

THE PRESENT AND FUTURE

TECHNOLOGY CORNER

Standardization of Fractional Flow Reserve Measurements



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CME Objective for This Article: After reading this article, the reader should be able to: 1) perform fractional flow reserve measurement in an accurate, standardized manner; 2) recognize and avoid potential pitfalls of fractional flow reserve measurement; and 3) conduct clinical studies that involve fractional flow reserve in a standardized and thus reproducible/comparable manner.

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ABSTRACT

Pressure wire–based fractional flow reserve is considered the standard of reference for evaluation of the ischemic potential of coronary stenoses and the expected benefit from revascularization. Accordingly, its application in daily practice or for research purposes has to be as standardized as possible to avoid technical or operator-related artifacts in pressure recordings. This document proposes a standardized way of acquiring, recording, interpreting, and archiving the pressure tracings for daily practice and for the purpose of clinical research involving a core laboratory. Proposed standardized steps enhance the uniformity of clinical practices and data interpretation. (J Am Coll Cardiol 2016;68:742-53) © 2016 by the American College of Cardiology Foundation.

To assess the contribution of a new diagnostic test, a hierarchical model of efficacy was proposed by Fryback and Thornbury (1). Although the model was developed for the evaluation of diagnostic imaging, its parameters also apply to “physiological imaging,” with its attributes of: 1) technical quality; 2) diagnostic accuracy; 3) diagnostic thinking efficacy; 4) effect on therapy; 5) patient’s outcome; and 6) economic aspects (Central Illustration). A key feature of this model is that for a test to be efficacious at a higher level in this hierarchy, it must be efficacious at lower levels.

Since the first description of pressure wire-based fractional flow reserve (FFR) (2-4), an abundance of data pertaining to each of these criteria have been reported. Accordingly, FFR is now considered to be the reference standard for the evaluation of the ischemic potential and the expected benefit from revascularization of coronary stenosis (5-8). Moreover, FFR is increasingly being used in clinical trials as an inclusion criterion or as an endpoint (9) and to validate new diagnostic modalities (10,11). Although all major outcomes-randomized clinical trials have

made decisions on the basis of operator-derived FFR values, a handful of recent diagnostic accuracy studies sent tracings to physiology core laboratories for post hoc analysis. However, no matter where analysis takes place, technical or operator-related artifacts in pressure recordings should be avoided, minimized, or at least identified if they occur.

FFR is calculated from distal coronary pressure (P_d) and aortic pressure (P_a) obtained during maximal coronary hyperemia. In principle, these measurements are straightforward and almost fully automated, as illustrated in Figure 1. Yet, minor differences among practices of different laboratories have led to some heterogeneity in acquiring and interpreting the data. Because FFR-based decisions are important for patients’ outcomes, and given the need for rigor and reproducibility in reading the tracings by core laboratories, the highest technical quality of FFR measurements is desirable. As FFR by itself is a highly reproducible diagnostic measure, deviations mainly derive from a lack of standardization (12).

Accordingly, this document proposes a standardized way of acquiring, recording, interpreting, and

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**ABBREVIATIONS
AND ACRONYMS**

- FFR** = fractional flow reserve
- P_a** = aortic pressure
- PCI** = percutaneous coronary intervention
- P_d** = distal coronary pressure

storing the pressure tracings for daily practice and for the purpose of clinical research through a core laboratory. Comprehensive reviews of the principle of FFR and of the FFR-based clinical outcome data have been described previously (13,14).

PATIENTS AND VESSEL SELECTION

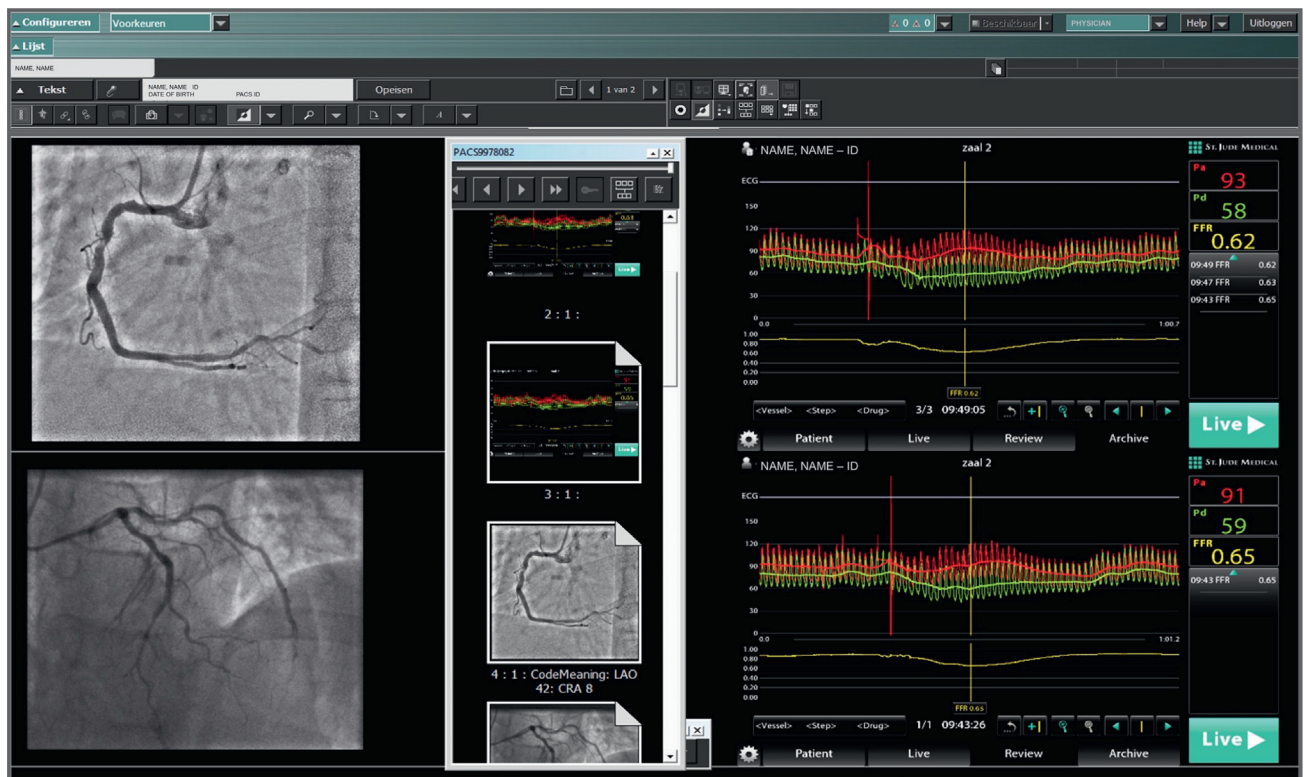
In clinical practice, 2 groups of patients undergo FFR assessment.

