Pulsatility index variations using two different transit-time flowmeters in coronary artery bypass surgery

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Abstract

Objective: Transit-time flow measurement is widely accepted as an intra-operative assessment in coronary artery bypass grafting (CABG). However, the two most commonly applied flowmeters, manufactured by MediStim ASA and Transonic Inc., have different default filter settings of 20 and 10 Hz, respectively. This may cause different flow measurements, which will influence the reported results. The aim was to compare pulsatility index (PI) values recorded by the MediStim and Transonic flowmeters in two different clinical settings: (1) analysis of the flow patterns recorded simultaneously by both flowmeters in the same CABGs; and (2) evaluation of flow patterns under different levels of filter settings in the same grafts.

Methods: Graft flow and PI were measured using the two different flowmeters simultaneously in 19 bypass grafts. Finally, eight grafts were assessed under different digital filter settings at 5, 10, 20, 30, 50 and 100 Hz.

Results: The Transonic flowmeter provided substantially lower PI as compared with the MediStim flowmeter. By increasing the filter setting in the flowmeter, PI increased considerably.

Conclusions: The MediStim flowmeter displayed a lower PI than the Transonic, due to a lower filter setting. In the Transonic, flow signals are filtered at a lower level, rendering a ‘smoother’ pattern of flow curves. Because different filter settings determine different PIs, caution must be taken when flow values and flowmeters are compared. The type of flowmeter should be indicated whenever graft flow measurements and derived indexes are provided.

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Keywords: CABG; Coronary graft assessment; Flowmetry; Pulsatile index; PI; Transit-time

1. Introduction

Intra-operative assessment of graft patency is an important aspect of coronary artery bypass grafting (CABG). Transit-time flow measurement (TTFM) has been in clinical use for more than a decade and is the most applied technique for intra-operative coronary graft assessment. Transit-time technology has proven to have a high reliability and accuracy with few sources of technical errors and provides volumetric flow patterns and derived indexes, such as the pulsatility index (PI) [1—4].

The PI is considered a non-invasive method for the assessment of peripheral vascular resistance of coronary arteries [5—9], as well as in arteries of other organs (i.e. brain, kidney, placenta, eye, and so on) [5]. It was first introduced by Gosling and King [6], and was originally defined as the peak-to-peak height of the waveform divided by the mean height during a single cardiac cycle, as assessed by Doppler ultrasound. With the introduction of TTFM, the definition of PI was replaced and simplified, and at present the following formula is applied: PI = [maximum volumetric peak flow — minimum volumetric peak flow]/mean volumetric flow.

The two most commonly used transit-time flowmeters are manufactured by MediStim ASA (Oslo, Norway) and Transonic Systems Inc. (Ithaca, NY, USA) and have different default filter settings of 20 and 10 Hz, respectively. Since the level of filter settings in a flowmeter may influence the wave form, different maximum and minimum peak flows may be registered and influence the PI values [10].

The aim of this study was to assess the potential variability of the PI as calculated by the MediStim and Transonic flowmeters, and to investigate whether increase in filtering of the flowmeter signals influences flow curves and PI values.
2. Material and methods

The idea to carry out this study came to us while studying two clinical series of patients operated upon with CABG, each of them assessed by TTFM of coronary grafts by the MediStim or the Transonic flowmeter, respectively (see Table 1). The first series was operated on by RH at the University Hospital of Trondheim, Norway, whereas the second series came from the University Hospital of Catanzaro, Italy, being operated upon by AR. All single and sequential saphenous vein grafts (SVGs), and left internal mammary artery (LIMA) grafts were included. All flow measurements were carried out after weaning of cardiopulmonary bypass and after administration of protamine. Factors such subclavian artery stenosis or spasm of the LIMA graft were not taken into consideration. We observed that the PI calculated by the Transonic was generally lower than the PI by MediStim. This difference was either due to a real difference between the two flowmeters (i.e. different levels of filter setting), or it was determined by the intrinsic biases associated with a comparison between different patient populations and surgeons. Moreover, we decided to search the literature for the largest clinical series reporting PI data of coronary grafts calculated by the MediStim or Transonic flowmeters, to find out whether the trend of different PI values calculated by the two machines were consistent in other series as well (see Table 2). Most of the relevant data available were obtained by the MediStim flowmeter [11–16], whereas just two series presented by the same investigators were found reporting PI values by Transonic [17,18]. Despite differences in the amount of data, we noted a trend towards lower PI values provided by the Transonic flowmeter versus the MediStim flowmeter. Thus, we decided to carry out the following study to ascertain whether this observation held true based on the technical characteristics of transit-time flowmeters.

