MICROVASCULAR (DYS)FUNCTION BY CONTINUOUS THERMODILUTION: Absolute Flow, CFR, and MRR (tips & tricks)

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Madrid Microculation Meeting 4th Edition
november 29th & 30th 2023

CATHARINA-ZIEKENHUIS

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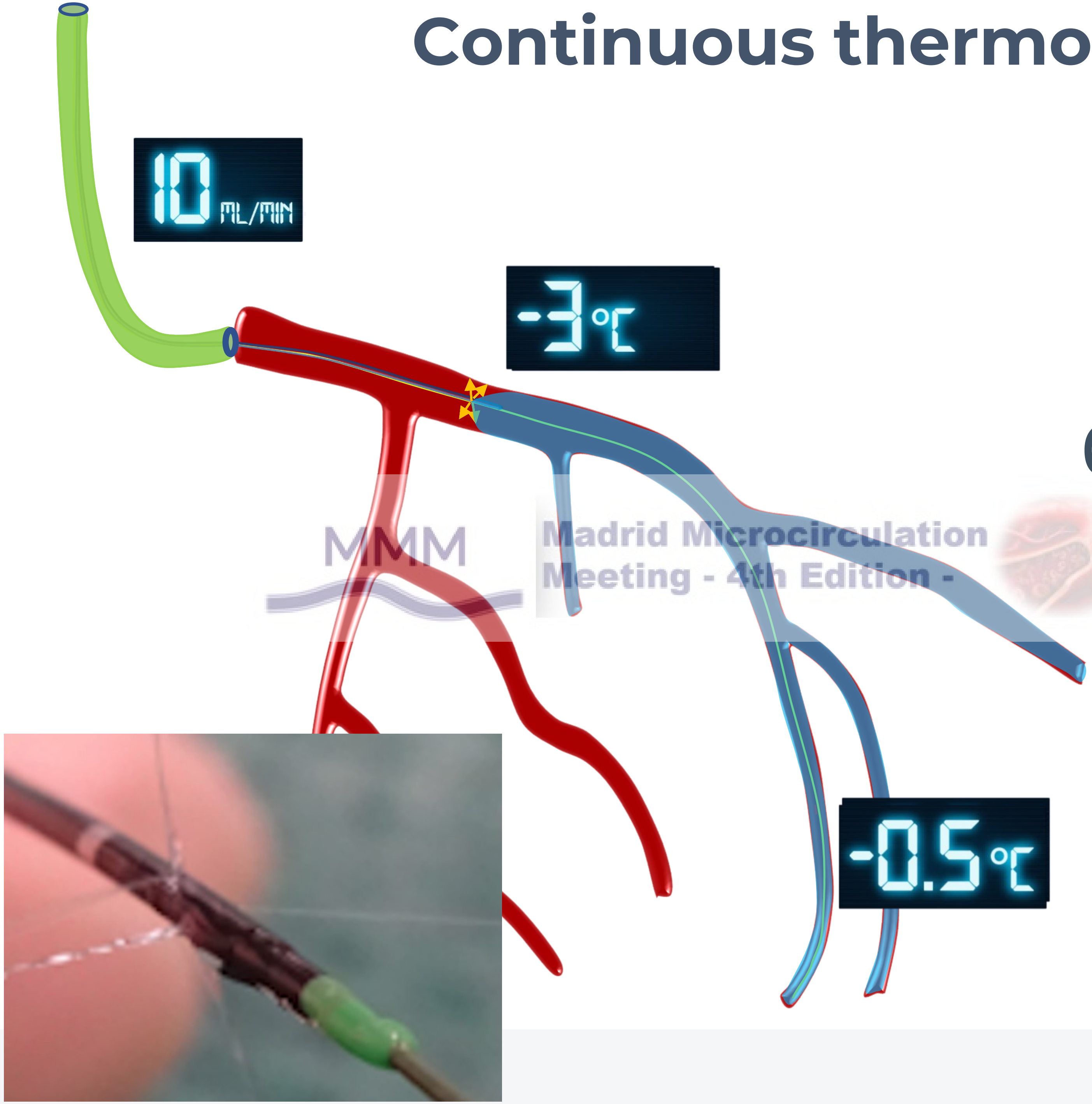
Catharina Hospital,
Eindhoven, The Netherlands

catharina ziekenhuis

Continuous thermodilution for absolute Q & R measurements



$$Q = Q_{saline} \times \frac{T_{saline}}{T_{mixture}} \times 1.08$$

Q = 65 mL/min

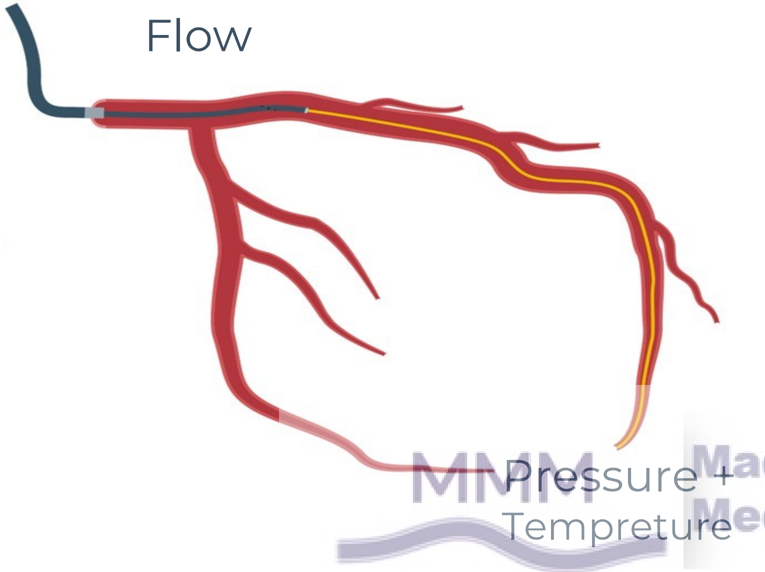
Q_{saline} is known infusion rate of saline (mL/min)

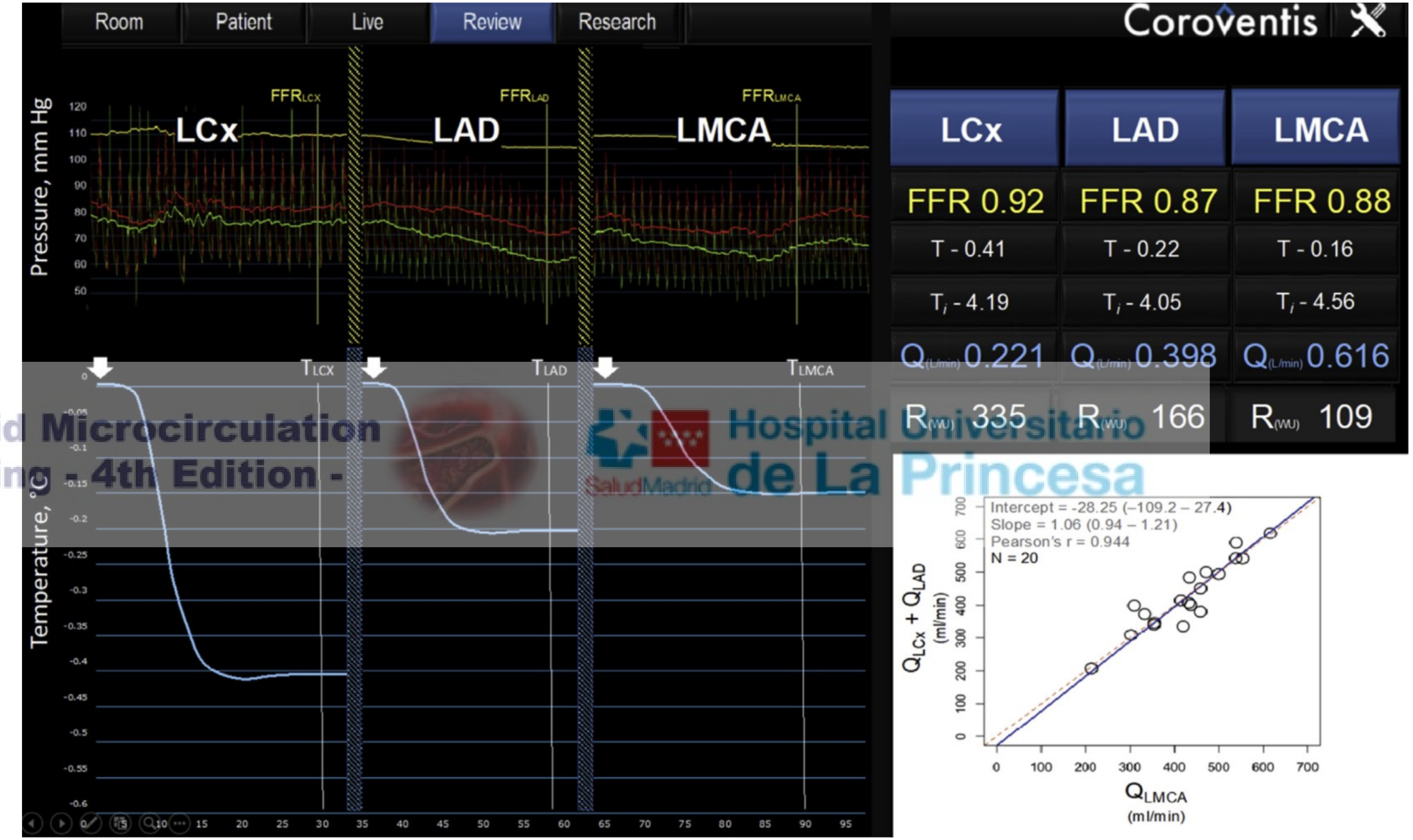
T_{saline} , T_{mix} are the **difference** vs body temperature (°C)