STABLE CORONARY DISEASE. In patients with signs suggesting stable coronary artery disease, the European Guidelines support FFR measurements with a Class IA recommendation for the evaluation of stenoses ranging between 50% to 90% diameter stenosis (by visual estimate of coronary angiogram) and when noninvasive ischemia testing is contraindicated,

nondiagnostic, or not available (15). Recent data indicate that even lesions of <50% by quantitative coronary angiography can be hemodynamically significant (16). Their precise characterization by physiological measurements is desirable when located in proximal coronary segments that supply a large myocardial mass, because they may have prognostic significance (17,18). Therefore, it seems advisable to perform FFR measurements more on clinical grounds than on strict angiographic criteria, especially in the case of atypical symptoms or contradictory noninvasive and invasive findings.

ACUTE CORONARY SYNDROMES. In most patients referred to the catheterization laboratory for “unstable angina,” noninvasive stress testing is lacking, and the diagnosis often relies solely on the clinical history, electrocardiographic tracings, or markers of myonecrosis. In these patients, angiographically less-severe

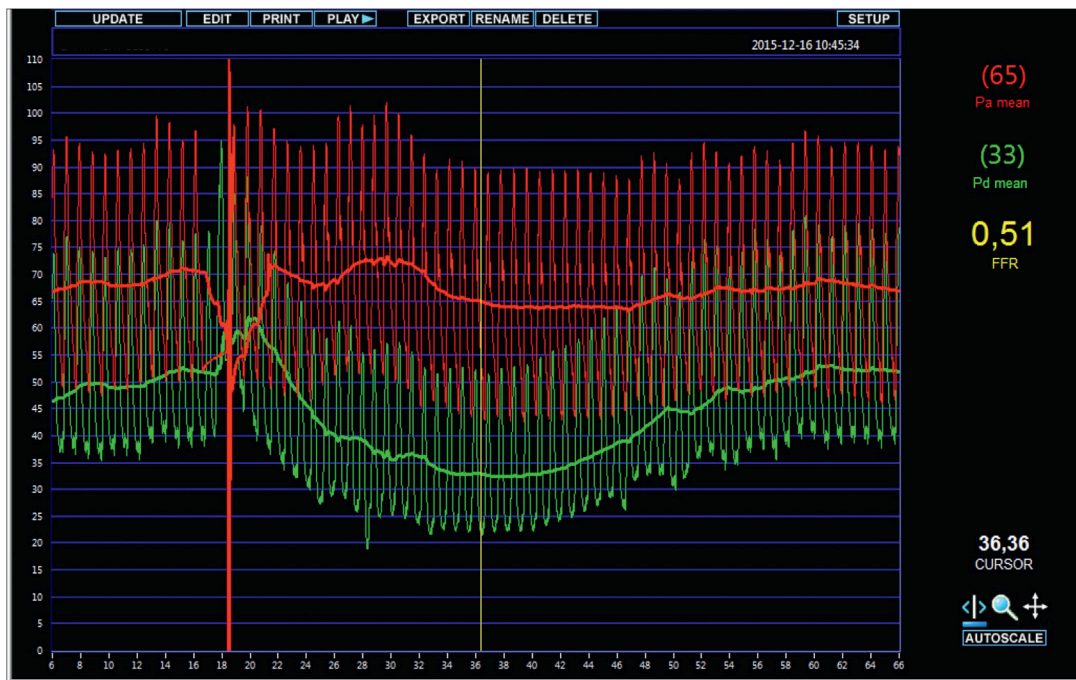
CENTRAL ILLUSTRATION Fractional Flow Reserve: Example of Simultaneous DICOM Format Storage of Complete Physiological and Angiographic Information



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Archiving this information (as well as intravascular ultrasound and optical coherence tomography, when available) side-by-side, in a format that is easily accessible (“same place, same time” principle) enables surgeons, interventional cardiologists, clinicians, and heart team meeting participants to be exposed to these different imaging modalities and to integrate “anatomy” and “physiology” into individual clinical decision making. CRA = cranial; DICOM = digital imaging and communications in medicine; ECG = electrocardiogram; FFR = fractional flow reserve; LAO = left anterior oblique; P_a = aortic pressure; P_d = distal coronary pressure.

