Cardiac surgery residents' learning curve of intraoperative transit-time flowmetry and high-frequency ultrasound in coronary artery bypass surgery: the LEARNERS study.

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ABSTRACT

Transit-time flowmetry (TTFM) allows grafts quality assessment during coronary artery bypass surgery by measuring the flow volume through them. Recently the intraoperative epicardial high-frequency ultrasound (HFUS) was introduced, with the possibility of capturing bidimensional images of the anastomoses. When combined, these two techniques provide high diagnostic yield reaching a positive predictive value of 100 percent.
Despite current guidelines recommend the employment of TTFM and HFUS, they remain largely underused probably because of limited information and the lack of standardization. Furthermore, surgeons must overcome a learning curve to handle both techniques properly, but few data are available according the current literature.
The main purpose of this study is to evaluate the complexity of HFUS and TTFM learning curve. This is a prospective, observational, monocentric cohort study. Adult patients undergoing coronary artery bypass surgery will be enrolled.

BACKGROUNG

During coronary artery bypass surgery, it is essential to verity grafts patency and functioning. Indeed, this has important consequences in the perioperative period and an impact on patient long-term prognosis (1,2).
Since the second half of the 1990s, this intraoperative quality control is possible thanks to the transit-time flow measurement (TTFM) that evaluates the flow volume through the grafts.

The evaluation of the coronary grafts by TTFM allows to acquire the following parameters:

- **Mean flow (ml/min)**: it is influenced by multiple factors including the size and quality of the graft, the size and quality of the coronary target, the quality of the anastomosis, the run-off of the distal coronary vascular territory, the hemodynamic condition of the patient, the presence of competitive flow between grafts pertaining to the same territory.
According to currently guidelines, the average flow should be above 20 ml/min (3,4).

- **Pulsatility index (PI)**: calculated as [(maximum flow - minimum flow)/average flow] through 5 cardiac cycles. It represents an estimate of resistance to flow. It can be influenced by multiple factors: anastomosis quality, coronary stenosis after the anastomosis, competitive flow.
Literature data suggest that an ideal value would be < 3 (4).

- **Backward flow (BF - percentage)**: it represents the percentage of flow directed from the native coronary artery to the graft during a cardiac cycle. It may indicate the presence of competitive flow between the graft and the coronary target; studies that evaluated the association between BF percentage and angiographic patency of remote graft concluded that this parameter can be considered a predictor of patency of anastomosis with an identified cut-off of 3 percent of the total flow; (5) practically, a retrograde flow area >3 percent of the total graft flow area represents a risk factor for failure.

- **Diastolic filling (DF - percentage)**: this is a parameter that describes the mode of flow distribution according to the phase of the cardiac cycle (systole/diastole); it provides an estimate of the diastolic flow within the graft, considering that:
1) the prevalence of diastolic flow is a distinctive feature of the left coronary circulation in which coronary resistances are higher during systole for higher transmural pressure;

2) the right coronary artery supplies the right ventricular myocardium in both systole and diastole; for this reason, in this territory a DF percentage is accepted around 50 percent and it may change in case of right coronary hyper-dominance.

The correct interpretation of the TTFM requires an integration of all these parameters and their analysis also in light of the result of the intraoperative HFUS, an intraoperative imaging technique introduced in 2009. Throughout a sterile probe, this technique consents to acquire bidimensional images of the anastomoses and, in addition to TTFM, serves as a benchmark of their patency and correct shape.

Once the data obtained throughout TTFM and HFUS are combined, the surgeon can consider the graft as functioning and patent in the long term. Indeed, recent studies found out that the positive predictive value of TTFM rose from 10 percent to 100 percent when HFUS was added to the intraoperative assessment (6, 7).

Our operative unit adopted this protocol and systematically applies it to every coronary artery bypass graft performed, both in isolated and combined procedures.

Although last European Guidelines on myocardial revascularization recommended intraoperative flowmetry and ultrasound (Class IIa, evidence level B) (1), their use remains substantially limited due to the lack of familiarity with instruments and results interpretation (8).

Furthermore, surgeons must overcome a learning curve to handle both techniques properly, but few data are available according the current literature. The ability of mastering TTFM and HFUS comes gradually but incessantly; constant learning and self-assessment make surgeons continuously improve (9).

