Towards continuous BP monitoring and real-time prediction of IDH in haemodialysis

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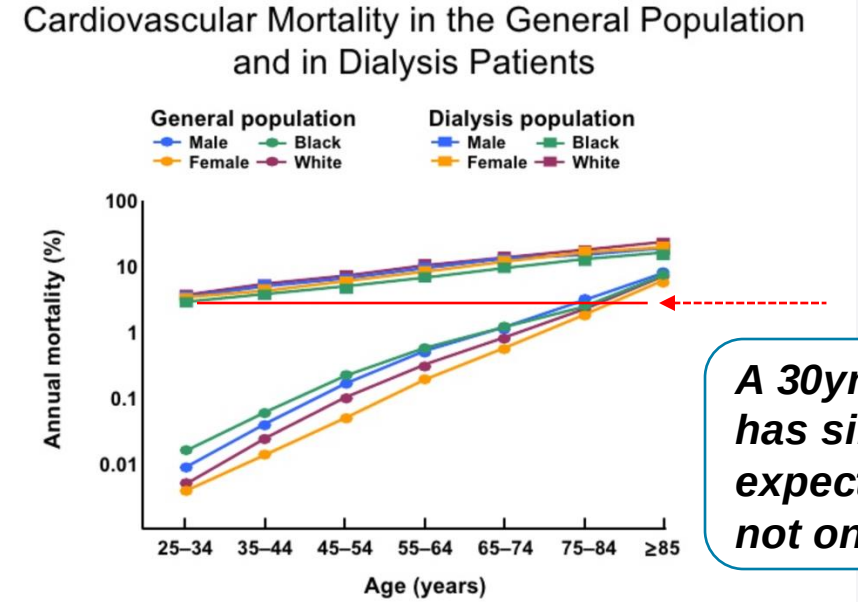
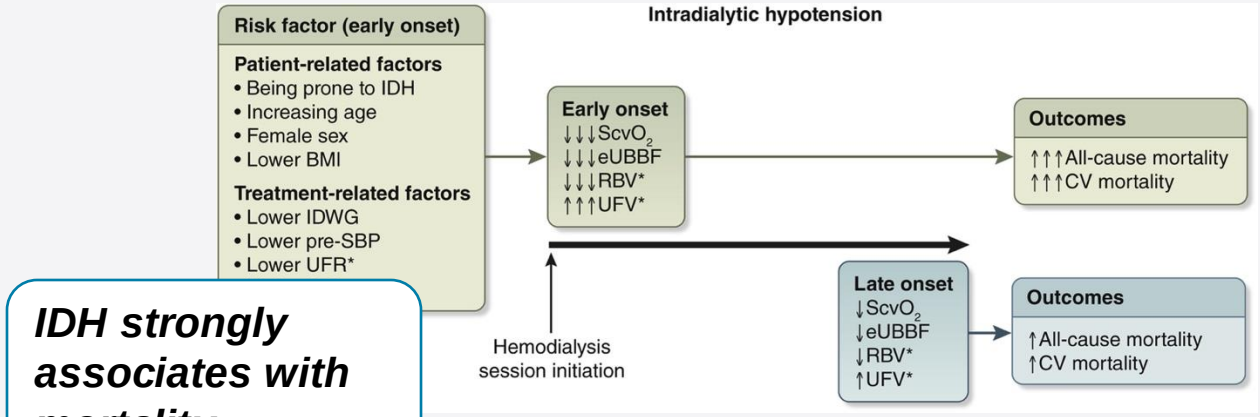
Haemodynamic effects of dialysis: driving CV mortality



A 30yr old on dialysis has similar life expectancy to 80yr old not on dialysis



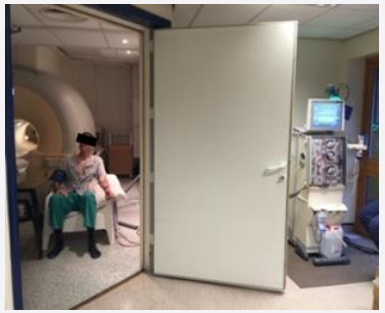
IDH strongly associates with mortality

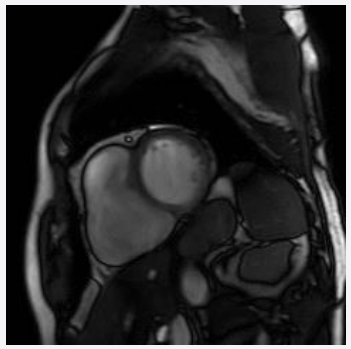
Sohn et al KI 2021; 99(6); 1269-72

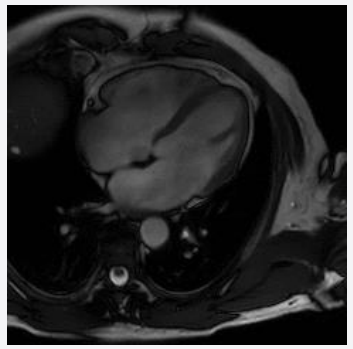
CLINICAL RESEARCH www.jasn.org

Intradialytic Cardiac Magnetic Resonance Imaging to Assess Cardiovascular Responses in a Short-Term Trial of Hemodiafiltration and Hemodialysis

Charlotte Buchanan,* Azharuddin Mohammed,† Eleanor Cox,* Katrin Köhler,‡ Bernard Canaud,‡ Maarten W. Taal,† Nicholas M. Selby,† Susan Francis,* and Chris W. McIntyre§‖

