical. With increasing amplitude in right atrial 'a' wave, discrepancy between TD-CSF and CBF$_{LAD+CFX}$ increased progressively. When right atrial 'a' wave increased by 4 mm Hg, TD-CSF was 50% higher than CBF$_{LAD+CFX}$. In one animal we measured coronary sinus flow by an electromagnetic flow transducer and by the thermodilution technique (fig. 12). The recording shows that mean electromagnetic CSF and CBF$_{LAD}$ decreased during VP, whereas TD-CSF increased.

Discussion

In their original publication, Ganz and co-workers validated TD-CSF measurements by comparison with measurements of the actually obtained drainage of the coronary sinus. Coronary sinus drainage was achieved by a tight-fitting cannula in the distal coronary sinus. An ex-

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**Figure 5.** Relationship between percent change in CBF$_{LAD+CFX}$ and TD-CSF following interventions that increase P$_{Rx}$. Position I was 25 to 35 mm from the ostium of the coronary sinus. Position II was 10 to 15 mm.

**Figure 6.** Bolus injections of cold saline into the inferior vena cava resulted in simultaneous changes in coronary sinus and pulmonary artery blood temperatures. Decrease in coronary sinus blood temperature was much more pronounced in the presence of atrial cannon waves. Oscillations on the coronary sinus thermodilution curve indicate the phasic appearance of the injectate at the external thermistor which was 13 mm inside the coronary sinus in this experiment. $T_{cs}$ = coronary sinus blood temperature; $T_{pa}$ = pulmonary artery blood temperature.

**Figure 7.** CBF vs TD-CSF during rapid atrial pacing. Shortening of the RR interval from 300 to 230 msec resulted in atrial cannon waves. At the same time, $P_{ad}$ and consequently CBF$_{LAD+CFX}$ decreased due to loss of atrial contribution to left ventricular filling. $T_{cm}$, however, remained essentially unchanged.
Figure 8. Relationship between CBF and TD-CSF during atrial pacing at different rates (indicated as numbers on the graph). Beyond a certain pacing rate which depended on A-V conduction, the atrial pacing stimulus fell into systole of the preceding beat causing an atrial cannon wave. Up to this rate there was a linear relationship between both methods; beyond it CBF remained unchanged or decreased, whereas TD-CSF increased. LAD = left anterior descending coronary artery blood flow; CFX = circumflex artery blood flow; LAD+CFX = combined left anterior descending and circumflex flow.

Figure 9. CBF vs TD-CSF during pulmonary artery constriction. Note the increase in the a-wave of the P\textsubscript{PA} during pulmonary artery constriction. In this experiment CBF decreased by 17%, TD-CSF increased by 102%.

Figure 10. CBF vs TD-CSF during increased intrathoracic pressure. With the increase in right atrial pressure CBF\textsubscript{LAD+CFX} decreased 17% but TD-CSF increased 27%.

Excellent correlation was found. The occluding cannula, however, removed the possibility of any right atrial reflux into the coronary sinus. In a later study, these observations were confirmed by comparing TD-CSF with electromagnetic coronary arterial blood flow. Almost identical values for TD-CSF and the sum of LAD and CFX coronary arterial blood flow were found. In open chest dogs on cardiopulmonary bypass, Van Devanter and co-workers also demonstrated excellent correlation between thermodilution coronary sinus flow and coronary blood flow measured with an electromagnetic flowmeter. The correlation between both methods was 0.90. In contrast to these studies, however, Weisse and Regan reported a rather poor correlation between simultaneous measurements of TD-CSF and myocardial blood flow measured by the \textsuperscript{85}Krypton washout method. They demonstrated large variations in percent change of TD-CSF compared with percent change in \textsuperscript{85}Kr myocardial blood flow during different interventions, such as pacing, catecholamine infusion and hemorrhage. They ascribed these discrepancies to a variable position of the TD-
CSF catheter inside the coronary sinus. The possibility of dilution of coronary sinus blood by right atrial reflux was demonstrated by Koberstein, Pittman and Klocke. They increased the right atrial pressure of closed chest dogs by partial obstruction of the pulmonary artery and showed a variable degree of contamination. At worst, 15% of blood sampled from the coronary sinus originated from the right atrium. The tip of the sampling catheter was within 2 cm from the ostium and the withdrawal rate was 30 ml/min. Therefore, considerable uncertainty still exists regarding the validity of considering the TD-CSF as truly representing coronary blood flow. The present study demonstrates that changes in coronary sinus flow measured by thermodilution technique do not represent accurately changes in coronary blood flow when there is a change in right atrial pressure. In patients in this study, TD-CSF was higher during ventricular pacing with atrial cannon waves compared to atrial pacing by an average of 38%, despite a decrease in the determinants of myocardial oxygen consumption. During ventricular pacing, peak left ventricular systolic pressure, maximum dp/dt and left ventricular filling pressure were significantly lower than during atrial pacing; myocardial oxygen consumption during ventricular pacing, compared to that during atrial pacing, is therefore expected to be less. Reduced myocardial oxygen consumption is also likely to be associated with less heat production and, hence, relatively cooler coronary sinus blood. Such cooler coronary sinus blood (Tb) during ventricular pacing compared to that during atrial pacing, should cause a reduction in TD-CSF during ventricular pacing because there will be an equal reduction in the temperature of the mixture of the coronary sinus blood and in the injectate (Ta), thus causing no change in the denominator (Ta-Tm), but reducing the value of the numerator (Ta-Tb). In this study, however, estimated TD-CSF during ventricular pacing was higher than during atrial pacing. Furthermore, in this study, the mean temperatures of coronary sinus blood during ventricular and atrial pacing before the infusion of the injectate were similar. Therefore, a higher value of TD-CSF during ventricular pacing, compared to that during atrial pacing, cannot be explained by variations in the baseline temperature. Higher TD-CSF during ventricular pacing, despite a decrease in the determinants of myocardial oxygen demand, led us to suspect that right atrial-coronary sinus reflux during right atrial cannon waves might have been responsible for higher thermodilution coronary sinus flow during ventricular pacing, compared to that during atrial pacing at identical rate. Indeed, bolus injections of cold saline during ventricular pacing indicated that right atrial reflux is the most likely cause for those paradoxical findings. This was confirmed by animal experiments, which showed that TD-CSF does not only represent myocardial venous blood outflow, but also a variable amount of right atrial reflux. As in patients, bolus injections of cold saline into the inferior vena cava resulted in an immediate decrease in coronary sinus blood temperature. Oscillations on the coronary sinus thermo-
dilution curve synchronous with each atrial ‘a’ wave indicate phasic reflux during atrial systole. In addition, we directly observed phasic reflux during continuous infusion of contrast medium into the coronary sinus.