Regarding TTFM, when correctly applied it can provide invaluable information about graft flow; however, proper handling technique is paramount. (6) A learning curve is required to interpret it correctly and, in particular at the beginning, diagnostic errors and unnecessary graft revision cannot be excluded. (8)
The basics of TTFM are easy to learn, while the nuances come gradually but constantly; with continued routine use, one begins to appreciate subtle changes of coronary flow in order to detect flow competition or the difference between a perfect graft and a less-than-perfect but functioning one. (9, 10). In light of this, some authors suggest starting first with use of TTFM, use on every graft at least 4 times/graft and continue with this modality alone for at least 6 months. (9)

Instead learning to master the HFUS presents bigger technical challenges. Performing ultrasound on a moving target can actually be more difficult than performing the anastomosis itself, due to the need of maintaining stable and optimal acoustic contact between the ultrasound probe and the target without distorting the anastomosis. (9, 11, 12)
Detractors of this technique have highlighted as its major limit the lack of standardization because of its operator dependency. (13) Some authors though compared two experienced surgeons letting them observe and independently evaluate 120 consecutive anastomoses; having obtained identical results, they proved how, in experienced hands, epicardial ultrasound evaluation appears reproducible and operator independent. (14) Therefore, in order to gain experience, it is mandatory to apply HFUS routinely, starting with selected patients and after proper training from peers or radiologists. (13, 15)
Despite HFUS learning curve requires more patience and attention to detail that TTFM, the basics can be learned in about 10–20 grafts. (9, 10)

STUDY OBJECTIVES

Primary objective

Evaluate the complexity of cardiac surgery residents' learning curve for grafts quality assessment with TTFM and HFUS.

Secondary objectives

- Evaluate the complexity of cardiac surgery residents' learning curve for grafts quality assessment with HFUS as isolated technique.

- Evaluate the complexity of cardiac surgery residents' learning curve for grafts quality assessment with TTFM as isolated technique.

STUDY DESIGN AND DURATION

This is a prospective, observational, monocentric cohort study in which adult patients undergoing coronary artery bypass surgery will be enrolled.

The study will last four months: three months for patients enrollment and data collection and one month for statistical analysis and scientific paper writing.

The trial will start after obtaining favourable opinion from the local Ethics Committee and could be considered completed when all the eight cardiac surgery residents involved have reached primary endpoint.

INCLUSION CRITERIA

- Age >= 18 years old;
- Written informed consent;
- Indication to CABG surgery (both «on-pump» and «off-pump»);
- Stable angina, unstable angina or acute coronary syndrome without ST elevation (NSTEMI).

EXCLUSION CRITERIA

- Age >= 18 years old;
- Written informed consent;
- Indication to CABG surgery (both «on-pump» and «off-pump»);
- Stable angina, unstable angina or acute coronary syndrome without ST elevation (NSTEMI).

STUDY PROCEDURES

All patients with coronary artery disease and an indication for surgical revascularization (coronary artery bypass grafting) who meet the above-described inclusion and exclusion criteria will be enrolled by signing the informed consent the day before surgery.

Patient data (anamnestic data, surgery description, *intraoperative echographic and flowmetric measurements*) will be recorded in a dedicated database. All data recorded in the database are commonly acquired for all patients undergoing this type of surgery and no further examinations will be performed for patients included in the trial.

The study will involve cardiac surgery residents with different levels of training and an expert cardiac surgeon who acts as supervisor and benchmark. Each resident will sign a dedicated informed consent form in the presence of a doctor foreign to the study protocol (Cardiac Surgery ward cardiologist). The residents will be "blinded" about the trial objective and the adopted score system. They will undergo a specific training including a quick lesson and a practical workshop to familiarize with the equipment.

During surgery, every graft will be evaluated through transit time flowmetry (TTFM) and intraoperative ultrasound control (HFUS).

In details, the ultrasound control is carried out through a dedicated sterile ultrasound probe connected to a machine (MiraQ - MEDISTIM) as soon as each anastomosis is completed. The result of the evaluation is recorded together with surgery data. This evaluation is intended to confirm the correct realization of the anastomosis and provides a proof of its patency.