FIGURE 1 Typical Example of FFR Measurement Obtained After Intracoronary Bolus Injection of Adenosine



The injection of the bolus is brief so that the aortic signal (red) is interrupted during no longer than 1 to 2 s. Automated calculation of FFR corresponds to the ratio of mean distal coronary pressure (green) to mean aortic pressure during maximal hyperemia. CRA = cranial; FFR = fractional flow reserve; LAO = left anterior oblique; P_a = aortic pressure; P_d = distal coronary pressure.

stenoses are common, and FFR is helpful to guide treatment decisions.

This also applies to patients with non-ST-segment elevation myocardial infarction (19). Moreover, in these patients, the presence of angiographic multi-vessel disease is frequent (20), and when present, FFR guidance of revascularization has been shown to improve the clinical outcome (21) similar to patients with stable angina, especially in nonculprit stenoses.

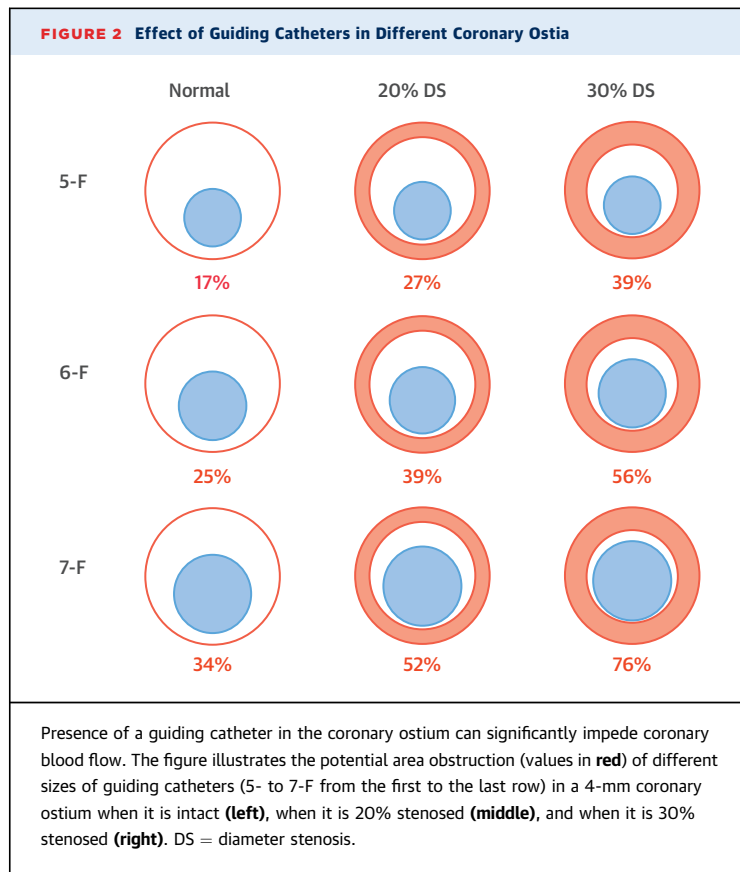
In patients with acute ST-segment elevation myocardial infarction, measuring FFR in the *culprit* stenosis makes little clinical sense. However, in remote myocardial infarctions, FFR enables the detection of residual reversible ischemic potential of an angiographically intermediate stenosis in the infarcted territory (22). FFR assessment of the nonculprit stenoses provides reliable information about the presence or absence of ischemia; therefore, it might be considered for treatment guidance, even when the measurements are performed in the setting of primary percutaneous coronary intervention (PCI). However, further data on clinical outcomes in this particular subset of patients are awaited (23). In patients with acute ST-segment elevation myocardial infarction,

functionally complete revascularization guided by FFR improves outcomes, although the precise timing of treatment remains debatable (24).

HEART FAILURE. Calculation of FFR considers the central venous pressure as negligibly low compared with the arterial values; therefore, its value is not incorporated in the formula. Recent data verified the validity of this concept, even in patients with pathologically elevated filling pressures. Therefore, the measured FFR value can also be considered accurate in patients with heart failure, and the incorporation of right atrial pressure is not indicated in any circumstances (25).

MATERIALS AND PRACTICALITIES

Considering that intracoronary manipulations are needed for FFR measurements, proper anticoagulation (i.e., ≥ 50 U/kg unfractionated heparin) is mandatory. Also, full vasodilation of the epicardial artery by intracoronary administration of nitrates (200 μ g isosorbide mononitrate) should be done routinely. These steps should not deviate from those routinely applied for any PCI or coronary imaging procedure.



To obtain FFR values, a catheter, a pressure-measuring guidewire, and a hyperemic agent are needed.

