Comparison of three different principles in the assessment of coronary flow reserve from digital angiograms

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Summary

In 70 patients without coronary disease we have compared three different principles to assess coronary flow reserve during diagnostic heart catheterization. Digital angiograms with ECG-triggered bolus injections of 4 to 8 ml of contrast medium at rest and after stimulation by dipyridamole (0.5 mg/kg i.v.) or papaverine (12.5 mg i.c.) were acquired in a 512 x 512 matrix at 8 bit resolution (ADAC 4100) and stored on a digital disk at 25 frames/sec. or 2 frames/cardiac cycle (PPR-mode). Angiograms were processed by cyclic R-wave-gated mask mode subtraction and coronary flow in the LAD area was assessed by three different approaches: 1. A traditional densitometric principle. 2. The ‘CMAP’ principle. 3. A modification of the Stewart-Hamilton principle comparing the total amount of contrast medium that enters the coronary circulation to the area of the contrast dilution curve in a fixed portion of the LAD. Flow was measured simultaneously during angiography using the thermodilution technique for coronary sinus/great cardiac vein flow.

Drug stimulation resulted in an increased coronary blood flow up to five times of resting flow. Regression analysis revealed the following results for the assessment of the coronary flow reserve by digital angiography (y) when compared to thermodilution (x):

<table>
<thead>
<tr>
<th>Method</th>
<th>Regression</th>
<th>Correlation</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>y = 1.36x + 0.02</td>
<td>r = 0.82</td>
<td>SEE = ± 0.69</td>
</tr>
<tr>
<td>2</td>
<td>y = 0.99x + 0.22</td>
<td>r = 0.69</td>
<td>SEE = ± 0.74</td>
</tr>
<tr>
<td>3</td>
<td>y = 1.30x - 0.21</td>
<td>r = 0.89</td>
<td>SEE = ± 0.43</td>
</tr>
</tbody>
</table>

Method 2 could be improved by replacing the density factor by morphometrically measured proximal LAD volume (y = 0.77x + 0.55; r = 0.78; SEE = ± 0.43).

In conclusion, our data suggest that the Stewart-Hamilton principle may be advantageous over time parameter-dependent approaches in the assessment of coronary flow reserve by digital angiography.

Introduction

Prudent decision making in the treatment of coronary artery disease should not be based on anatomical aspects of the coronary circulation alone, but should include information on the hemodynamic significance of coronary artery lesions, i.e. the impact on ‘coronary reserve’ under conditions of increased demand in the dependent myocardial area.

In a time of rapidly evolving and expanding techniques for nonsurgical, transvascular recanalization or revascularization, it is obvious that methods that could provide this information during coronary arteriography without the need for any additional procedure would be highly desirable.
The assessment of coronary flow reserve requires the measurement of blood flow in epicardial coronary arteries or in a given myocardial region at rest and under maximal flow stimulation [1]. In the present study, we have compared several techniques that can provide the assessment of absolute flow or relative flow equivalents from digital angiograms obtained during routine heart catheterization.

Methods

1. Patient selection

This study was carried out in 70 patients, age 21–64 years, who had undergone orthotopic heart transplantation one or two years previously and now underwent routine follow-up heart catheterization. The reason to select transplant patients for this study were the following:

1. For some of the angiographic techniques under investigation [2, 3], a stable heart rate during coronary angiography is an essential requirement. Due to cardiac denervation, this is guaranteed in post-transplant patients without the need for cardiac pacing, that would have been necessary in other groups.

2. There are few techniques that can provide the dynamic assessment of blood flow in the coronary circulation in conscious man. We selected the coronary sinus thermodilution technique as the reference method for our study, since it carries the smallest risk and inconvenience for the patient. In the post-transplant patient, coronary venous blood flow drains coronary arterial inflow exclusively thus excluding potential sources of error in the coronary sinus thermodilution method such as pericardial or additional broncho-pleural inflow.

All patients gave informed consent for this study. Routine right heart and left heart catheterization including angiography of both ventricles and coronary arteries revealed normal cardiac function and anatomically normal coronary arteries in all patients.

Coronary sinus blood flow measurement

Flow in the upper coronary sinus was used as reference and was measured according to the technique of Ganz et al. [4]. A No 7-F-thermodilution catheter (Wilton Webster, Altadena, USA) was introduced from the right jugular vein and advanced with its tip into the great cardiac vein, positioning the thermistor at the great cardiac vein/coronary sinus juncture. Saline at room temperature was infused at a rate between 55 and 60 cc/min and flow (Q) was calculated according to the formula:

\[ Q = \left( \frac{TB - TI}{TB - TM} - 1 \right) \times F + 1.08 \]  

Where \( F \) = infusion flow, \( TB \) = blood temperature, \( TI \) = temperature of the saline infusate, \( TM \) = mixing temperature of saline and blood in the coronary sinus during infusion.

Aquisition of digital angiograms

Digital angiograms were acquired with ECG-triggered bolus injections of 4 to 8 ml of nonionic contrast medium (Ultravist 370) into the left coronary artery, and stored on an ADAC 4100 computer system at frame rates of 25/sec. or 2 frames/cardiac cycle (ECG-gated, at 25 and 75 percent of cycle length) using a 512 \times 512 pixel matrix with 8 bit grey level resolution. As a first step, ECG-gated, cyclic mask-mode-subtraction was performed on all angiograms before further processing. Flow (Q) equivalents were calculated by use of the following principles:

1. The traditional ‘double window’ principle

This method relates geometrically measured vascular volume (vol) to the travelling time (TT) of a contrast bolus between two points on an epicardial artery [5] measured by densitometry (see Fig. 1):

\[ Q = \frac{vol}{TT} \]  

According to the indicator dilution theory, bolus