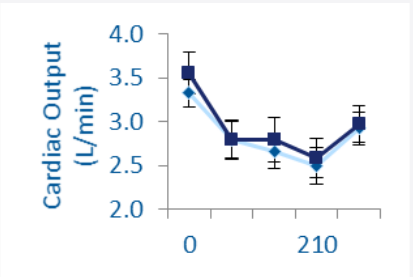


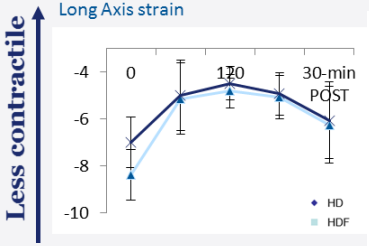


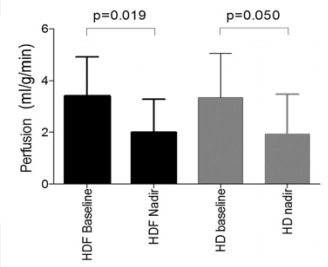


During dialysis:

↓ cardiac output **↓ LV contractility** **↓ perfusion**



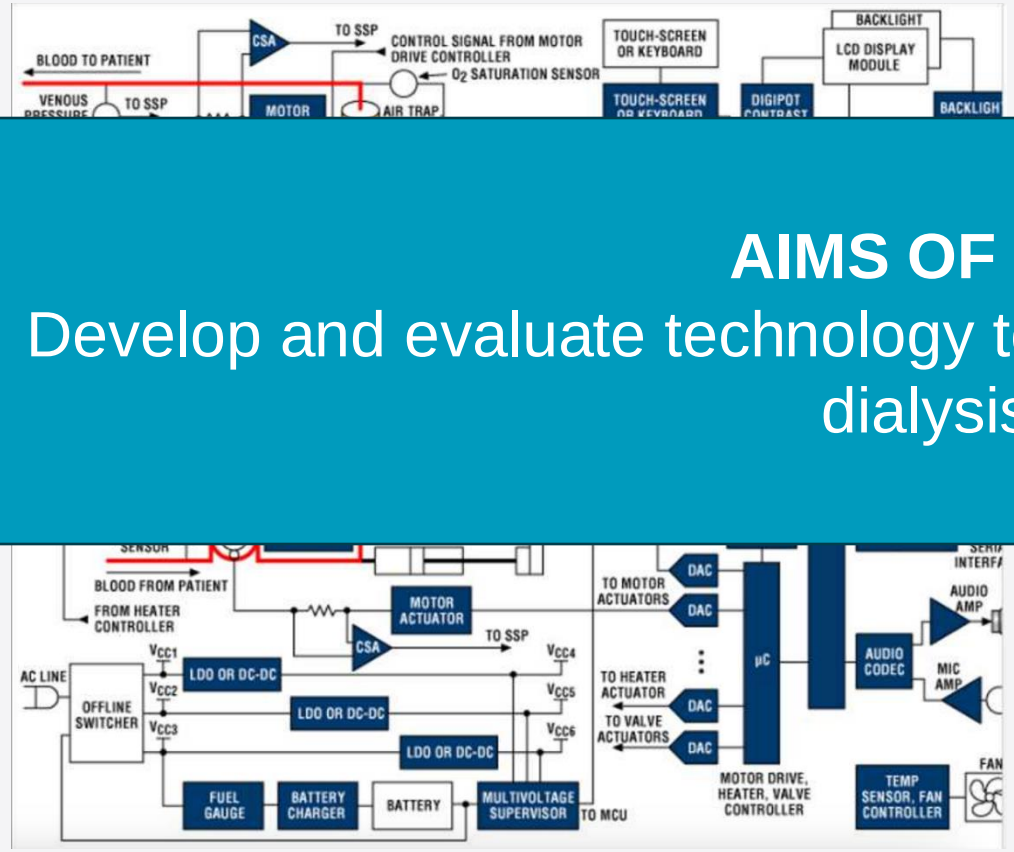




Current haemodialysis practice

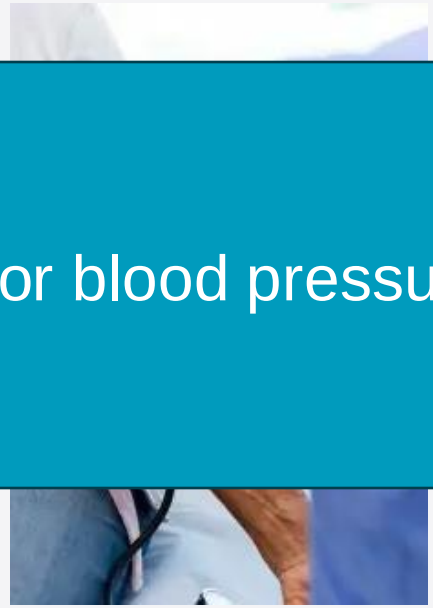
SENSORS IN HD MACHINE vs. PATIENT MONITORING

(lots!) (very little!)