CATHETERS. Guiding catheters. Any size of guiding catheter can be used. However, it is important to realize that, depending on the relative size of the guiding catheter and the coronary ostium, the presence of the catheter can impede coronary flow (Figure 2). Impeded flow can be detected by ventricularization of the P_a signal, which becomes apparent predominantly during hyperemia. This phenomenon will falsely increase the FFR value, and thus underestimate the degree of myocardial ischemia. Therefore, it is critical to pay close attention to the morphology of the aortic pressure tracing and to slightly disengage the guiding catheter immediately upon induction of hyperemia. Another potential pitfall is damping of the aortic waveform by residual contrast material in the guiding catheter. This occurs more frequently in smaller catheters (i.e., 5-F), and can be easily remedied by flushing the guiding catheter with saline prior to FFR measurements. Ideally, the dicrotic notch should be discernable on the aortic waveform to verify an adequate pressure tracing.

Guiding catheters with side holes. Their use is not recommended for FFR measurements. The pressure signal obtained through these catheters does not reflect the pressure proximal to the stenosis, but rather reflects a mix between the coronary pressure (through the distal end) and the P_a (through the side holes). However, if the usage of a catheter with side holes is needed for clinical reasons, measurements should be performed with intravenous adenosine administration and with the guiding catheter disengaged from the coronary ostium.

Diagnostic catheters. Although technically feasible with most systems (see later discussion) and conceptually appealing, FFR measurements through diagnostic catheters should be discouraged, as a reliable aortic waveform cannot be routinely obtained. Furthermore, only a guiding catheter allows immediate intervention, when indicated.

PRESSURE-MEASURING SYSTEMS. Currently, 5 coronary pressure-measuring systems are commercially available.

1. *PressureWire* (St. Jude Medical, St. Paul, Minnesota). This is a 0.014-inch pressure-measuring guidewire, equipped with an *electric* pressure sensor 3 cm from the tip, at the junction between radiopaque and nonradiopaque portions of the wire. It is available in 2 versions that are connected either by wire (*Certus*) or wirelessly (*Aeris*) to the console. It can be used as a regular guidewire when PCI becomes indicated.
2. *WaveWire* (Philips, Eindhoven, the Netherlands). This is a 0.014-inch pressure-measuring guidewire, equipped with an *electric* pressure sensor 3 cm from the tip, at the junction between radiopaque and nonradiopaque portions of the wire. It can be used as a regular guidewire when PCI becomes indicated. It is available in 2 versions that are connected with either a rotational (*PrimeWire Prestige*) or clip (*Verrata*) attachment to the console.
3. *OptoWire* (Opsens Medical, Quebec, Quebec, Canada). This is a 0.014-inch pressure-measuring guidewire, equipped with a *fiber optic* pressure

TABLE 1 Hyperemic Stimuli

Drug	Dosage
Adenosine	100 μ g in RCA/200 μ g in LCA as intracoronary bolus
Nitroprusside	140 μ g/kg/min as intravenous infusion 0.6 μ g/kg as intracoronary bolus
Nicorandil	2 mg as intracoronary bolus
Regadenoson	400 μ g as intravenous slow bolus over 10 s
Papaverine	8 mg in RCA/12 mg in LCA as intracoronary bolus

LCA = left coronary artery; RCA = right coronary artery.

sensor 3.5 cm from the tip. It can be used as a regular guidewire when PCI becomes indicated.

4. *Comet Pressure Guidewire* (Boston Scientific, Marlborough, Massachusetts). This is a 0.014-inch pressure-measuring guidewire, equipped with a *fiber optic* pressure sensor 3 cm from the tip, at the junction between radiopaque and nonradiopaque portions of the wire. It can be used as a regular guidewire when PCI becomes indicated. The system allows both wired and wireless communication with the console.
5. *Navvus* (Acist Medical Systems, Eden Prairie, Minnesota). This is a 0.020-inch monorail pressure-measuring microcatheter, equipped with a *fiber optic* pressure sensor. It can be used over any regular guidewire. Note that the introduction of the catheter, albeit very small, will inevitably induce an additional resistance to flow, and therefore underestimate the true FFR value (i.e., overestimate lesion severity) (26). The extent of this underestimation depends on the flow and the dimensions of the stenosis under investigation, and can therefore vary between individual patients.

HYPEREMIC AGENTS. In addition to the vasodilation of the epicardial arteries by intracoronary administration of nitrates, FFR measurements require full vasodilation of the microvasculature to induce maximal hyperemia. Several pharmacological agents have been demonstrated to induce maximal vasodilation. Their characteristics are summarized in **Table 1**. The most commonly used hyperemic agent is adenosine, given by either intracoronary or intravenous administration.

Intravenous adenosine. Administration of intravenous adenosine provides reliably stable maximal hyperemia, maintainable for minutes, when indicated. Therefore, in daily practice, it is to be applied when intracoronary administration is difficult (e.g., in case of ostial stenosis) or when pullback measurements have to be performed (e.g., for the evaluation of serial stenosis). The recommended dose is 140 $\mu\text{g}/\text{kg}$ of body weight/min (27). Some investigators suggest increasing the dose to 180 $\mu\text{g}/\text{kg}$ or adding a bolus of intracoronary adenosine when in doubt. As there is no general clinical benefit of further increasing the dosages, this might therefore be considered only in case of fluctuating hyperemic status. Although in practice, central venous administration of adenosine provides less fluctuation in hyperemic status and allows maximal hyperemia to be achieved somewhat faster, there is no clinically relevant difference in terms of accuracy between central venous versus peripheral cubital venous administration (28).

The latter is of increasing importance with the growing use of the radial approach.