1.08 accounts for **specific heats** of saline and blood

"1 + 1 = 2" study

Accuracy

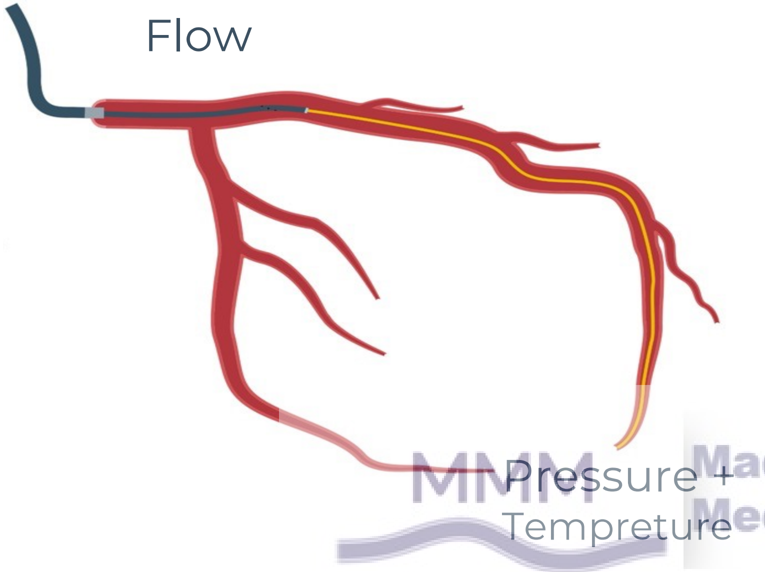


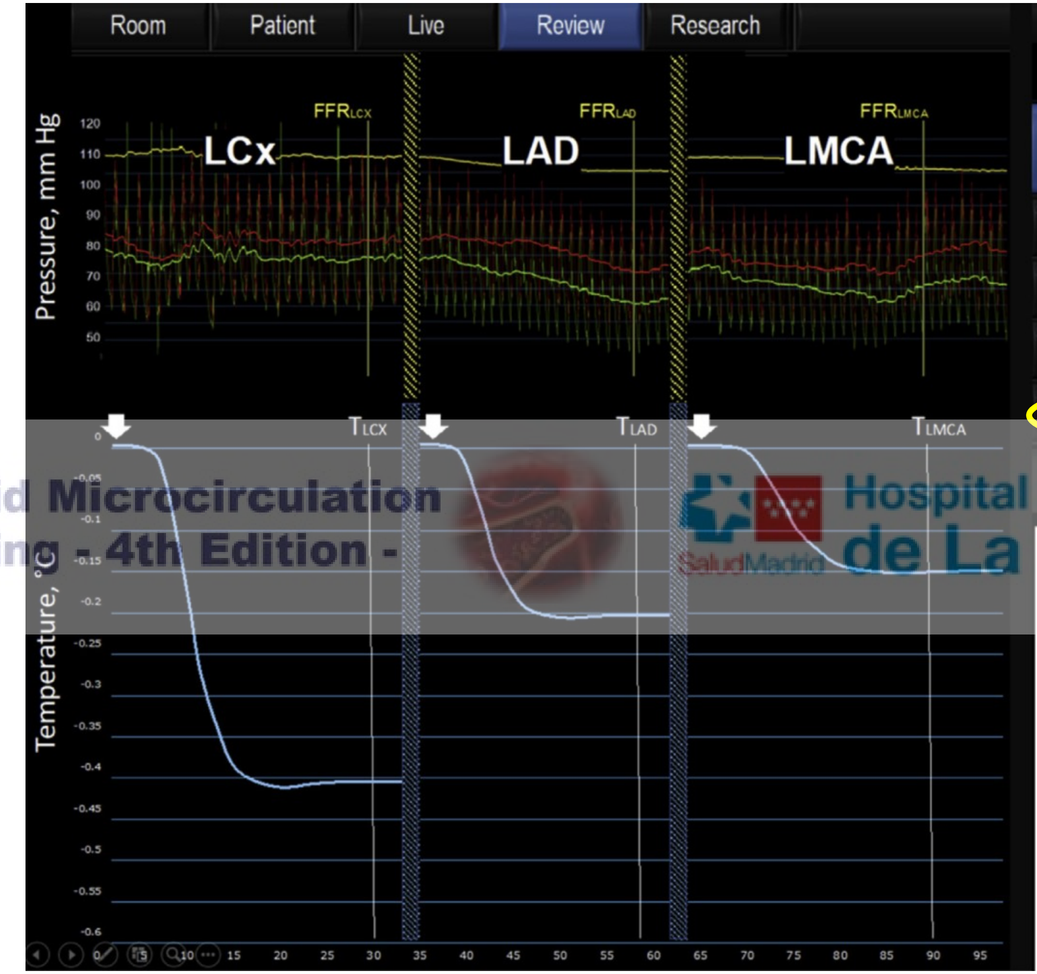


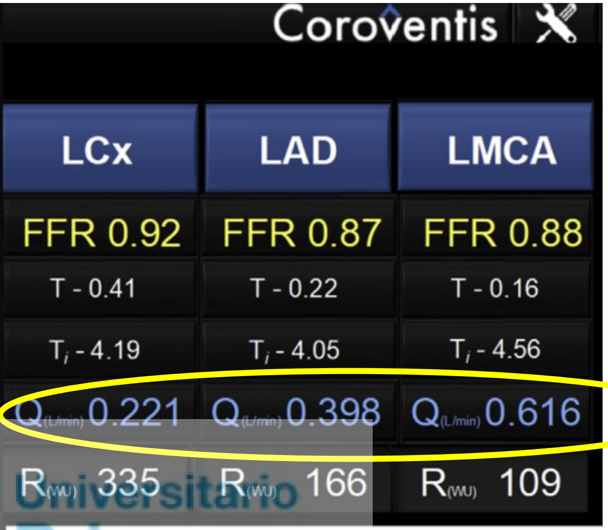
In humans

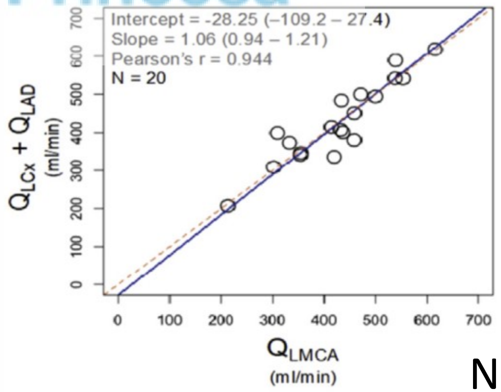
LAD + LCx = LM (!)