AIMS OF ITREND PROJECT:

Develop and evaluate technology to continuously monitor blood pressure during dialysis and predict IDH



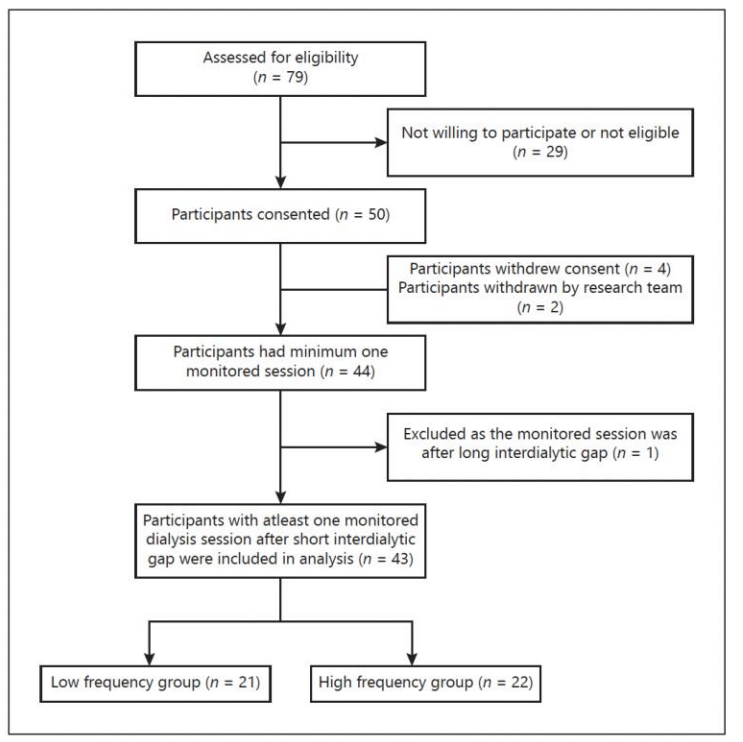
Here are several common problems that account for inaccurate blood pressure measurements.

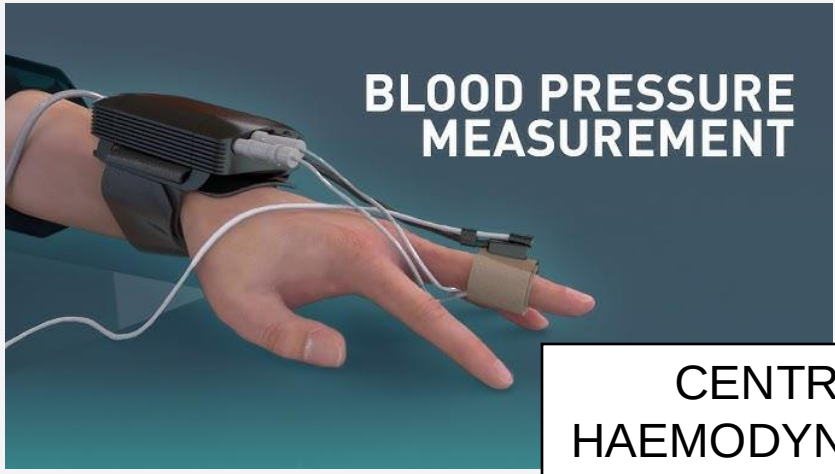
When patient has ...	BP can change by this much ...[3,4]
Cuff over clothing	10–40 mm Hg

Initial approach – digital artery pulse wave analysis

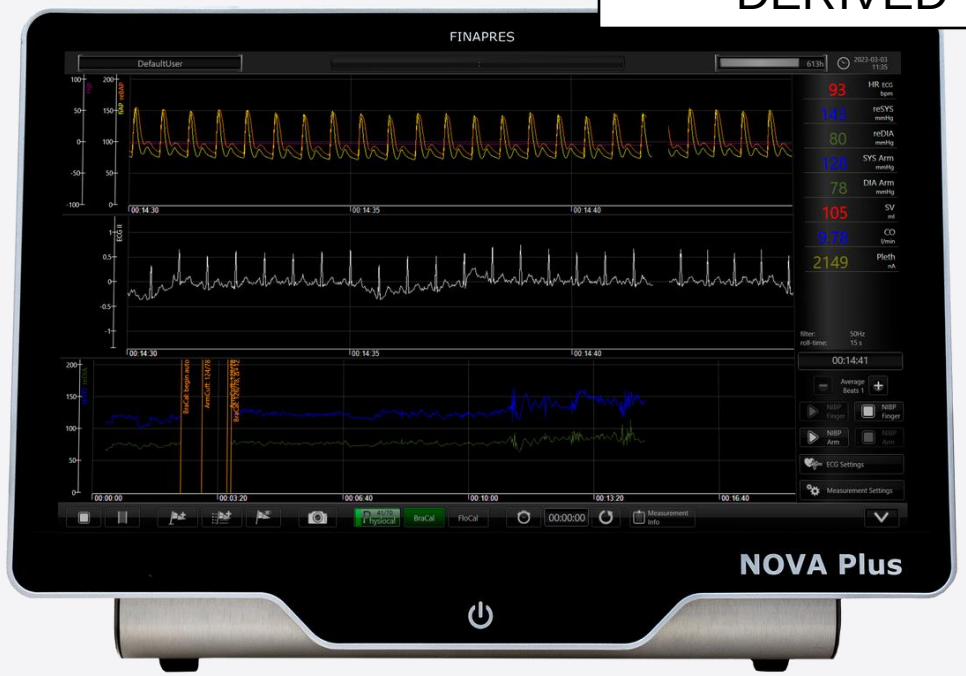
An Analysis of Frequency of Continuous Blood Pressure Variation and Haemodynamic Responses during Haemodialysis

Venkata R. Latha Gullapudi[a, b] Kelly White[c] Jill Stewart[d] Paul Stewart[d]
Mohammed T. Eldehni[c] Maarten W. Taal[a, c] Nicholas M. Selby[a, c]