Intracoronary adenosine. Maximal hyperemia is inducible by intracoronary administration of adenosine. The degree of vasodilation is very similar and the FFR values are comparable to those obtained with intravenous administration. The test/retest repeatability tends to be better with intracoronary than with intravenous administration of adenosine. As dose-response analysis data have shown, 100 μg in the right coronary artery and 200 μg in the left coronary artery reliably and reproducibly achieve >95% of maximum hyperemia without any significant side effects. The hyperemic effect of these doses is clinically indistinguishable from higher dosages, but with a lower rate of atrioventricular block; thus, there is no reason to use higher dosages (29).

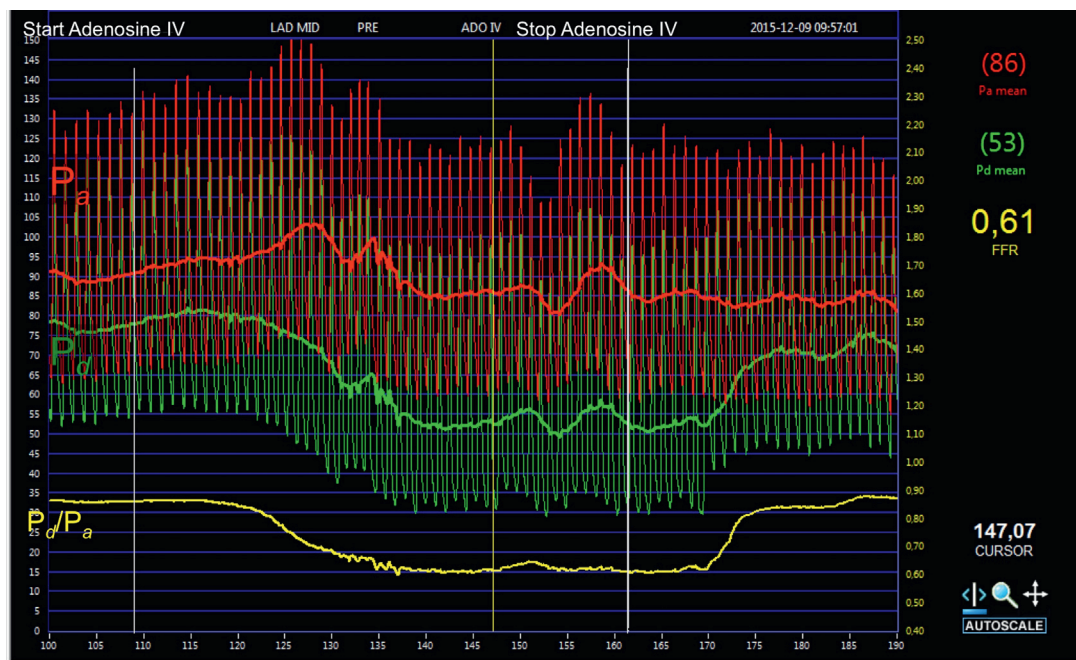
Alternative agents. Other agents, such as regadenoson, nicorandil, nitroprusside, and dobutamine, can be used for inducing maximal microvascular dilation; however, they are not widely used in clinical practice (30-32). The use of papaverine is not recommended due to the occasional occurrence of ventricular arrhythmia (33).

In daily practice, it is recommended to always use the same means of producing hyperemia. This routine simplifies the process, increases familiarity among staff and operators, and thereby minimizes errors.

PRACTICALITIES OF FFR MEASUREMENTS

For the sake of standardization, a systematic step-by-step procedure can be proposed (34). As there are minor differences between the different commercially available systems, the manufacturer's instructions should be followed. To create a routine and to minimize the risk of errors, it is advisable to become familiar with 1 commercially available system in a catheter laboratory.

CALIBRATION OF PRESSURE SYSTEMS. Before pressure-wire insertion, setting atmospheric pressure as the zero reference should be done carefully for the fluid-filled pressure transducer and for the coronary pressure-measuring systems. Both pressure transducers have to be "taught" what the atmospheric pressure is so that the latter can be taken out of the equation. All fluid-filled pressure lines should be carefully flushed with saline. If there is an electric sensor, the wire should also be flushed before calibration. For the coronary pressure-measuring systems, the "zero reference" is taken either automatically or manually when it is electronically connected to the console. There are only minor differences between the different coronary pressure-monitoring system wires.

FIGURE 3 FFR Recording With Intravenous Adenosine

Soon after the start of the infusion, a short-lasting increase in P_a is paralleled by a decrease in P_d . During maximal hyperemia, the fluctuations of P_a are paralleled by proportional fluctuations of P_d resulting in a stable P_d/P_a ratio. IV = intravenous; other abbreviations as in Figure 1.

“EQUALIZING” THE 2 PRESSURES. The pressure sensor should then be advanced and positioned 1 or 2 mm distal to the tip of the guiding catheter. The latter should be flushed with saline to remove any residual contrast used when positioning the guide. At that location, the 2 pressures should be identical. If this is not the case, the measured pressures have to be equalized electronically, using that function of the console. If ostial coronary disease exists, this can be performed with the guiding catheter disengaged and the pressure sensor positioned in the aorta. After these “zeroing” and “equalization” procedures, the 2 pressure systems “speak the same language.”

An introductory needle can be used only if it is very thin and does not leak. If the needle leaks, thus losing adenosine and also lowering the P_a reading, the needle should be removed from the Y connector for equalization, for the measurements, and for the final check for the absence of drift.