"1 + 1 = 2" study → indicates the extreme accuracy of these measurements







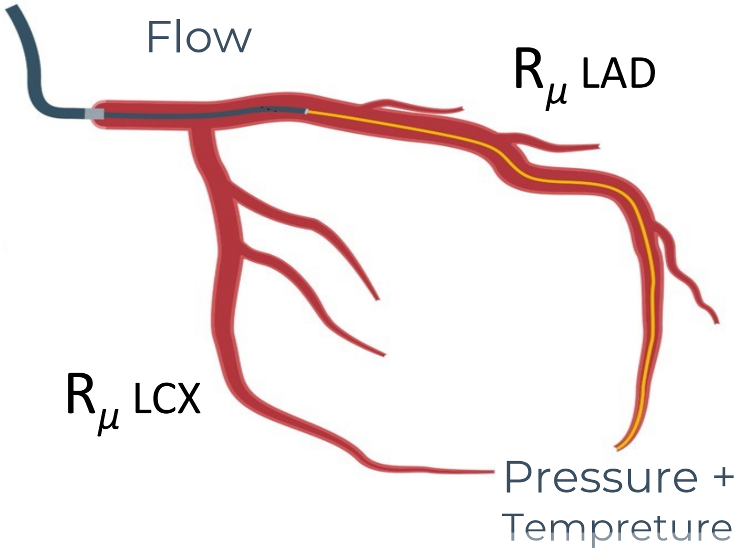


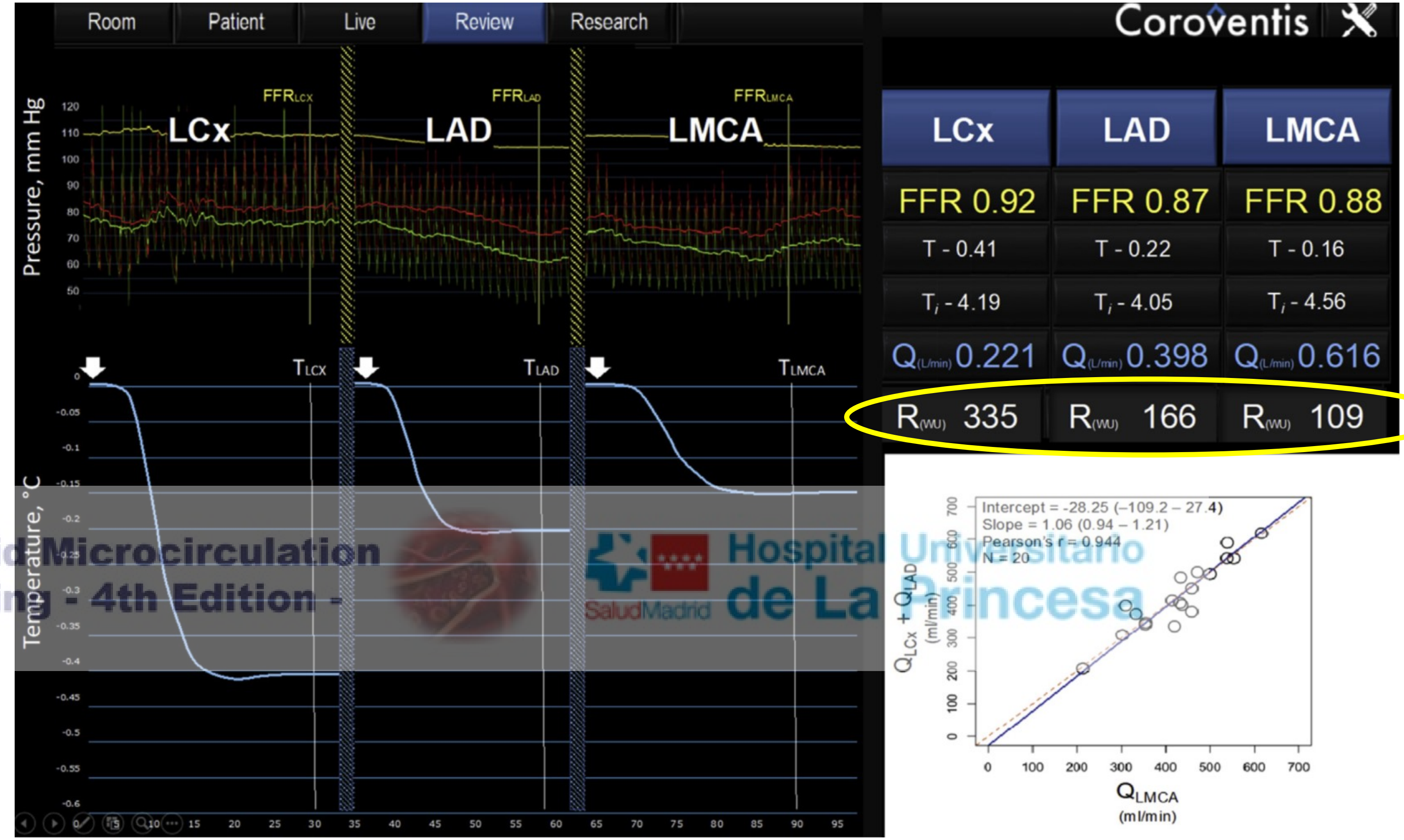
N=17

In humans

LAD + LCx = LM (!)

398 ml/min + 221 ml/min = 619 ml/min ~ 616 ml/min



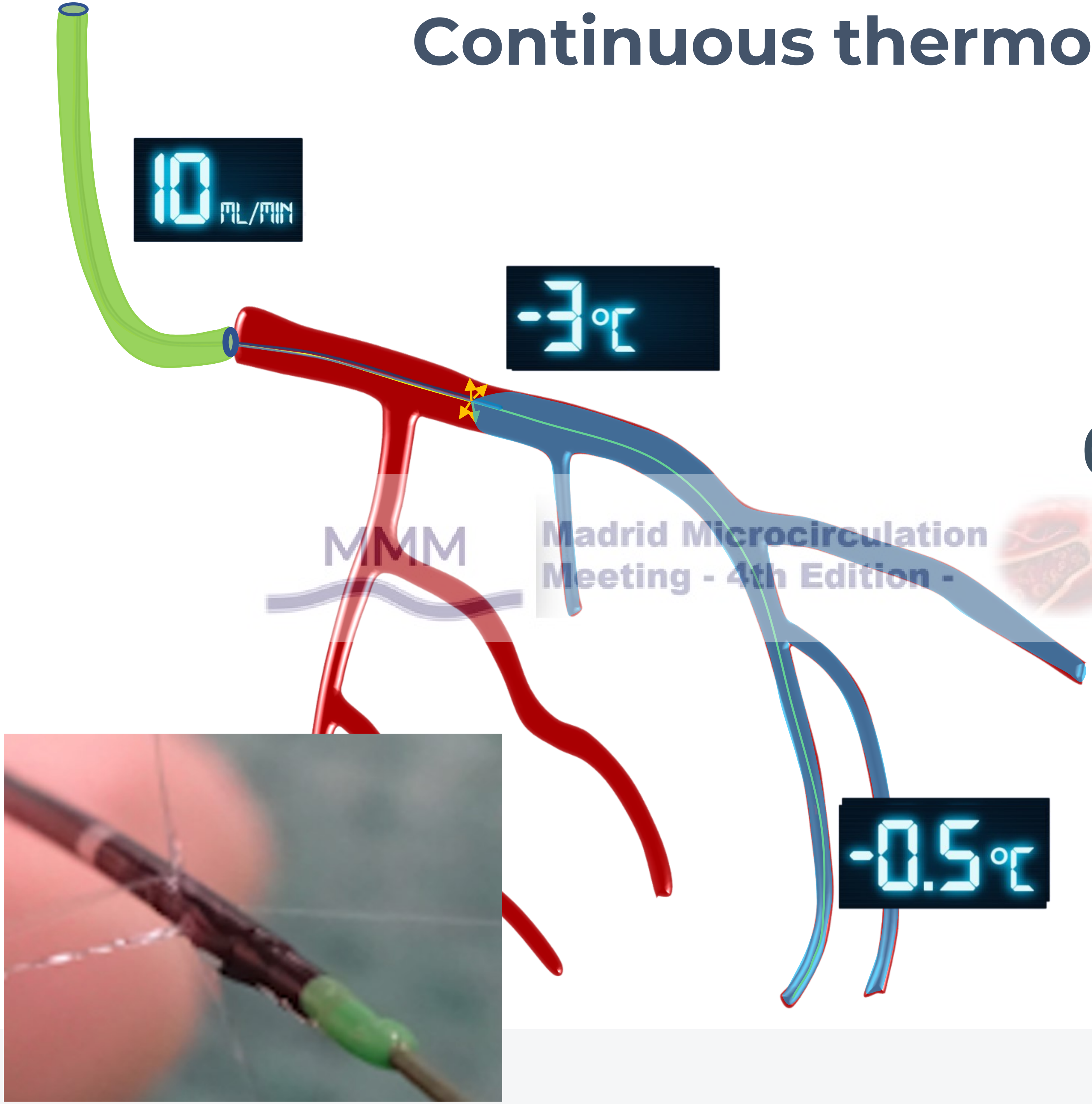


Ohm's Law of parallel resistances:

R1 + R2 = (R1 x R2) / (R1 + R2)

<u>Calculated</u> R_μ LM = (335 x 166)/(335+166) = 111 WU, whereas directly <u>measured</u> R_μ LM = 109 WU

Continuous thermodilution for absolute Q & R measurements



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Q = 65 mL/min

Q_{saline} is known infusion rate of saline (mL/min)
T_{saline} , T_{mix} are the **difference** vs body temperature (°C)
1.08 accounts for **specific heats** of saline and blood

Tips and Tricks (1): *Infusion Pump and RayFlow Catheter*

- Know the *programming of your infusion pump* very well. It takes a short investment of your time *only once* with high profit (doctor, fellows, and nurses!)
- Fill pump in advance, connect line to *RayFlow catheter* in advance, flush Rayflow with 5 ml/min 20 sec before and during introduction into guiding catheter, and stop flushing when RayFlow catheter is introduced into guiding catheter

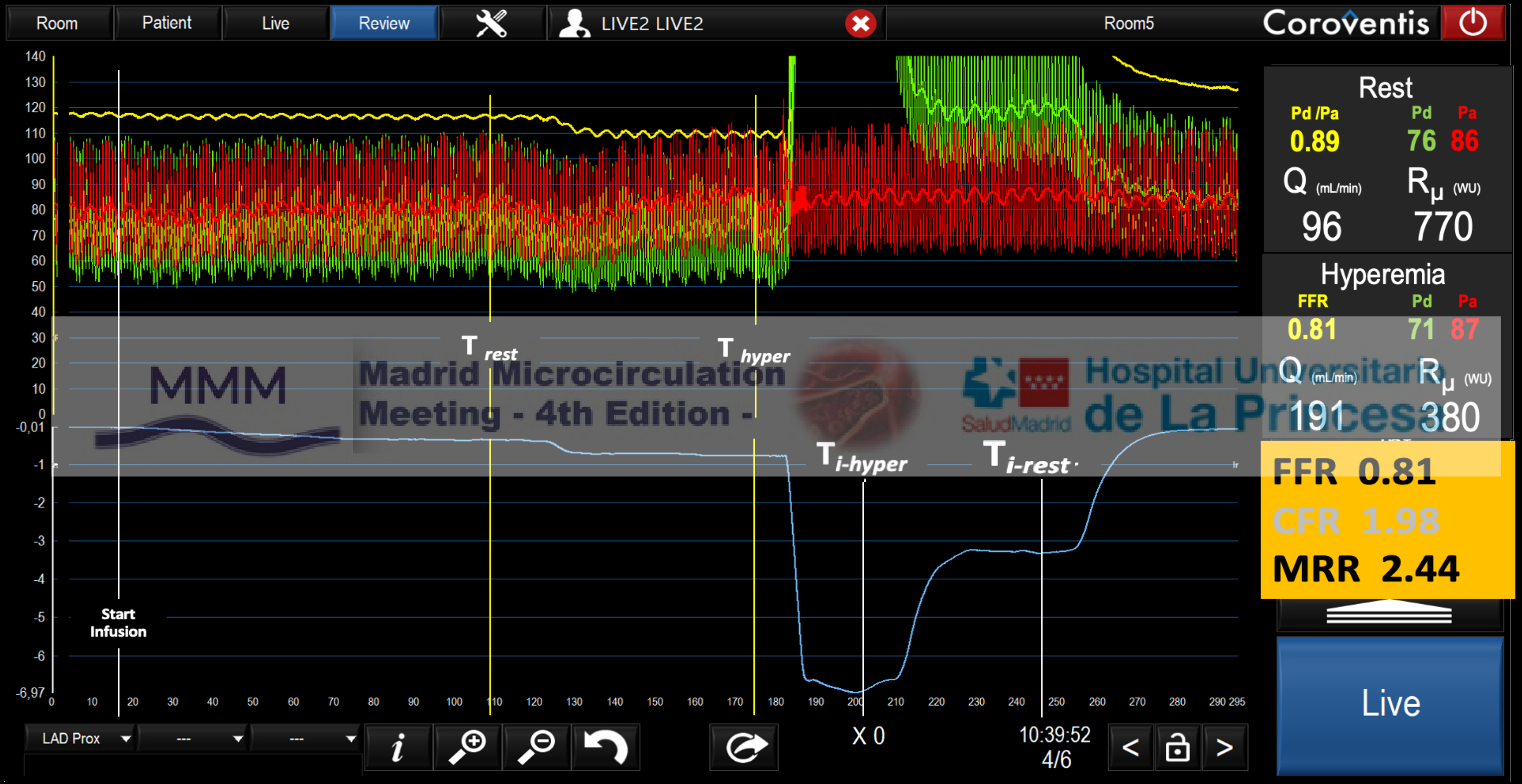
→ Upcoming Review in JACC by Belmonte et al:
"Standardization of Absolute Flow and Microvascular Resistance Measurements by Continuous Thermodilution"