CENTRAL HAEMODYNAMICS DERIVED



Extrema points analysis of continuous BP data

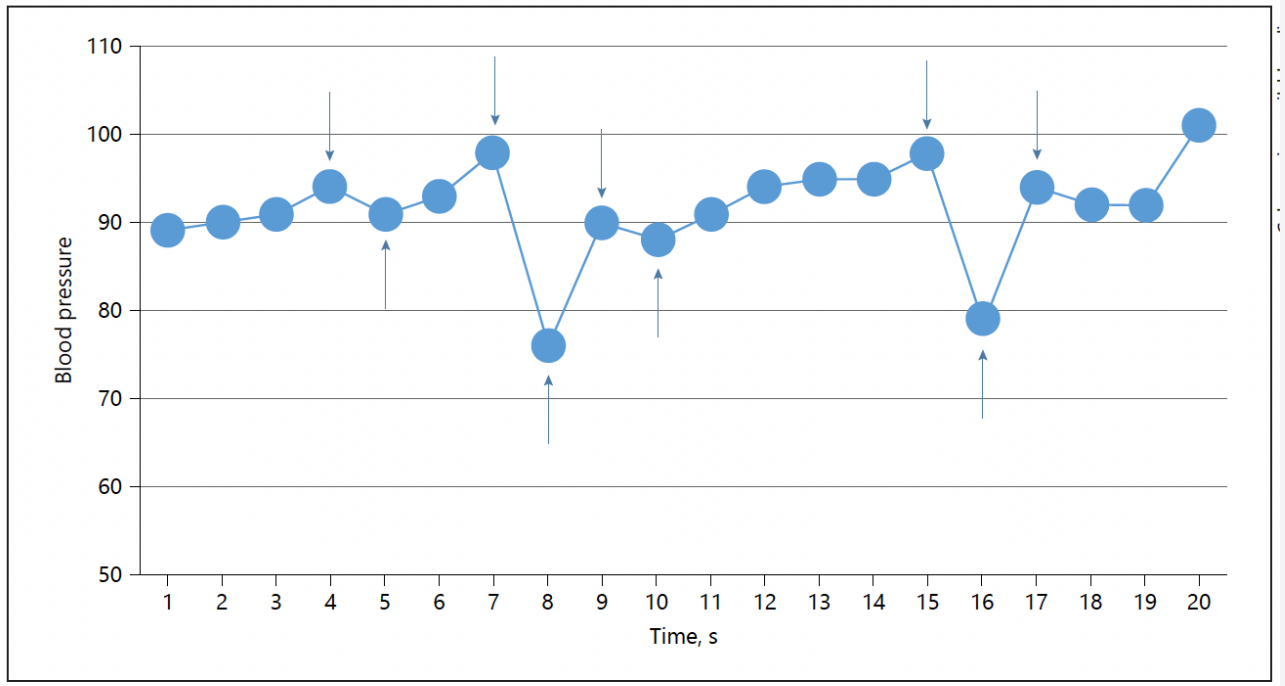
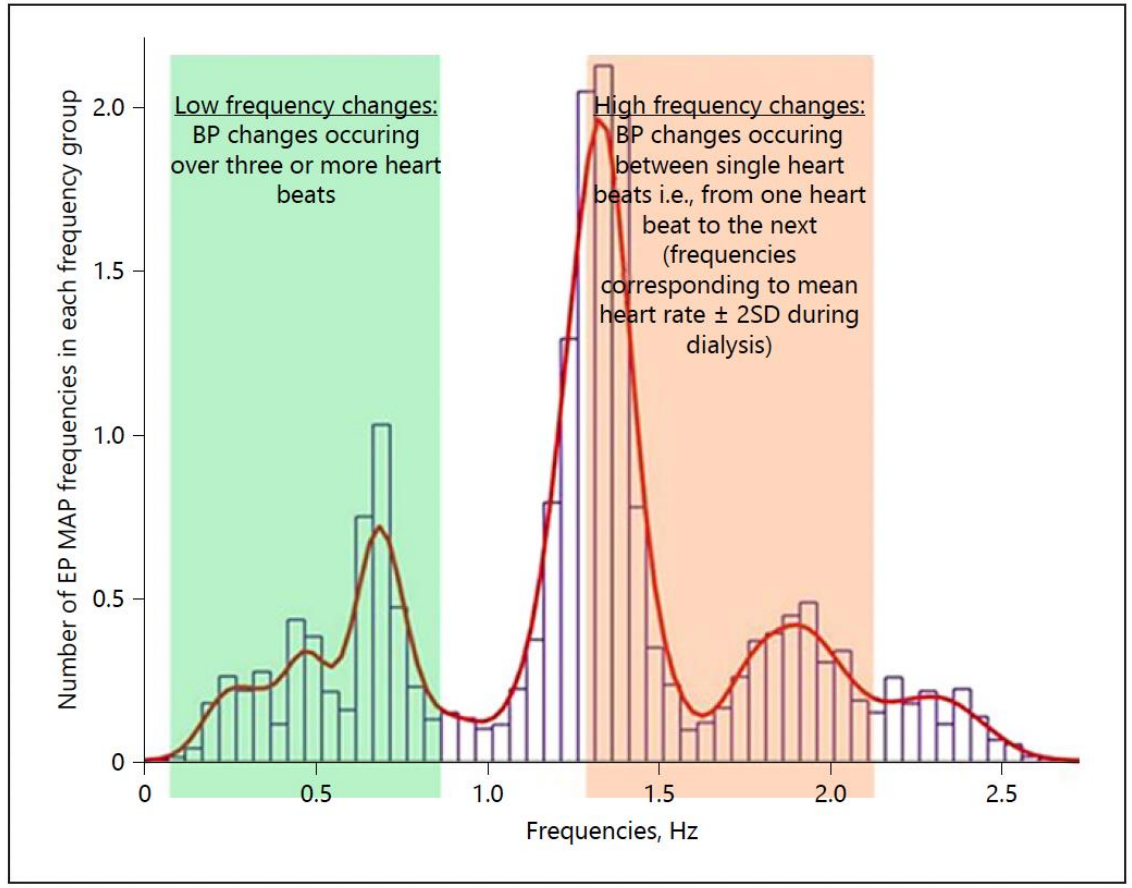