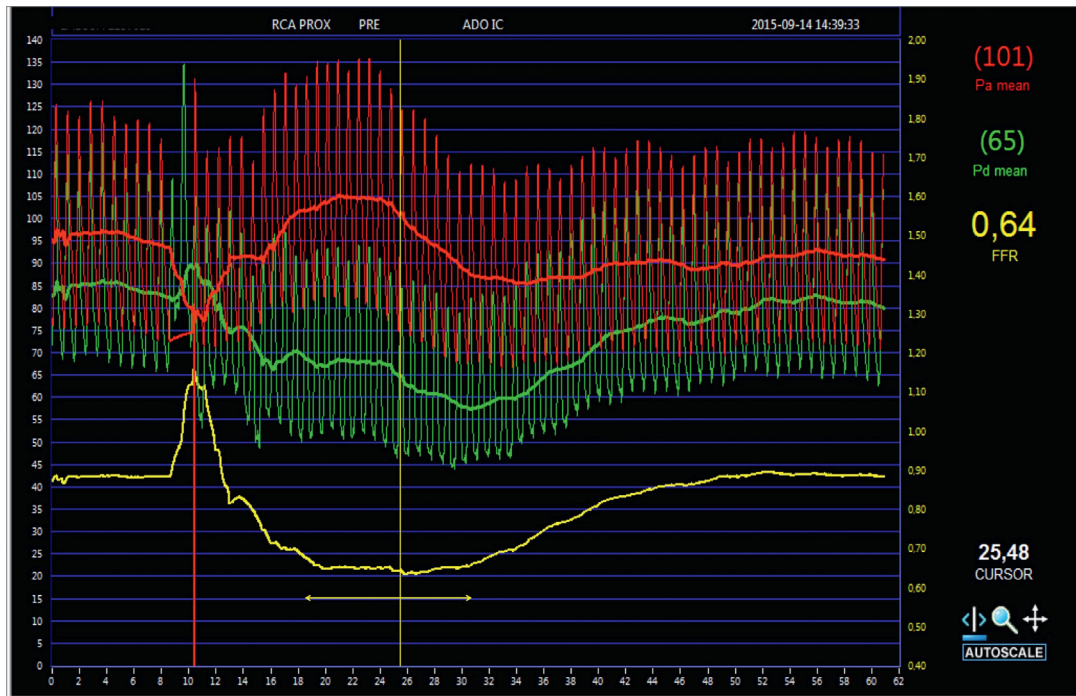
POSITIONING THE PRESSURE SENSOR FOR THE MEASUREMENT. The sensor should be manipulated in the distal part of the artery. In any case, the sensor should be placed at least 2 to 3 cm distal to the stenosis to be assessed, a distance where post-stenotic laminar flow is restored, avoiding flow eddies and pressure

recovery phenomena. In general, to evaluate whether a given coronary artery is responsible for myocardial ischemia in the myocardial territory it supplies, the pressure sensor should be positioned at the very distal part of the coronary artery. From the clinical point of view, it makes sense to perform measurements with the sensor positioned just distal to where surgeons would anastomose a bypass graft. Note that in some tortuous vessels, it is important to recognize that positioning the sensor in the very distal part of the artery may induce an accordion phenomenon, which might lead to falsely low FFR values. The exact position of the sensor should be documented by angiography.

INDUCING HYPEREMIA AND RECORDING. Electronic recording of the pressure tracings should start at least 30 s after the last contrast medium injection to ensure stable baseline conditions. These stable baseline conditions should be captured for at least 10 heart cycles before the induction of hyperemia. The pressure scale should be set to take as much advantage as possible of the whole height of the screen.

When *intravenous adenosine* is given (140 $\mu\text{g}/\text{kg}/\text{min}$), the intravenous line should be filled with adenosine up to the place where the line enters the patient to avoid a long delay between the start of the pump

FIGURE 4 FFR Tracing Illustrating a Constant P_d/P_a Ratio at Maximal Hyperemia, Despite Changing Aortic and Distal Coronary Pressures, Immediately After Administration of the Vasodilator