Tips and Tricks (2): *Pressure guidewire & Pullback (T_i)*

- Generally, you can start with the PressureWire as guidewire.
  It can be used as primary wire in a vast majority of patients/arteries
  Only in case of tortuous or severely calcified vessels (or if PW fails to reach your target) use regular wire and exchange.

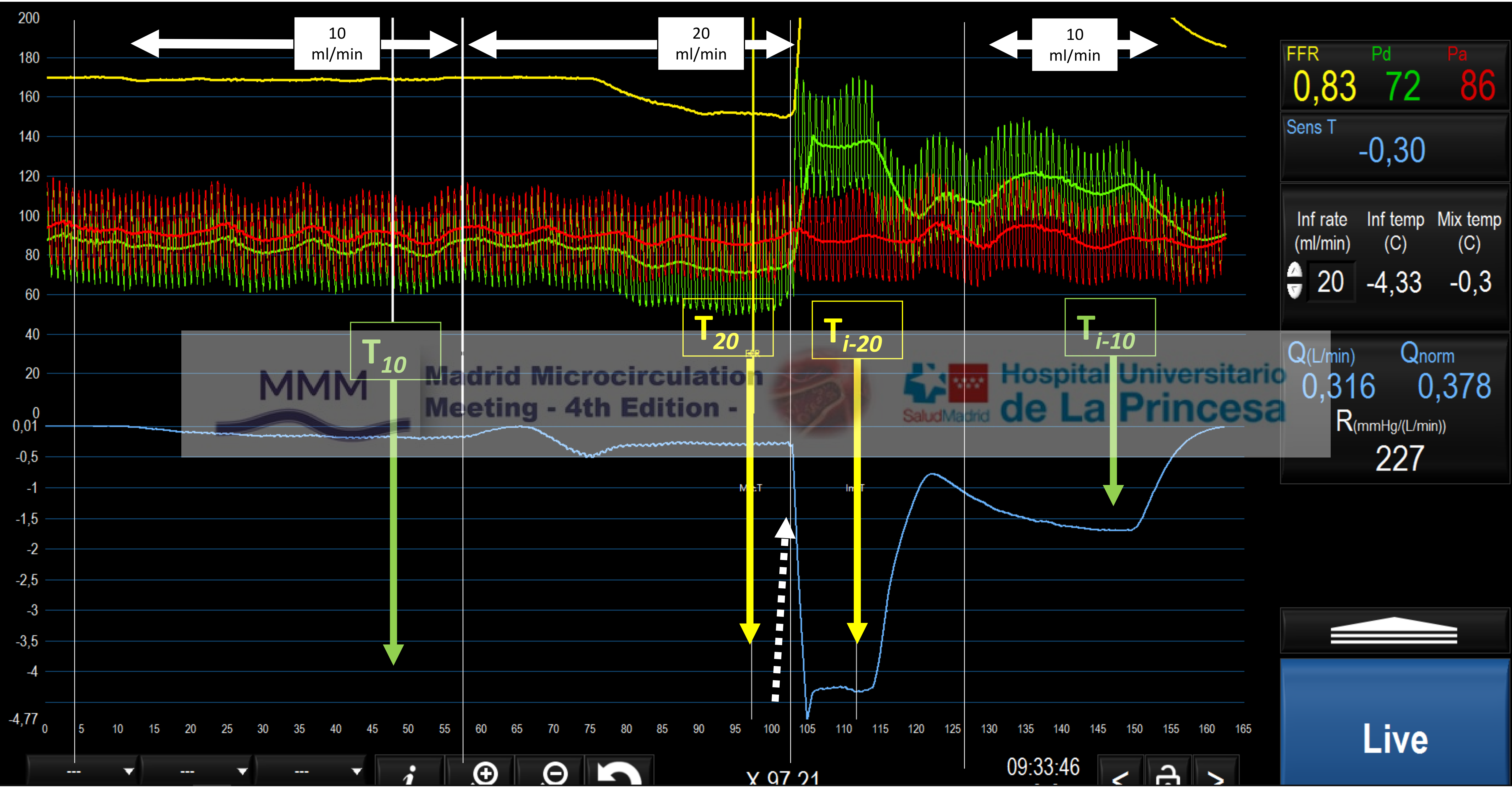
- If manipulation with the PW was difficult and you have to perform PCI, try to do the absolute flow measurement at the end *(unless the protocol does not permit).*

- In such cases, the possibilty to perform "one long run" with only one pullback manoeuvre, is advantageous. (*Programmable pump, or "trick"*)



De Bruyne, Pijls, Collet, Fearon et al J Am Coll Cardiol 2021;78:1541–1549

CoreAalst | OPTIMA



10 ml/min
20 ml/min
10 ml/min
T10
T20
Ti-20
Ti-10
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FFR Pd Pa
0,83 72 86
Sens T
-0,30
Inf rate (ml/min)
Inf temp (C)
Mix temp (C)
20 -4,33 -0,3
Q(L/min) Qnorm
0,316 0,378
R(mmHg/(L/min))
227
Live
09:33:46
X 97,21

Tips and Tricks (2): *Pressure guidewire & Pullback (T_i)*

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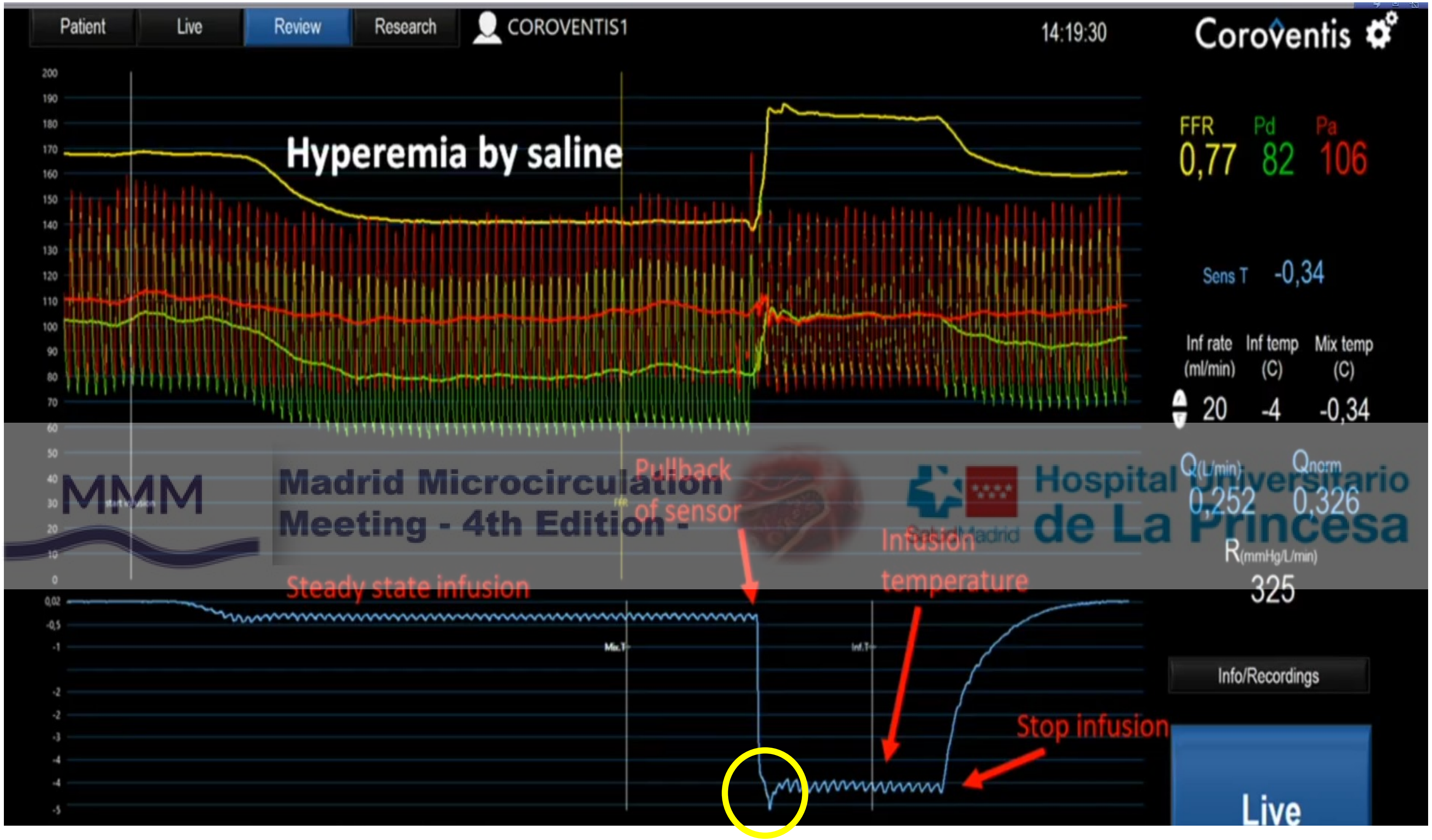
- If manipulation with the PW was difficult and you have to perform PCI, try to do the absolute flow measurement at the end *(unless the protocol does not permit).*