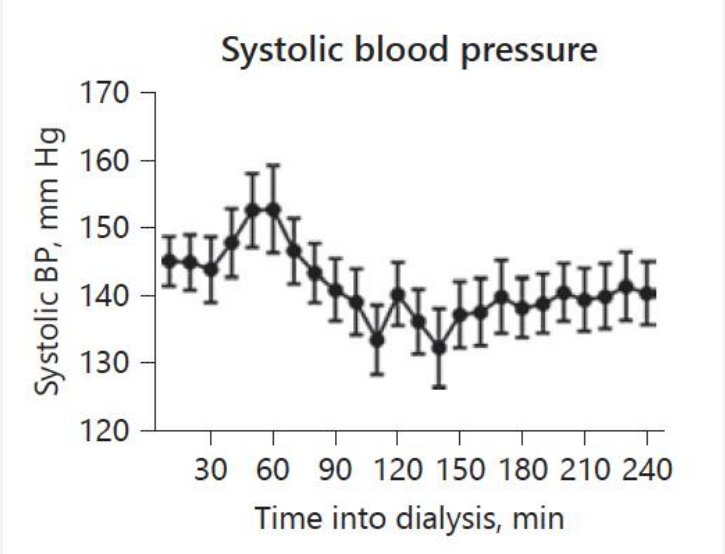
Fig. 1. Illustration of identification of EPs (minima and maxima identified by arrows) on a 20-s trace of MAP (labelled as BP) measurements. Once identified, frequency is calculated using the following formula $f = 1/\text{time}$ difference between 2 consecutive EPs. EPs, extreme points; MAP, mean arterial pressure; BP, blood pressure.

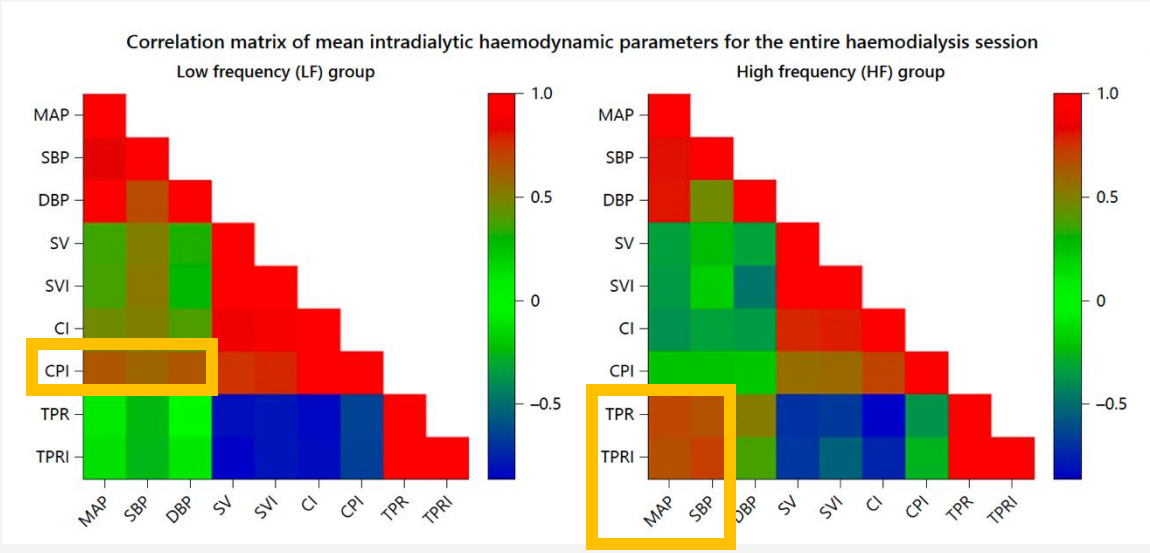


Low-frequency (LF) group: HFC/LFC ratio ≤0.5
High-frequency (HF) group with HFC/LFC ratio >0.5

Results

- Continuous BP measurement during HD allows assessment of beat-to-beat BP variability
- BP frequency correlates with NTpro-BNP
- Patterns of BP variability (frequency and magnitude) categorise patients according to haemodynamic response to dialysis
- Limitations of Finapres