2.1. Digital signal processing technology in transit-time flowmeters

The transit-time flowmeters measure the time difference between an upstream and downstream ultrasonic pulse when transmitted and received by two spatially separated transducers in the flow probe. This time-delay difference can be converted to volume flow, which is displayed on-screen as a digitised signal. The flow is recorded as analogue signals that are initially digitally sampled at a sufficiently high frequency according to the Nyquist–Shannon sampling theorem [19]. Further, the flowmeter typically uses a low-pass filter to smooth the signal and attenuate noise. MediStim and Transonic flowmeters use default low-pass filters at 20 and 10 Hz, respectively. In other words, the flowmeters filter the signals differently, which may determine different flow curve patterns.

Table 1
Mean PI of two patient populations assessed by MediStim and Transonic flowmeter, respectively.

<table>
<thead>
<tr>
<th>Graft</th>
<th>Group A</th>
<th></th>
<th>Group B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean 95% CI</td>
<td>p</td>
<td>Lower Upper</td>
</tr>
<tr>
<td>LIMA-LAD</td>
<td>482</td>
<td>2.1 2.1 2.2</td>
<td></td>
<td>100 1.7 1.8</td>
</tr>
<tr>
<td>Single SVG to LCA</td>
<td>198</td>
<td>1.8 1.7 1.9</td>
<td>&lt;0.001</td>
<td>36 1.7 1.5</td>
</tr>
<tr>
<td>Double SSVG to LCA</td>
<td>264</td>
<td>1.8 1.7 1.9</td>
<td>0.52</td>
<td>19 1.4 1.0</td>
</tr>
<tr>
<td>Single SVG to RCA</td>
<td>371</td>
<td>2.1 1.9 2.2</td>
<td>0.03</td>
<td>25 1.6 1.3</td>
</tr>
<tr>
<td>Double SSVG to RCA</td>
<td>41</td>
<td>2.2 1.9 2.5</td>
<td>0.001</td>
<td>61 1.7 1.5</td>
</tr>
</tbody>
</table>

Group A: MediStim flowmeter; Group B: Transonic flowmeter; CI: confidence interval; LCA: left coronary artery; RCA: right coronary artery; SSVG: sequential saphenous vein graft; and SVG: saphenous vein graft.

Table 2
Mean PI from different published studies.

<table>
<thead>
<tr>
<th>Flowmeter</th>
<th>Author</th>
<th>Type of graft (N)</th>
<th>PI ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MediStim</td>
<td>Becit [11]</td>
<td>LIMA-LAD (102)</td>
<td>2.32 ± 0.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to Diagonal (48)</td>
<td>2.26 ± 0.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to OM (80)</td>
<td>2.51 ± 0.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to RCA (73)</td>
<td>2.23 ± 0.94</td>
</tr>
<tr>
<td></td>
<td>Goel[12]</td>
<td>LIMA-LAD (162)</td>
<td>2.71 ± 0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG overall (224)</td>
<td>2.48 ± 1.04</td>
</tr>
<tr>
<td></td>
<td>Gwozdziewicz [13]</td>
<td>SSVG (50)</td>
<td>1.8 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>Kim*** [14]</td>
<td>To LCA (67)</td>
<td>2.4 ± 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To RCA (36)</td>
<td>3.1 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>Hassanein [15]</td>
<td>LIMA-LAD (421)</td>
<td>1.98 ± 1.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to Diagonal (69)</td>
<td>1.72 ± 0.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to OM (71)</td>
<td>1.88 ± 0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to RCA (107)</td>
<td>1.80 ± 1.82</td>
</tr>
<tr>
<td></td>
<td>Nordgaard*** [16]</td>
<td>LIMA-LAD (495)</td>
<td>2.4 ± 0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to LCA (527)</td>
<td>2.0 (0.05 SEM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to RCA (368)</td>
<td>2.4 (0.06 SEM)</td>
</tr>
<tr>
<td>Transonic</td>
<td>Onorati [17]</td>
<td>LIMA-LAD (199)</td>
<td>1.53 ± 0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to RCA (102)</td>
<td>1.67 ± 1.20</td>
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<tr>
<td></td>
<td></td>
<td>SVG to OM (61)</td>
<td>2.06 ± 0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to Diag (25)</td>
<td>2.25 ± 1.25</td>
</tr>
<tr>
<td></td>
<td>Onorati [18]</td>
<td>LIMA-LAD (45)*</td>
<td>1.2 ± 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LIMA-LAD (45)*</td>
<td>1.0 ± 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVG to OM*</td>
<td>1.46 ± 0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SSVG to OM*</td>
<td>0.71 ± 0.4</td>
</tr>
</tbody>
</table>