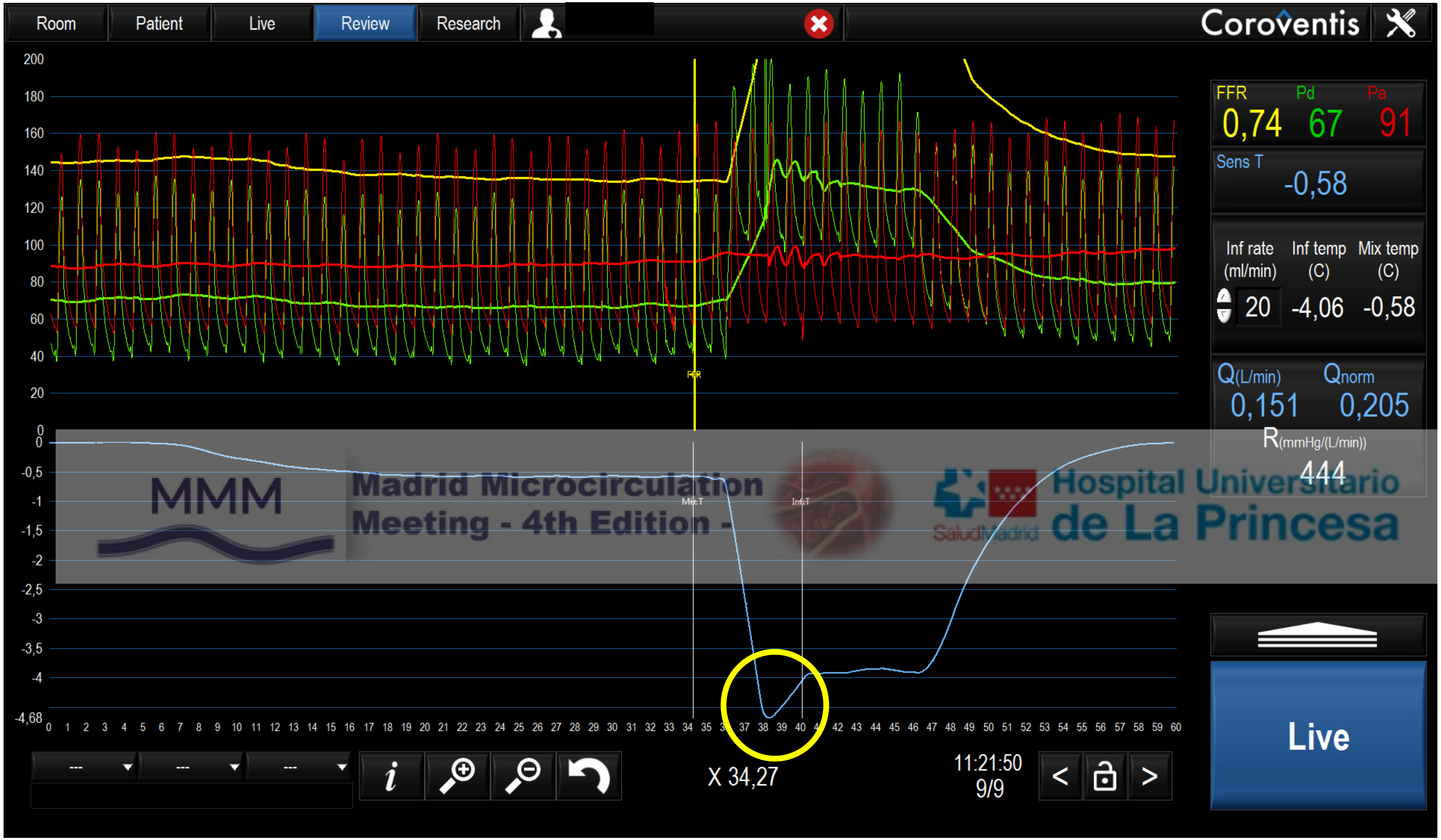
- In such cases, the possibilty to perform "one long run" with only one pullback manoeuvre, is advantageous *(programmable pump, or "trick" with regular pump)).*

- *Note: the short initial deflection in Ti is artificial and due to the construction of the pressure/temperature sensor*



Example of one hyperemic run (20 ml/min)

Coroventis radio-receiver laptop system (fully integrated in cathlab)



Run # 9: hyperemische flow meting proximaal van LIMA *(herhaald omdat eerste meting niet zo mooi was)*

Tips and Tricks (3): *location of the RayFlow tip and influence on measurements*

- Generally, *measure FFR first*, before introducing the RayFlow catheter.
  In case of positive FFR, this enables you to perform PCI first

- After positioning of RayFlow, realize that
  - ***Flow you are measuring is ALL the flow distal from the tip of the RayFlow catheter***
    (not the flow distal to the temperature sensor) *and:*
  - ***Microvascular Resistance relates to ALL the myocardium distal to the tip of the RayFlow***

- When searching for microvascular disease, place the tip of the Rayflow catheter in the *proximal part* of the coronary artery (e.g. 1-2 cm) *(minimal influence on hemodynamics)*

- When searching for microvascular disease, and in the absence of other cardiac pathology, it is presumed that one coronary artery is sufficient, generally the *LAD artery.*

- As a matter of fact, in *specific cases* the location of the tip should be at a different place, e.g if you like to measure Q and R_{μ} in an *infarct area*, place tip just before or into the stent

Tips and Tricks (4): *In case of hemodynamic influence of the RayFlow catheter*

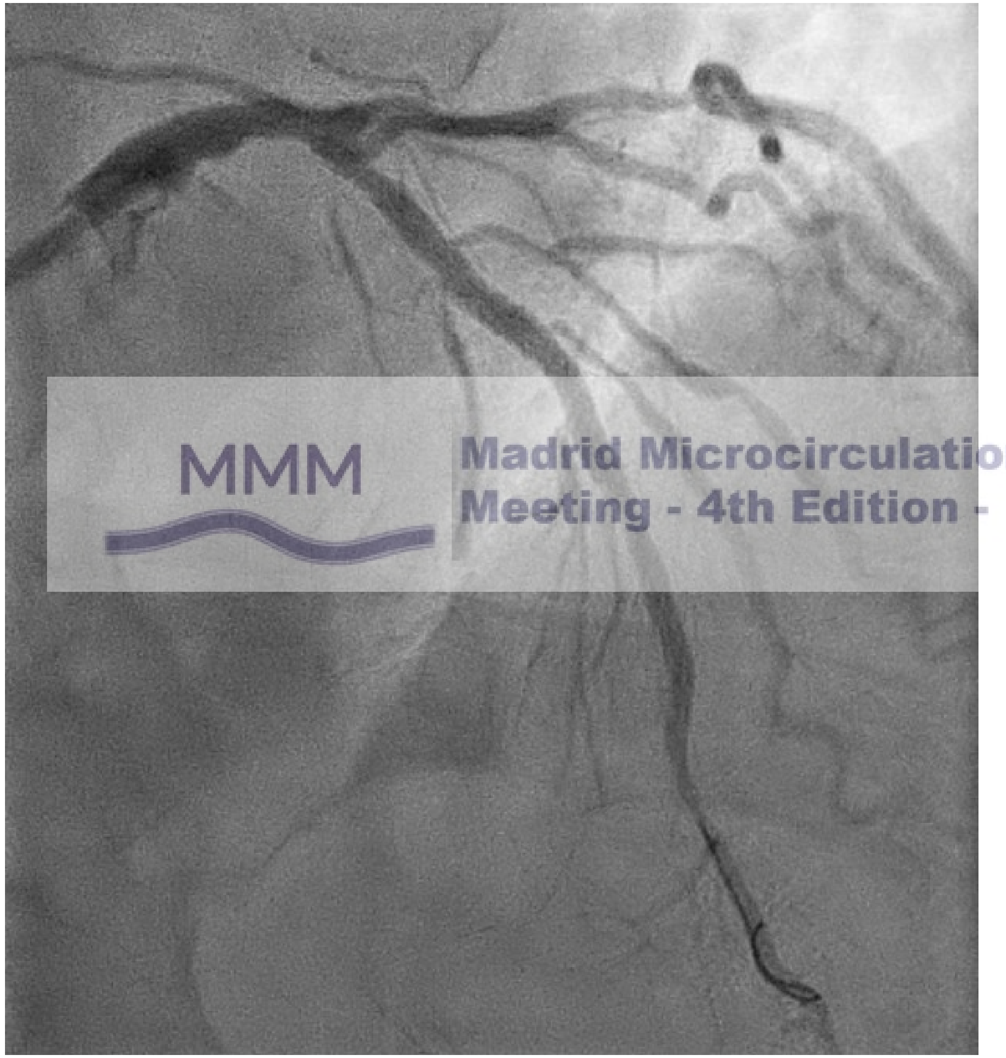
- If FFR with RayFlow catheter is significantly lower than FFR without RayFlow catheter, use in your calculations for MRR just the *hemodynamics with the RayFlow catheter.* This does ***NOT*** affect calculation of Q_{rest} , R_{μ} (***true** rest and hyperemic*) and MRR.