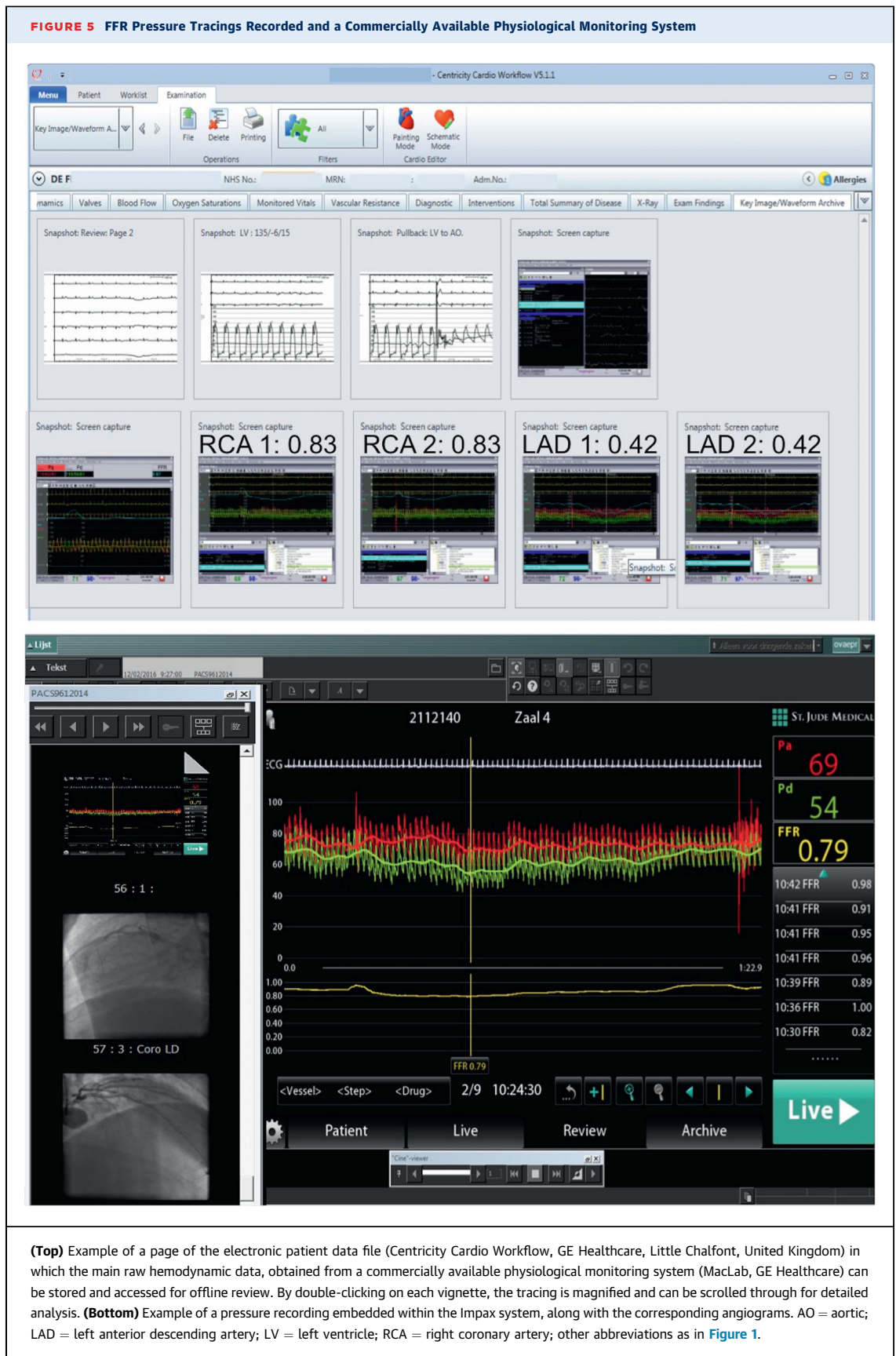
The yellow arrow indicates the period of approximately 12 s during which the FFR values are stable between 0.64 and 0.65. ADO = adenosine; IC = intracoronary; RCA PROX = proximal right coronary artery; other abbreviations as in Figure 1.

and the effect of adenosine. For this purpose, it is convenient to place a 3-way stopcock at the skin and to prime the intravenous lines, leaving the flush with adenosine. The total length of the recording will vary between 1 and 4 min to encompass the baseline, the beginning of the maximal hyperemic phase, and the recovery phase. Once recording is started, the manifold should be put down on the table to avoid any movement artifacts (Figure 3).

With intracoronary adenosine, it is convenient to use a 10-ml syringe filled with 200 µg of adenosine. For the right coronary artery, 5 ml (100 µg in total) and for the left coronary artery 10 ml (200 µg in total) are briskly injected (29). After the adenosine is injected, the P_a signal should be immediately switched back and the manifold should be gently placed on the table to avoid any artifacts. The duration of disconnection of the P_a signal should not exceed 1 to 2 heart beats. During the bolus injection, the guiding catheter must be well engaged with the coronary ostium, but it has to be quickly disengaged immediately at the end of the injection to avoid any wedging phenomena. Please note that to keep the duration of disconnection of the aortic pressure

signal as short as possible, adenosine should not be flushed with saline or with contrast medium, but can be used itself to flush. That implies that approximately 2.5 ml will remain in the “dead space” of the guiding catheter. Accordingly, 2 to 3 ml more than the intended amount of the injection solution should be taken into the syringe and injected to compensate for this difference. The total length of the recorded tracing should be approximately 50 to 60 s to encompass the baseline (10 beats), the beginning of the maximal hyperemic phase, and the recovery phase (Figure 4). The short-lasting effect of intracoronary adenosine allows these measurements to be made in duplicate without losing more than 1 min. A second hyperemic stimulus can then be given and the exact same tracing recorded. Because the test/retest repeatability of FFR is very high (12), the variation between the 2 consecutive values should be minimal. These duplicate measurements are therefore the first quality check for the FFR measurements.

The advantage of always recording for the same length of time is that the tracings become immediately recognizable, even for noninterventional cardiologists, as well as for core laboratory purposes.



DETERMINATION OF THE FFR VALUE. FFR is to be measured at the level of the *nadir* of the P_d/P_a tracing. Most systems indicate it automatically, but manual control and fine-tuning is always recommended to avoid false calculations derived from artifacts in the coronary or the arterial pressure tracings. Data from large series have shown that the minimum P_d/P_a during intravenous infusion of adenosine and the minimum P_d/P_a after an intracoronary bolus of adenosine show good agreement and are both highly reproducible (12).