* Single SVG group.

b Sequential SVG group.

* OPCAB in 36% of cases.

** OPCAB in 11% of cases.

*** Only arterial grafts were used: mammary (n = 78), gastroepiploic (n = 38) and radial artery (n = 1).

Includes values from single and sequential SVG as no PI difference was found between the groups [16].
The study protocol was divided into two steps:

1. Controlled comparison of PI as calculated by the MediStim and Transonic flowmeters applied simultaneously on the same coronary grafts;
2. Evaluation of changes in the flow curves and PI with different filter settings.

2.1.1. Assessment of PI in the same graft by MediStim and Transonic flowmeters

The two flowmeters were simultaneously compared in 19 coronary bypass grafts (10 single and five sequential SVGs, and four LIMA grafts) in 10 patients who were operated on by the same surgeon (RA) in the same unit (Trondheim). Two 4 mm flow probes, each connected to the respective MediStim or Transonic flowmeter, were placed next to each other on the middle segment of the grafts. Each measurement was done at a stable haemodynamic condition after weaning from cardiopulmonary bypass, and good acoustical coupling was obtained between the flow probe and the graft.

2.1.2. Assessment of PI during different filter settings

Finally, to investigate the influence of different filter settings on the flow curves, eight grafts in four patients, who were operated on by the same surgeon (RA), were assessed by gradually increasing the filter setting of the flowmeter from 5 Hz to 10, 20, 30, 50 and 100 Hz. To accomplish this, the MediStim VeriQ flowmeter was used since it is fitted to adjust the filter level. After discontinuation of the cardiopulmonary bypass and at stable haemodynamic conditions, the flow patterns of the grafts were recorded for 5—10 s at each filter level. The analysis of the flow curves was carried out using the MediStim VeriQ 2.0 software.

The complete study protocol was approved by the Regional Medical Ethics Committee on Human Research at both institutions. All data were entered into a single clinical database according to the regulations of the Norwegian Social Science Data Services.

2.2. Statistical methods

The grafts were nested into LIMA-LAD, single and double sequential SVGs to the left and right coronary arteries, respectively. In Table 1, a logarithmic transformation of the flow data was performed to achieve normal distribution. The comparisons between grafts from the two cardiac centres were performed using two sample t-tests except for the single SVGs to the left coronary artery, where a random effects model with random intercept using the ‘xtreg’ command in STATA was used. A random effects model was used to account for repeated measurements as several patients got more than one single SVG to the left coronary artery system. A Wilcoxon signed rank test was used to compare the simultaneous flow assessments in the same grafts. Bland—Altman plots of the simultaneous flow measurements were made in Excel. The PI values are expressed as geometric mean and 95% confidence interval. p < 0.05 was considered significant. Statistical analysis was performed using SPSS for Windows version 15 (SPSS Inc., Chicago, IL, USA) and STATA for Windows version 10 (StataCorp, College Station, TX, USA).
3. Results

3.1. Assessment of PI by MediStim versus Transonic flowmeter in the same grafts

The MediStim and Transonic flowmeter provided mean PI and standard deviations of 2.7 ± 1.2 and 1.8 ± 0.6, respectively (p < 0.001; Wilcoxon signed ranks test). Fig. 1 clearly demonstrates the difference between the two flowmeters. The Transonic flowmeter achieved systematically lower PI values. The degree of difference depended on the flow pattern. In a spiky flow curve pattern the resultant PI was high, with remarkable differences between the two flowmeters. However, with a smoother flow pattern the PI was low, and the two flowmeters produced similar values, demonstrating that the difference between the flowmeters becomes greater as PI increases (Fig. 2).