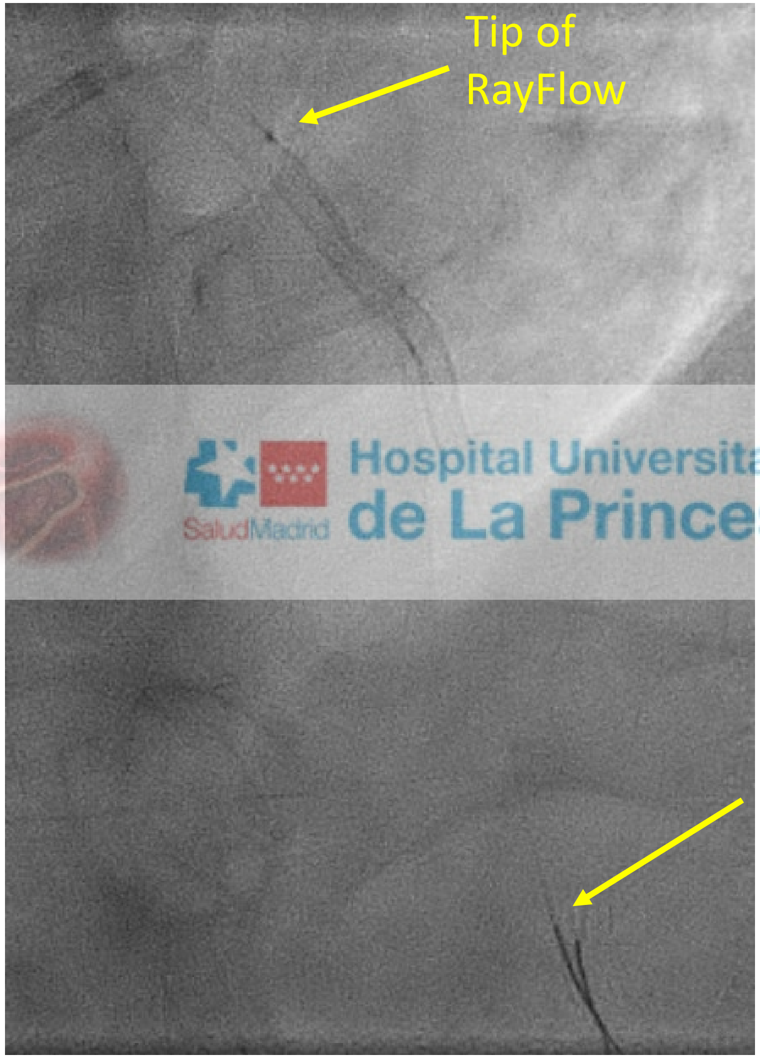
- In contrast, Q_{max} is affected. (as is ***"actual or apparent"*** $R_{\mu,rest}$)
  Q_{max} as it would be without RayFlow catheter, is easily found by multiplying the measured value of Q_{max} with: (FFR without RayFlow / FFR with Rayflow).

- This issue plays sometimes a role in case of proximal disease, small coronary arteries, or in case that the tip of the RayFlow catheter needs to be located more distal in the coronary artery

- Similarly, measuring *before or after PCI* (as a matter of fact) does ***NOT*** affect Q_{rest} , R_{μ} (true rest and hyperemic) and MRR, but of course does affect hyperemic flow Q_{max}

Positioning of the RayFlow ® catheter over the PressureWire ® to measure absolute flow and resistance





Abso

Room
Patient
Live
Review
Arena patient 040222
Coroventis
FFR 0,70 Pd 61 Pa 87
Pd/Pa 0,86 Pd 85 Pa 99
CFR 1,9 CFRNorm 2,6
IMR 12 IMRCorr 11
RRR 2,8
Pd/Pa
FFR
Resting 0,36s 0,34 0,45 0,27
Hyperemic 0,19s 0,13 0,26 0,18
Resume
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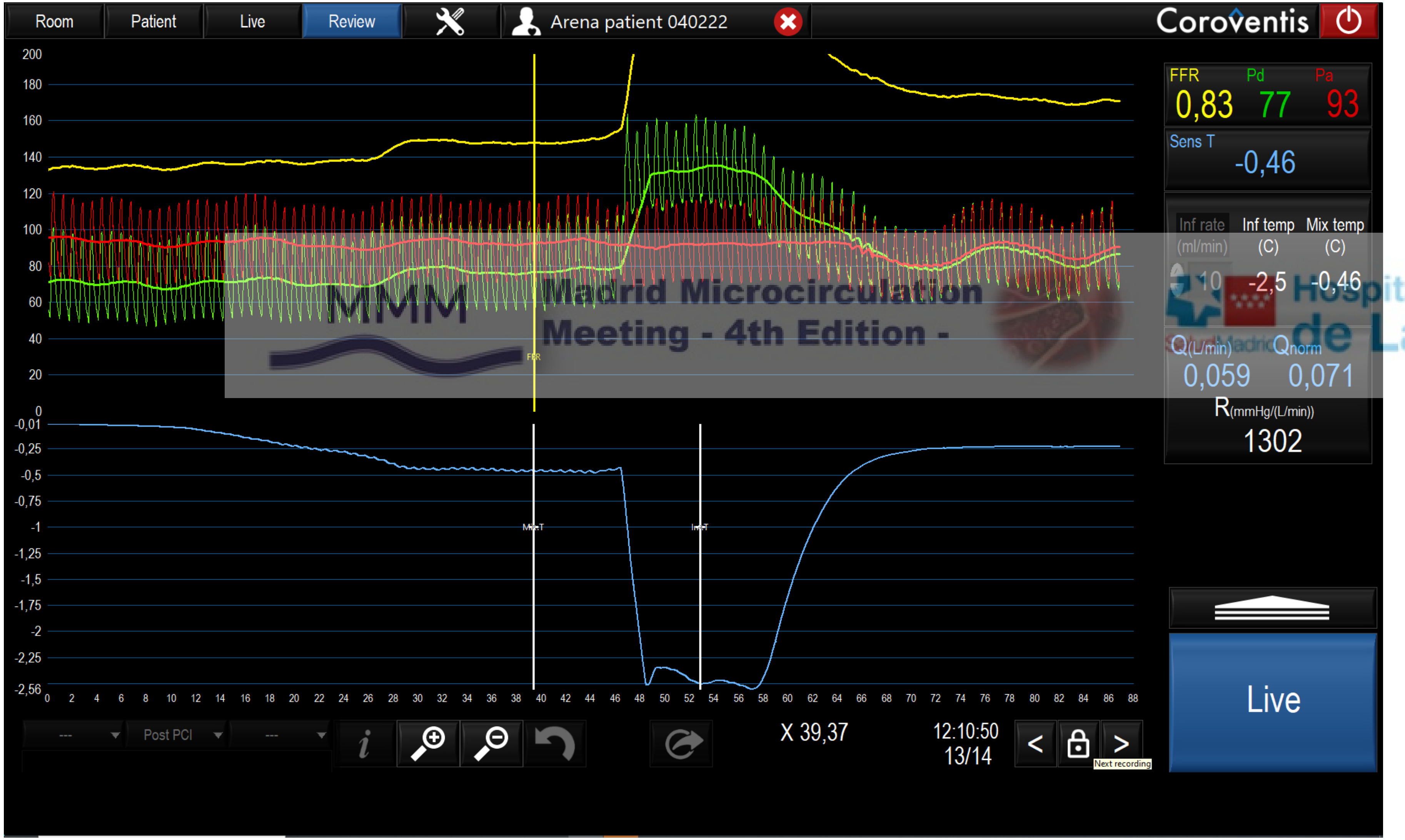
Post PCI
X 0
D 23,08
12:08:52
12/14
Previous recording
Live
Zoeken
NLD
15:17
22-11-2023

Absolute flow measurements after PCI, **"resting conditions"** (saline 10 ml/min) :

resting flow = 59 ml/min   actual (=***apparent)*** resting R_μ = 1302 WU   ***true resting*** R_μ = 1576 WU



Actual or apparent resting microvacular resistance:

$$R_{\mu,\ rest,\ sten} = P_d / Q_{rest,\ sten}$$

77 mmHg / 0.059 l/min = 1302 WU

True resting microvacular resistance:

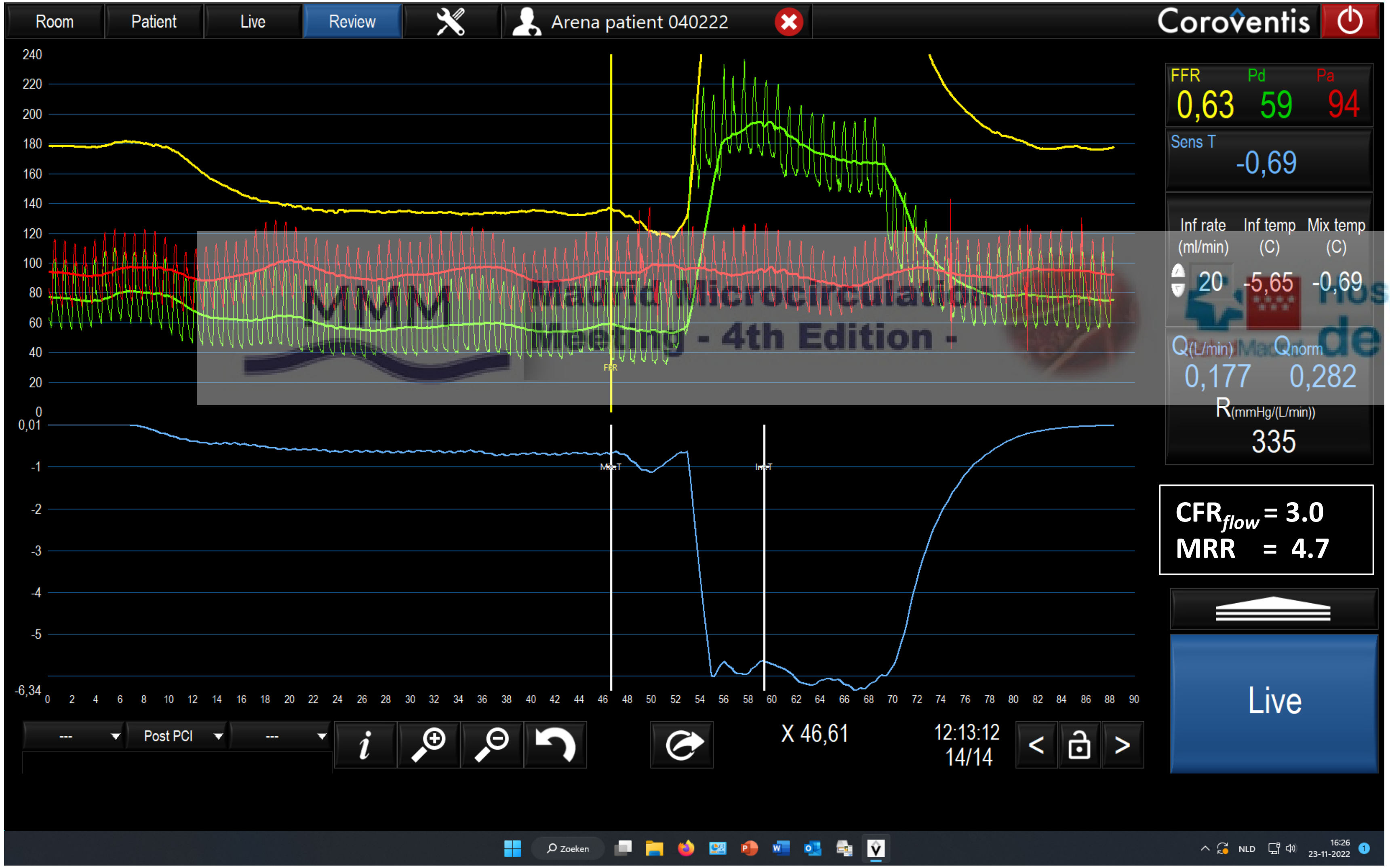
(i.e resting resistance *as it **would** be in the absence of any epicardial disease)*

$$R_{\mu,\ rest,\ sten} = P_a / Q_{rest,\ sten}$$

93 mmHg / 0.059 l/min = 1576 WU

Absolute flow measurements after PCI, hyperemic conditions (=20 cc/min NaCl infusion):

hyperemic flow = 177 ml/min   ***minimal*** R_{μ} = 335 WU CFR_{flow} = 3.0   MRR= 4.7



hyperemic flow = 177 ml/min

minimal $\mathbf{R_{\mu}}$ = $R_{\mu,hyper}$ = 335 WU

$R_{\mu,hyper} = P_d / Q_{max} =$

59 mmHg / 0.177 l/min = 335 WU

$\mathbf{CFR_{flow}}$ = 3.0

0.177 l/min / 0.059 l/min = 3.0

MRR= 4.7

(3.0 / 0.63) x (93/ 94) = 4.7

Absolute Flow & Resistance, Absolute CFR, and MRR by continuous thermodilution

Upcoming paper:

Pijls et al: "Deep Dive Into The Theory of Microvascular Resistance Reserve"

Demonstration of autoregulation in conscious human:

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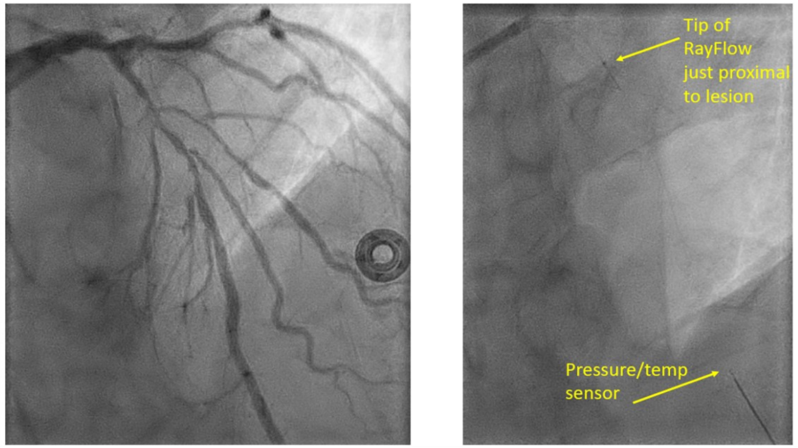
A Pre-PCI Coronary Angiogram And Positioning of The RayFlow Catheter



B Absolute flow measurements before PCI, **"resting conditions"** (saline infusion 10 ml/min):

Resting Flow = 56 ml/min

Actual or apparent resting microvacular resistance:

$R_{\mu,\,rest} = P_d / Q_{rest}$

29 mmHg / 0.056 l/min = ***514 WU***

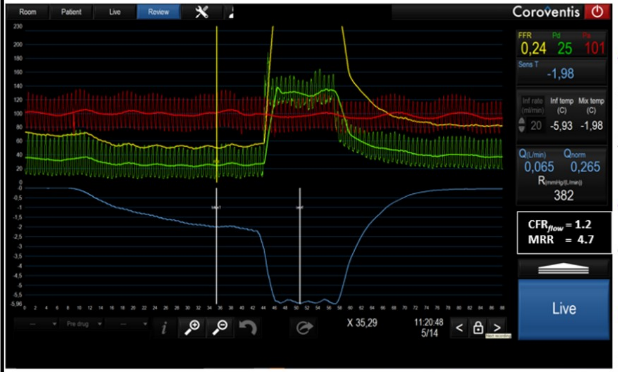
True resting microvacular resistance:

(i.e resting resistance as it would be in the absence of any epicardial disease)

$R_{\mu,\,rest} = P_a / Q_{rest}$

95 mmHg / 0.056 l/min = ***1696 WU***

C Absolute flow measurements before PCI, **"hyperemic conditions"** (saline infusion 20 ml/min):



Hyperemic flow = 65 ml/min

Minimal R_μ = $R_{\mu,hyper}$ = 382 WU

$R_{\mu,hyper} = P_d / Q_{max}$ =

25 mmHg / 0.065 l/min = ***382 WU***

CFR_{flow} = **1.2**

0.065 l/min / 0.056 l/min = 1.2

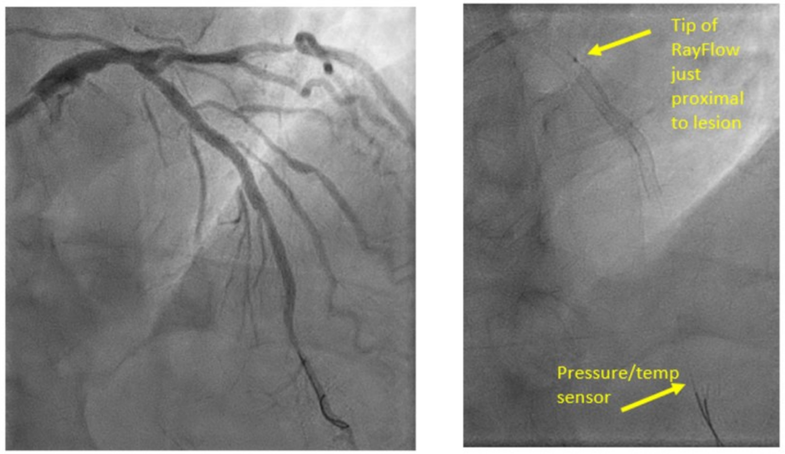
MRR = **4.7**

(1.2 / 0.24) x (95/101) = 4.7

- *61-year old male,*
- *focal ánd diffuse LAD disease*
- *Poor result of PCI*
  (FFR 0.24 → 0.63)
- *All measurements done both before and after PCI (ARENA study)*

FFR	:	0.24 → 0.63
Q_{rest}	:	56 → 59 ml/min
Q_{max}	:	65 → 177 ml/min
CFR_{abs}	:	1.2 → 3.0
$R_{\mu,rest}$	:	514 → 1302 WU
$R_{\mu,hyp}$	:	382 → 335 WU
$R_{\mu,rest,true}$	:	1695 → 1576
MRR	:	4.7 → 4.7

D Post-PCI Coronary Angiogram And Positioning of The RayFlow Catheter



E Absolute flow measurements after PCI, **"resting conditions"** (saline infusion 10 ml/min):

Resting Flow = 59 ml/min

Actual or apparent resting microvascular resistance:

$R_{\mu,\,rest} = P_d / Q_{rest}$

77 mmHg / 0.059 l/min = ***1302 WU***

True resting microvascular resistance:

$R_{\mu,\,rest} = P_a / Q_{rest}$

93 mmHg / 0.059 l/min = ***1576 WU***

F Absolute flow measurements after PCI, **"hyperemic conditions"** (saline infusion 20 ml/min):