Following interventions that increase right atrial pressure and decrease aortic pressure there was a significant decrease in \( CBF_{LAD-CFX} \), but a significant increase in TD-CSF. Whereas during atrial pacing TD-CSF and \( CBF_{LAD-CFX} \) were, on the average, identical during ventricular pacing, TD-CSF measurements exceeded \( CBF_{LAD-CFX} \) by an average of 60%, during pulmonary constriction by 44%, and during increased intrathoracic pressure by 76%. Discrepancy between TD-CSF and CBF was not only transient, but present as long as right atrial pressure was elevated. Discrepancy between TD-CSF and CBF were also observed during rapid atrial pacing in two experiments. Compared to CBF, TD-CSF increased, but less rapidly, as the atrial pacing rate was increased. This was probably related to higher extracoronary sinus venous drainage that has been observed at higher pacing rates. At a RR interval where atrial cannon waves occurred, CBF either did not change or slightly decreased, but TD-CSF markedly increased (fig. 7). These findings suggest that at a very high pacing rate, if there are right atrial cannon waves due to prolonged PR interval, TD-CSF significantly exceeds actual coronary sinus outflow; in such circumstances, TD-CSF should not be regarded as representative of CBF.

As apparent from figure 5, correlation between percent change in TD-CSF and \( CBF_{LAD-CFX} \) was significant only when the TD-CSF catheter was advanced in the coronary sinus so that the external thermistor was 25–35 mm inside the coronary sinus. Despite this relationship, there was a wide scatter of the individual measurement. It may be argued that the higher TD-CSF values in the presence of an increased right atrial pressure were not due to right atrial reflux, but redistribution of Thebesian vein flow. During the interventions studied, Thebesian vein flow might have been reduced and coronary sinus flow correspondingly higher. For this purpose, simultaneous measurements of coronary sinus flow by the thermodilution technique and by electromagnetic flow transducers were performed. Redistribution of Thebesian vein flow would be expected to result in an increase in both electromagnetic and thermodilution coronary sinus flow. Right atrial reflux, however, would appear as discrepancy between the two measurements, since the reflux passes the electromagnetic flow transducer twice in opposite directions and, therefore, cancels out in the flow measurement. As evident from figure 11, electromagnetic coronary sinus flow decreased during ventricular pacing as did electromagnetic \( CBF_{LAD} \), whereas TD-CSF increased. Therefore, it is unlikely that redistribution of Thebesian vein flow is responsible for the difference between \( CBF_{LAD-CFX} \) and TD-CSF.

Discrepancy between TD-CSF and electromagnetic \( CBF_{LAD-CFX} \) as observed in this study is at variance with that reported by Ganz et al.4 In that study, TD-CSF and electromagnetic CBF were compared presumably in the absence of increased right atrial pressure, which may account for the close agreement between TD-CSF and \( CBF_{LAD-CFX} \) in their study.

In the experiment shown in figure 11, an attempt was made to quantitate the relationship between the amplitude of right atrial ‘a’ wave and the amount of right atrial reflux. There was a significant linear relationship between the pressure amplitude of the right atrial ‘a’ wave and the discrepancy between TD-CSF and \( CBF_{LAD-CFX} \). In the presence of low right atrial pressure, discrepancy was only slight; however, it increased considerably as right atrial pressure was increased. These findings suggest that coronary sinus blood flow determined by thermodilution technique cannot be regarded as representative of coronary blood flow in the presence of increased right atrial pressure.

As this study demonstrates, that significant reflux of right atrial blood occurs into coronary sinus with increasing right atrial pressure, it is obvious that quantitation of indicators or metabolites in coronary sinus blood is also impossible in the presence of unknown amounts of right atrial reflux. Clinical conditions where this artifact has to be taken into account include pulmonary hypertension, Valsalva maneuver, ventricular pacing, rapid atrial pacing with atrial cannon waves, tricuspid stenosis or insufficiency, and possibly even where there is a significant respiratory fluctuation in right atrial pressure. The error in the measurement of indicator-concentrations in the coronary sinus blood that may be caused by right atrial reflux can be reduced by choosing a sampling site further upstream in the coronary sinus. However, this would be no longer represented sample of the total left ventricular venous blood. To be sure that even in the proximal coronary sinus or the great cardiac vein no reflux is present, we would recommend performing bolus injections of cold saline into the right atrium and measuring the change in coronary sinus blood temperature under the conditions of the study.

Acknowledgment

The authors would like to acknowledge the technical assistance of Dr. Arthur Anonas and Ms. Anne Norman, as well as Mr. Robert Smith, and the editorial assistance of Miss Barbara Salecker and Mrs. Kathleen Hecker.

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Circulation. 1978;57:778-786
doi: 10.1161/01.CIR.57.4.778

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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