PULLBACK MANEUVER. A slow pullback of the pressure sensor under steady state hyperemia (induced by intravenous infusion of adenosine) is the best means to assess the distribution of the abnormal epicardial resistance, which is of extreme importance in case of multiple sequential stenoses, diffuse atherosclerotic disease, or ostial lesions. For this purpose, the exact position of the wire has to be documented, and it is advisable to interrogate the whole length of the artery over a period of approximately 15 to 20 s. Well-recognized angiographic landmarks could be indicated with markers on the pressure tracing, linking the angiographic finding to the FFR assessment.

CHECK FOR SIGNAL DRIFT. All pressure sensors are susceptible to a tendency to drift that will offset readings from the original calibrated state; however, this can be minimized with adequate device preparation, such as the calibration and equalization procedures described previously. For optimal FFR measurement, the drift should be absent or minimal. This is the case for both the coronary pressure-measuring systems and (albeit to a lesser extent) the fluid-filled pressure transducer. Checking for the absence of significant drift of both transducers immediately upon making the measurement should be part of the measuring procedure and should be documented. After finishing a measurement, the pressure sensor should be pulled back until positioned 1 or 2 mm distal to the tip of the guiding catheter. At that location, the 2 measured pressures should once again be identical. Please note that when checking for drift, the setting has to be consistent with the setting during equalization and during the measurement itself. If this is not the case, the measured pressures have to be equalized again electronically, and the measurement has to be repeated.

ELECTRONIC ARCHIVING OF THE PRESSURE TRACINGS

Like any other measurements upon which important medical decisions are made (e.g., left ventricular ejection fraction, left ventricular volumes and

pressures, angiographic measurements, among others), the raw data of the pressure tracings from which FFR was calculated should be saved (**Central Illustration**). Ideally, these tracings should be automatically stored and incorporated into the electronic medical database in conjunction with the angiography. When a multidisciplinary heart team discusses clinical cases, these tracings should be at hand for review, akin to any other imaging technique.

The appropriateness of the clinical decision will largely depend on the quality of the recordings and of their actual display: the time scale should not be too long, so as to remain readable, and the pressure scale should be adjusted to the actual P_a to take advantage of the full height of the screen. Confirm the accuracy of FFR by viewing the pressure tracings. Decisions should not be taken blindly on the basis of a number automatically produced by the console, nor made by figures manually filed in the database or the medical report.

Figure 5 shows an example of FFR pressure tracings recorded and saved on a commercially available physiological monitoring system and automatically stored in the patients' electronic medical database. This allows the FFR measurements to be available for later checks and for discussion at heart team meetings. Another possibility for storage with easy access is to save the pressure tracings in DICOM (digital imaging and communications in medicine) format with the corresponding angiogram. Seeing the raw FFR tracing data is more convincing than trusting a plain figure manually introduced in the database. The proper storage of FFR tracings might also have non-negligible medico-legal implications.

QUALITY ASSURANCE FOR FFR MEASUREMENTS

FFR is increasingly being used in scientific trials as an inclusion criterion or as a study endpoint (9), as well as to validate new diagnostic modalities (10,11). In many of these trials, akin to most other metrics, FFR tracings are also analyzed in core laboratories because modern clinical research relies on processes being highly specific, accurate, and consistent with pre-specified definitions. Just as for clinical decision-making, the accuracy of events adjudication depends on the accuracy and reproducibility of the FFR measurement and analysis. Therefore, each participating center should be trained in the step-by-step approach of FFR measurements and uniform recording of the FFR tracings. Also, core laboratory personnel should be trained in tracing interpretation and recognition of the potential pitfalls and errors. It

is suggested that to maximize transparency and accountability of future trials, the anonymized raw pressure tracings should be made publically available through dedicated websites.

TRANSFER OF THE TRACINGS TO CORE LABORATORIES

In contrast to most other diagnostic methods in interventional cardiology, FFR tracings, even as fully-detailed raw data, can be stored in extremely small files of fewer than 300 kilobytes per tracing. This allows for easy and quick data transfer to central core laboratories without placing a massive load on the network. In the future, even automated data transfers may be possible. The current limitations of data transfer and core laboratory analysis stem from the use of different formats of the various FFR consoles. A uniform output would enable easy data transfer and allow for more standardized data analysis. Additionally, “single-click” online data transfer via the FFR console would be desirable, and would allow for the possibility of rapid central data analysis or data validation, when requested.

TRIAL DESIGN ISSUES

As trial designs more frequently incorporate the use of FFR to establish the indication for revascularization or defining of endpoints, protocols must explicitly and uniformly outline which lesions to

include for physiological evaluation. On the basis of recent data (16,35) and consensus statements (36), a more liberal use of FFR might be indicated, and interrogation of a wider range of stenoses (30% to 90% diameter stenosis) should be recommended, especially in cases of ambiguous pre-test probability and angiographic findings. Performance of the measurement must follow a rigorous and uniform protocol, and centrally trained investigators or, eventually, core laboratories should perform data analysis when indicated.

CONCLUSIONS

FFR has been established in multiple clinical trials to improve patient outcomes when used routinely for guidance of coronary revascularization. Accordingly, FFR-guided revascularization strategies have the strongest recommendation in the latest PCI guidelines. This benefit can be optimized when FFR measurement and analysis are performed in a rigorous and standardized manner. The same rigor in acquisition, recording, storage, and transfer is mandated for FFR measurements used in the setting of clinical studies.

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