Hyperemic flow = 177 ml/min

Minimal R_μ = $R_{\mu,hyper}$ = 335 WU

$R_{\mu,hyper} = P_d / Q_{max}$ =

59 mmHg / 0.177 l/min = 335 WU

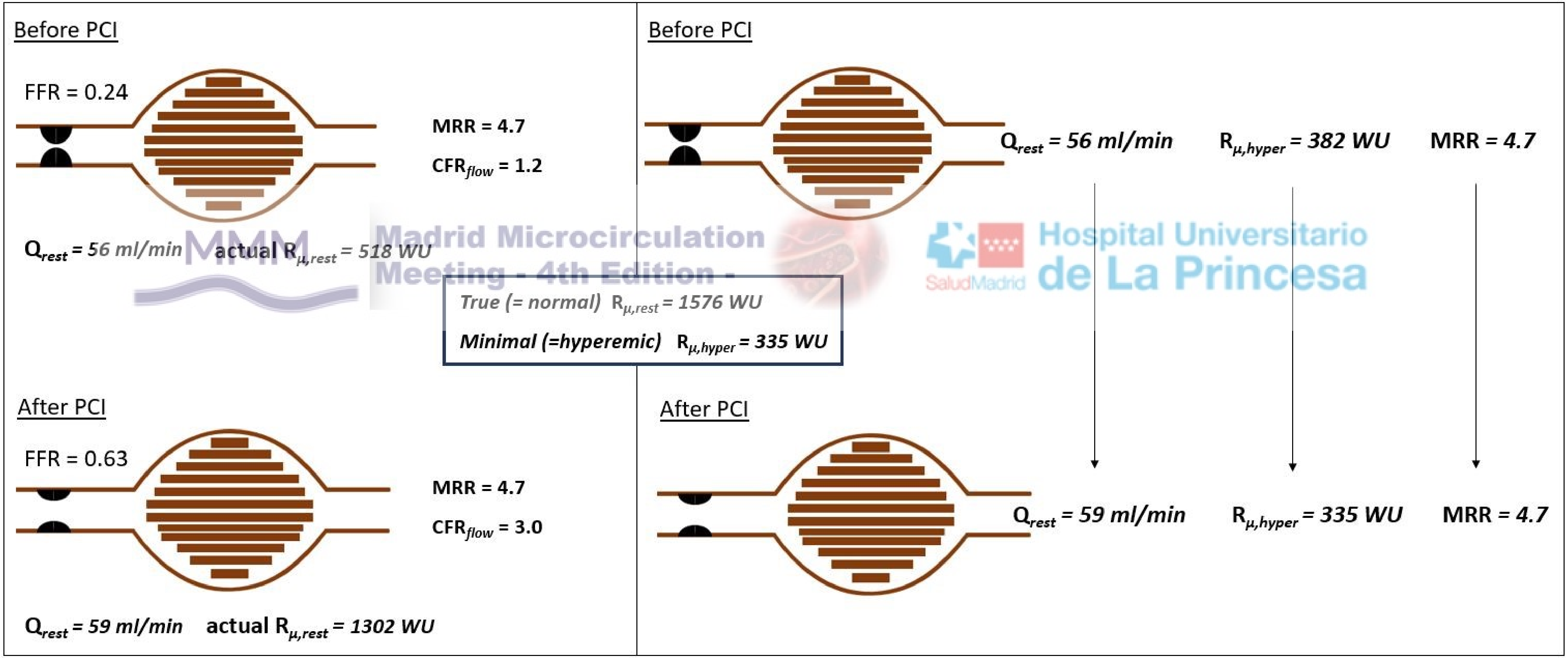
CFR_{flow} = 3.0

0.177 l/min / 0.059 l/min = 3.0

MRR= 4.7

(3.0 / 0.63) x (93/ 94) = 4.7

Demonstration of autoregulation in conscious human:



Tips and Tricks (5): FFR (or $P_{d,hyp}$) and Flow (or CFR) are *not measured in the same session*

- Retrospective studies with bolus thermo or Doppler
- Hybrid approaches (invasive FFR and non-invasive PET)
- Full non-invasive approaches (Heartflow FFRCT and PET)

MRR = Qmax/Qrest x Pa,rest/Pd,hyp = CFR/FFR x Pa,rest/Pa,hyp

Bottomline of the message:

- *The pressures you are using should be taken as measured simultaneously with the flow or CFR measurement (because hyperemic flow and CFR are pressure-dependent)*

- *The FFR can be measured at a different moment or with a different method, because FFR is pressure **in**dependent*

Upcoming paper: *Pijls et al: "Deep Dive Into The Theory of Microvascular Resistance Reserve"*

Thank you!

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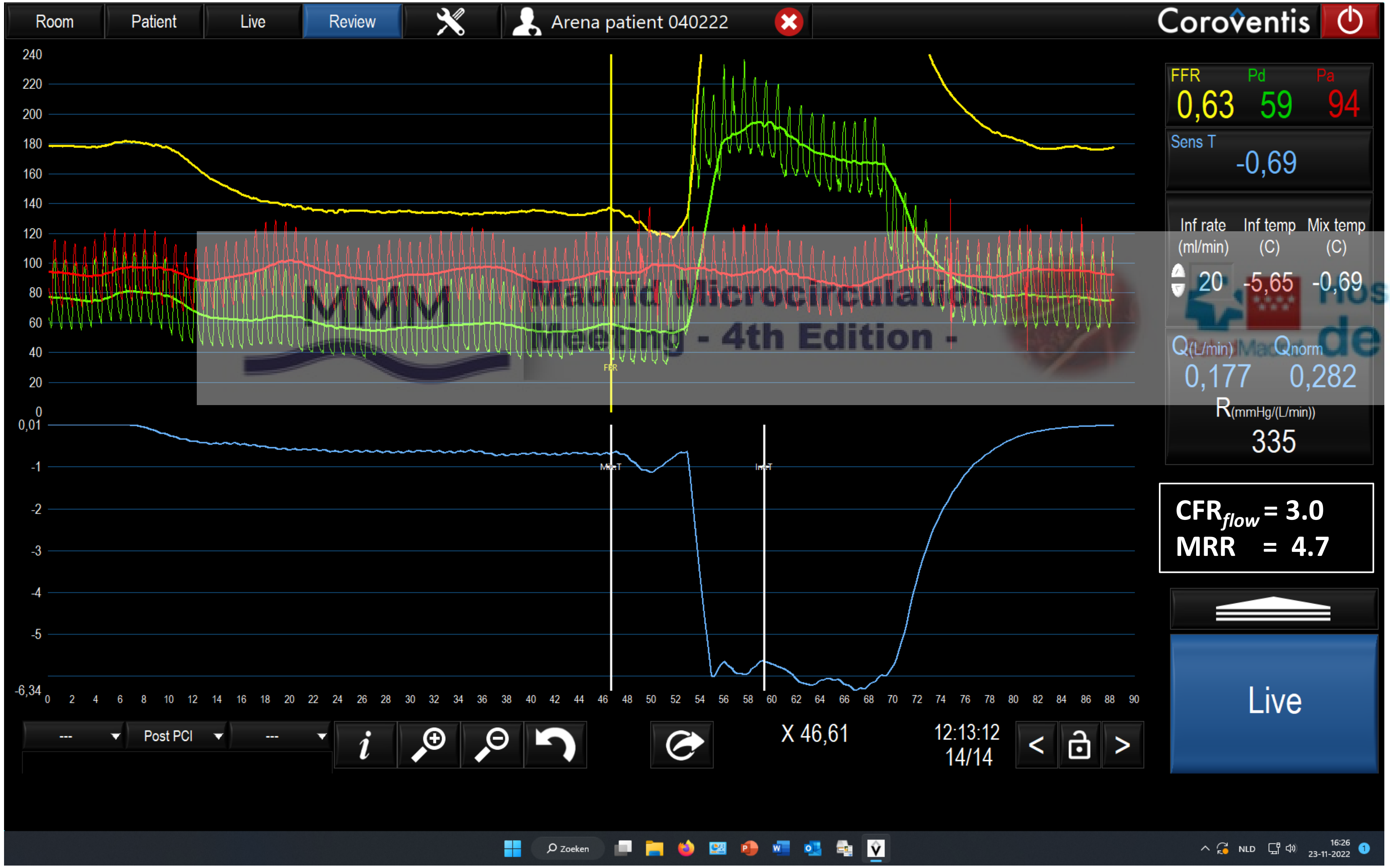
Absolute flow measurements after PCI, hyperemic conditions (=20 cc/min NaCl infusion):

hyperemic flow = 177 ml/min   ***minimal*** R_μ = 335 WU CFR_{flow} = 3.0   MRR= 4.7



Important note:

In the calculation of MRR on the previous slide, we took the FFR with the RayFlow catheter in the first part of the artery (0.63). Consequently, also Pa,rest en Pa,hyp (93 en 94 mmHg) should be taken as recorded in that situation.

Would somebody state that true FFR (without the presence of the RayFlow) equals 0.70 and should be used for the calculation of MRR, then as a matter of fact you should also take the pressures during that FFR measurement (99 and 87 mmHg; see IMR measurement)

In both cases, you find the same value of MRR. See calculations herebelow.
This indicates once more that MRR is fully independent of epicardial disease, no matter whether it is focal, diffuse or artificial by the Rayflow catheter

MRR= 4.7
(3.0 / 0.63) x (93/ 94) = 4.7

MRR= 4.8
(3.0 / 0.70) x (99/ 87) = 4.8

!!

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Absolute Flow & Resistance, Absolute CFR, and MRR by continuous thermodilution

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