Once each graft is completed, the resident will be given 60 seconds to acquire two HFUS recordings (short and long axis). After that, the supervisor will perform his personal recording which will stand as benchmark. The following items will be evaluated:

A) Long axis recording acquired within 60 seconds [YES—> 1] [NO —> 0]
B) Long axis recording judged as suitable by the supervisor [YES —> 1] [NO —> 0]
C) Short axis recording acquired within 60 seconds [YES —> 1] [NO —> 0]
D) Short axis recording judged as suitable by the supervisor [YES —> 1] [NO —> 0]

<u>E) Correct interpretation of the anastomosis as adequate or inadequate [YES —> no penalty] [NO —> total score becomes 0 and the resident isn't allowed to perform TTFM]</u>

Each resident will be given a HFUS-related score from a minimum of 0 to a maximum of 4.
Whenever one of the recordings will be judged as non-suitable by the supervisor and consequently useless for a correct interpretation of the anastomosis (score 0 for items A and/or C), item E won't be evaluated and the HFUS will be given a total score of 0.

Next step will be the TFM evaluation, which is carried out through a specific sterile device connected to the same machine (MiraQ - MEDISTIM) once the patient has been weaned from the cardiopulmonary bypass and before protamine administration. This recording is performed under EKG and pressure-controlled conditions. Although there is no general agreement on the optimal mean arterial pressure at which the measurement has to be recorded, we will adopt the standard used in the REQUEST study protocol (16), that is an average pressure of 80 mmHg.

The resident will acquire the TTFM recording after each graft is completed. To make the comparison as accurate as possible, the resident will perform TTFM evaluation on one graft at a time and successively the supervisor will do the same for each graft (making sure that delta between the pressure during the two recordings is lower than 10 percent and that no drug has been administered). The following items will be evaluated:

F) Time necessary to acquire the measures [< 30 sec —> 1] [> 30 sec, < 60 —> 0.5] [> 60 sec —> 0]
G) Need for multiple measurements before the final one: [>2 —> 0] [1 —> 0.5] [0 —> 1]
H) Need to change probe dimensions: [NO —> 0] [YES—> 1]

I) ACI [delta between resident and supervisor measurements < 10%—> 1] [> 10%, < 20% —> 0.5] [> 20% —> 0]
L) Mean Flow [delta between resident and supervisor measurements < 10%—> 1] [> 10%, < 20% —> 0.5] [> 20% —> 0]
M) Pulsatility Index [delta between resident and supervisor measurements < 10%—> 1] [> 10%, < 20% —> 0.5] [> 20% —> 0]
N) Backward Flow [delta between resident and supervisor measurements < 10%—> 1] [> 10%, < 20% —> 0.5] [> 20% —> 0]
O) Diastolic Filling [delta between resident and supervisor measurements < 10%—> 1] [> 10%, < 20% —> 0.5] [> 20% —> 0]

P) Correct interpretation of the graft quality as working [YES —> no penalty] [NO —> total score becomes 0]

Each resident will be given a TTFM-related score from a minimum of 0 to a maximum of 8.
The final score for each graft will be the sum of the two scores (HFUS and TTFM), from a minimum of 0 to a maximum of 12.

The same procedure will be repeated for each graft performed during the surgery.
Each resident will continue until reaching a ratio between total score and number of evaluated anastomoses of 11.

END-POINTS

Primary end-point

Number of anastomoses needed to reach a ratio (total score/n. of anastomoses) >= 11

Secondary end-points

- Number of anastomoses needed to reach a ratio (HFUS score/n. of anastomoses) = 4
- Number of anastomoses needed to reach a ratio (TTFM score/n. of anastomoses) >=7

STATISTICAL ANALYSIS AND SAMPLE SIZE CALCULATION

Sample size calculation

Our cardiac surgery unit performs between 5 and 10 coronary artery bypass grafts surgeries per week on average. Considering the inclusion and exclusion criteria and assuming that some patient may not give their informed consent, we expect to enroll 4 patients per week. Considering that the involved residents (8 in total) will take part to the procedures in turn and that we estimate around 10 surgeries to become autonomous, we estimate to enroll 80 patients during a period of 3 months.

Statistical analysis

Data will be collected in a specific database (Microsoft Excel worksheet). The Kolgomorov-Smirnoff test was used to check for variables distribution. Continuous variables with a normal distribution are summarized by mean and standard deviation. Continuous variables with a non-normal distribution are expressed with median and interquartile range.
Categorical variables are reported as absolute frequency distribution and percentage. Continuous data are analyzed using the unpaired t-test or the Mann – Whitney test according to their distribution. Categorical data are compared with the Fisher's exact test. Statistical findings were considered significant if p value was less than 0.05. Statistical analysis will be performed with the statistic software SPSS (IBM).

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