3.2. Assessment of PI under different filter settings

Typical changes in the flow pattern occurred under different filter settings. At low-filter setting, a smoother flow pattern appeared with no sharp flow spikes. By increasing the filter setting, a 'noisier' flow pattern appeared which produced higher PIs. Fig. 3 visualises the different flow curves at different filter settings with the MediStim VeriQ flowmeter, and in this case as well, the difference between filter settings becomes greater as PI increases.

4. Discussion

This study identified important differences between the two most frequently used TTFMs. Because of a lower filter setting, the Transonic flowmeter produced smoother flow curves than the MediStim, which influenced the calculation of the PIs. Specifically, PIs calculated by Transonic are lower than those calculated by MediStim.

Direct comparisons of flow and PI results of the same grafts by the two flowmeters provided evidence that the Transonic produced a lower PI than the MediStim, which was observed consistently during the testing of 19 grafts. Furthermore, PI differences between the two flowmeters seemed to be more pronounced at higher PI values, as shown in Fig. 1.

The next step in our analysis was to find out whether a lower PI was achieved by applying a lower filter setting, which produced smoother flow curves. We discovered that a constant increase in PI value occurred in concomitance with an increase in the filter setting, and that higher filter settings are characterised by a pronounced spiky pattern that determined very high maximum and low minimum peaks on the flow charts, resulting in increased PI values.

The PI is calculated automatically by the flowmeters. The MediStim flowmeter and the Transonic flowmeter measure the higher and lower peaks during a blood flow recording time of 2 and 8 s, respectively. Therefore, one would expect higher and lower peaks, resulting in higher PIs, to most likely be recorded by the Transonic flowmeter, rather than the MediStim because of its longer recording time. Interestingly, but still of unknown
reason, this was not the case since the Transonic produces systematically lower PIs due to its lower filter setting.

Similar outcomes, which document the differences between these two flowmeters, have only previously been published in an abstract.1 Fifty-five grafts from 23 patients were assessed intra-operatively by both devices. On the one hand, a significantly higher PI of 2.2 was shown with the MediStim as compared with a PI of 2.7 by the Transonic. On the other hand, the differences in mean flow were also significant: it was 45.6 ml/min⁻¹ using the MediStim as compared with 62.1 ml/min⁻¹ with the Transonic. Unfortunately, the authors did not comment on these findings.

In vitro and in vivo comparisons of TTFTMs have both shown a high accuracy and precision in regard to volumetric flow [1,3,20]. To the best of our knowledge, this variation in flow pattern as seen in different flowmeters has not been previously described, although it is highly relevant. The simultaneous comparison of the two flowmeters confirmed the differences seen clinically as presented in Table 1.

On clinical grounds, the difference in waveforms due to different filter settings may have important repercussions. The shape of the flow curve is an element which comes into play when assessing grafts that are difficult to interpret (low flows and high PI). In cases involving a failed anastomosis or a graft directed to coronary arteries with high peripheral vascular resistance, the waveform will present multiple spikes that will be higher than expected. On the one hand, a device equipped with a high filter setting will produce very spiky flow curves, making it difficult to evaluate the graft flow. On the other hand, a device with a low filter setting will smooth out most of the spikes, making the graft assessment appear to be better than it actually is.

Unfortunately, there are no clear cut-off values of mean flow and PI that allow surgeons to adequately establish the quality of a coronary graft. There has been much debate over the identification of these cut-off values, but so far, no general agreement has been reached due to the many variables influencing the identification of these cut-off values, but so far, no general agreement has been reached due to the many variables involved in graft assessment[14,21,22]. The important issue of having separate cut-off values for different flowmeters has not been discussed. Therefore, based on the results of our investigation, it is important to refer to the type of flowmeter used when presenting flow values.

In conclusion, MediStim and Transonic TTFTMs are not directly comparable because of their filter settings at 20 and 10 Hz, respectively. Different levels of filter settings in the flowmeters determine different shapes in the flow curves, which results in different PI values. In particular, more pronounced differences in PIs were noted when the PI was around 3. Thus, the type of flowmeter should always be reported together with the graft flows and PI.

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References