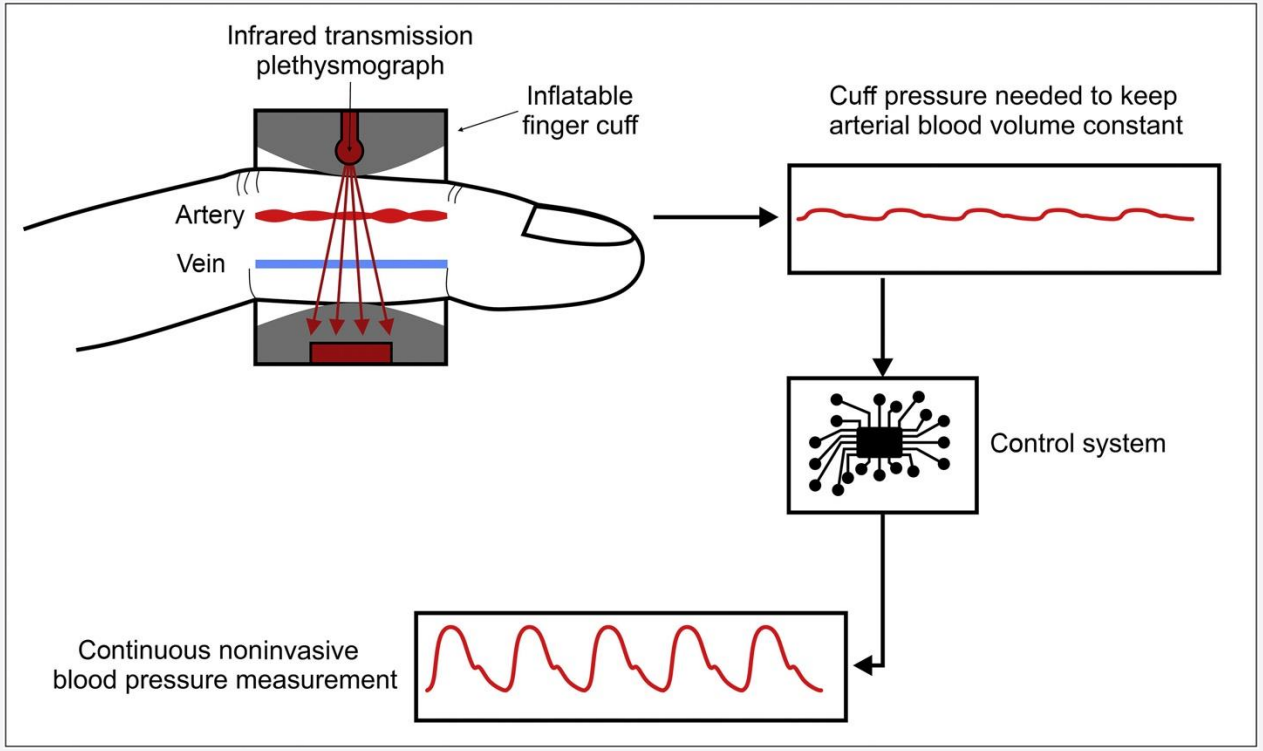




Gullapudi VRL et al. Blood Purif, 2022; 51 (5): 435–449.

Improving on Finapres

- Finapres derives aortic pressure wave by applying a mathematical model to peripheral pulse wave form
- Calibrated against brachial blood pressure cuff
- Hypothesis: arterial pressure can be measured from pressure wave in AV fistula



Experimental setup – A and V line pressure sensors

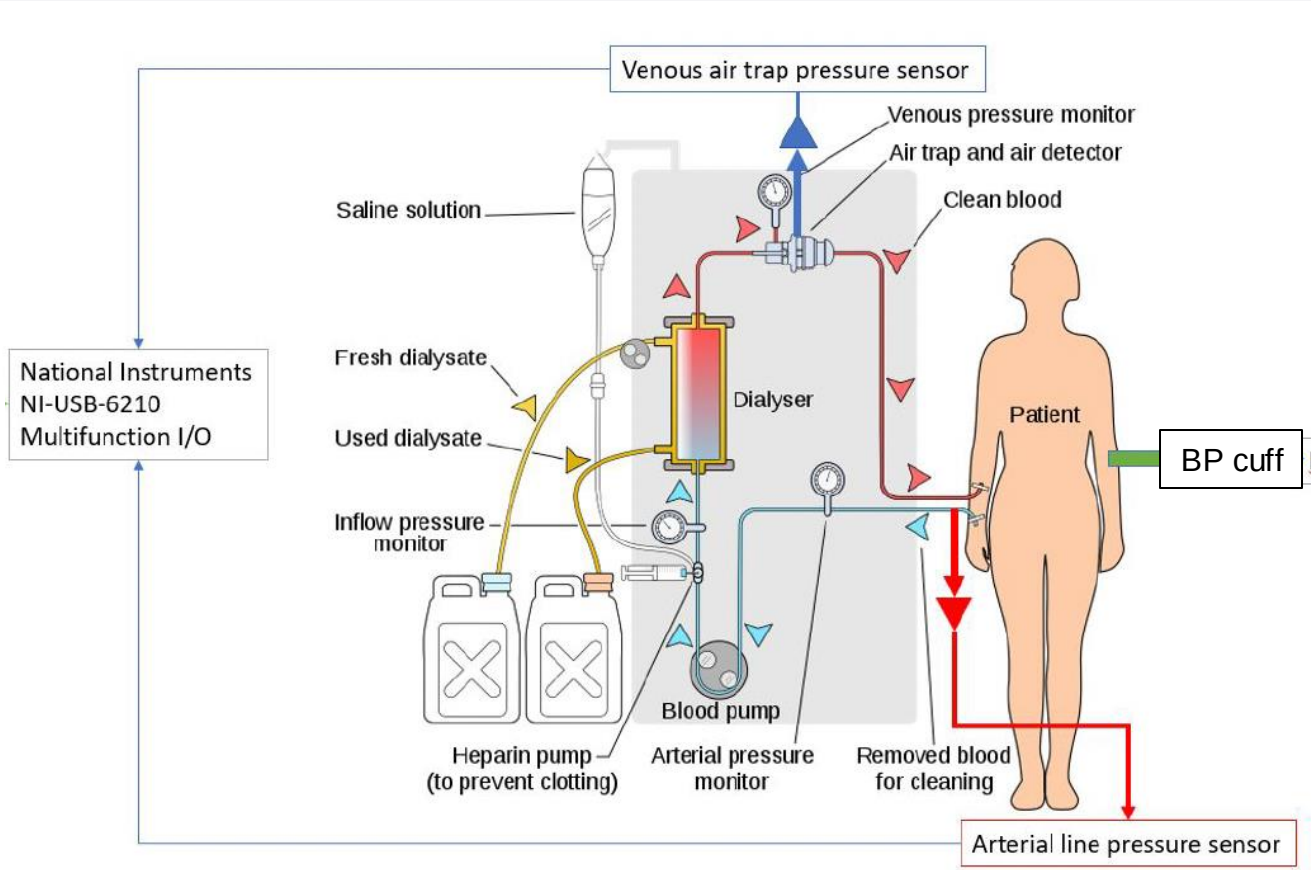
2 additional pressure sensors:

- 1 close to arterial needle in AVF
- 2 in venous bubble trap

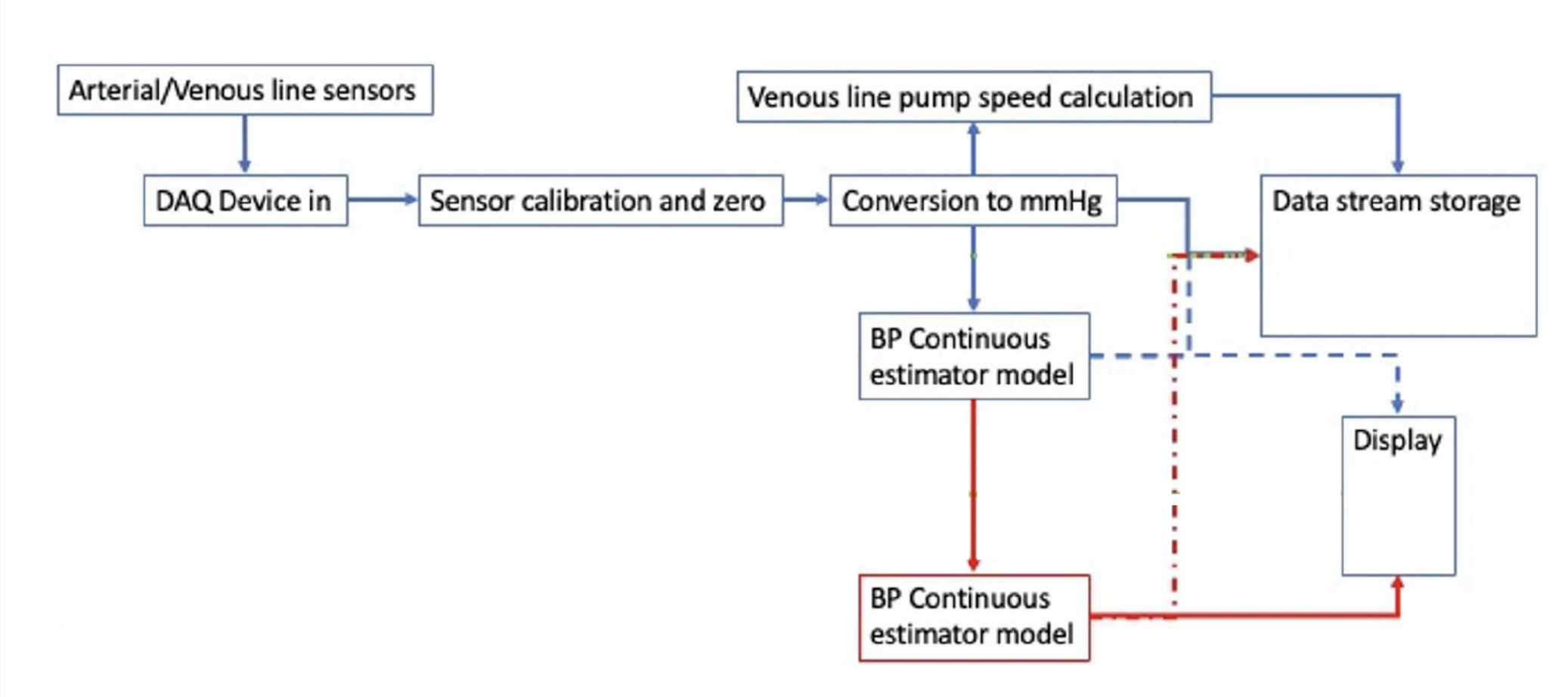
Challenges:

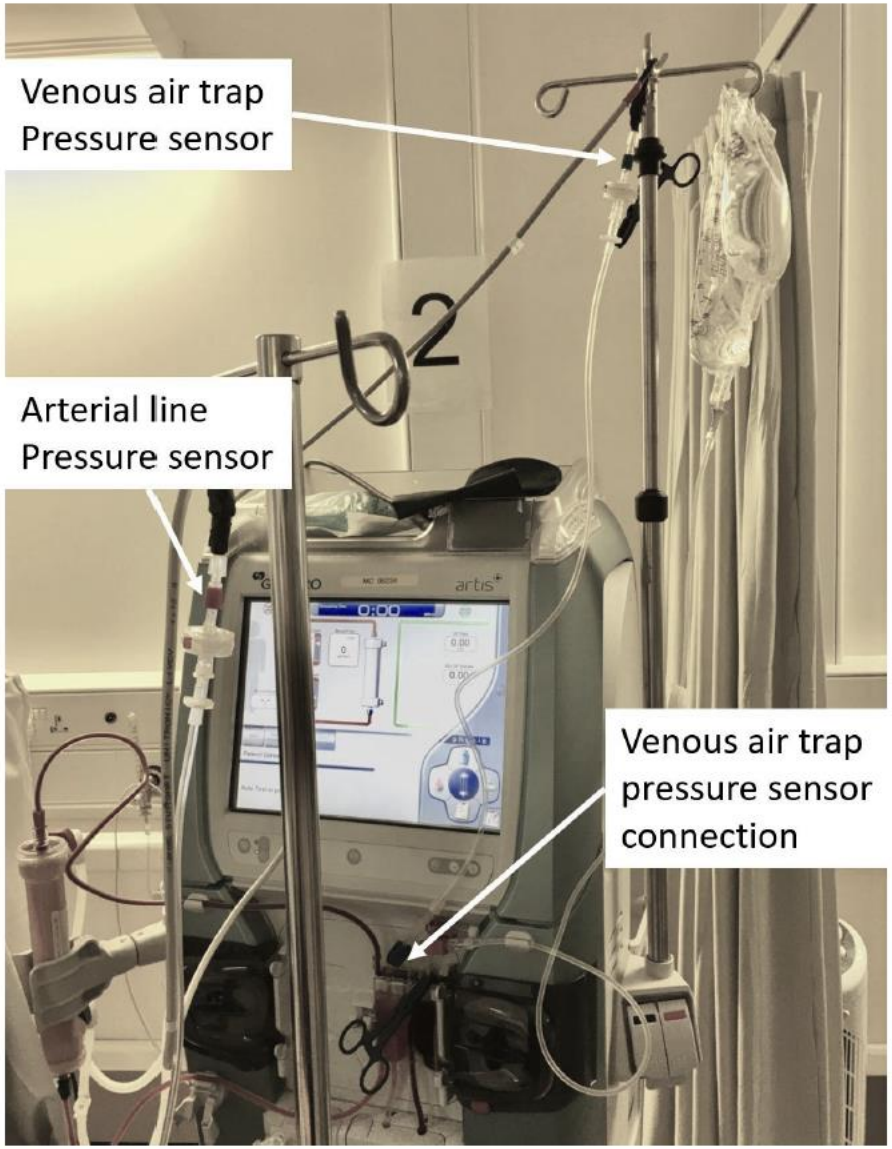
1. **Pressure wave form in extracorporeal circuit dominated by peristaltic blood pump**

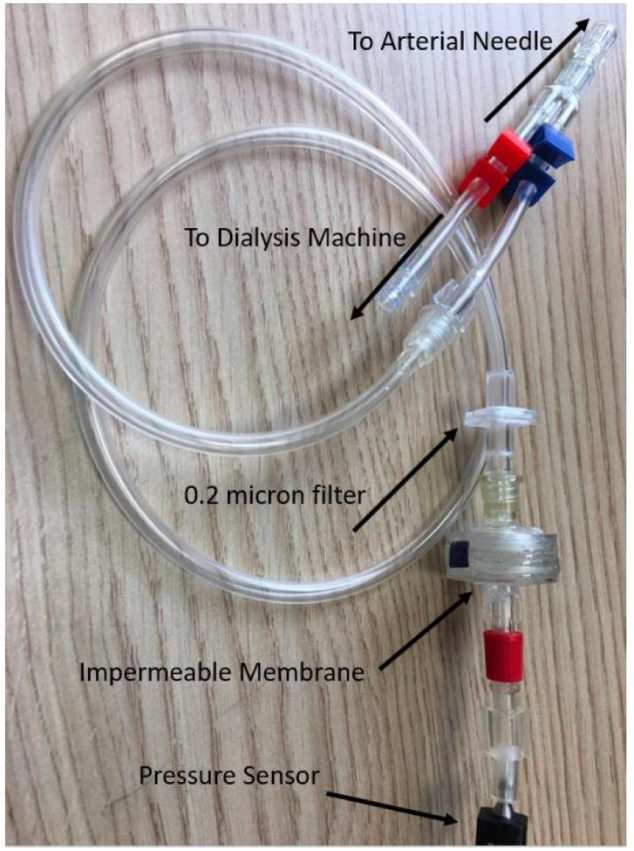
2. **Complex relationship between A-line pressure and brachial BP**

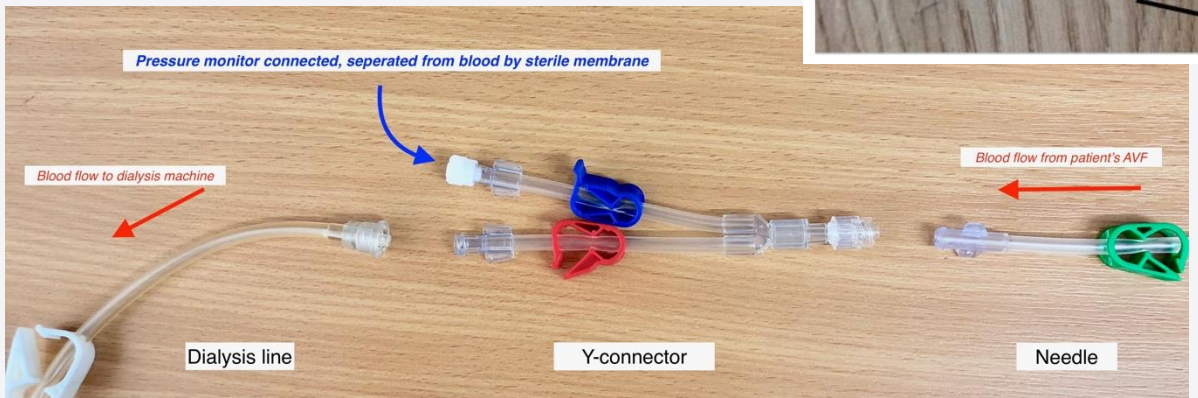


Schematic of experimental setup

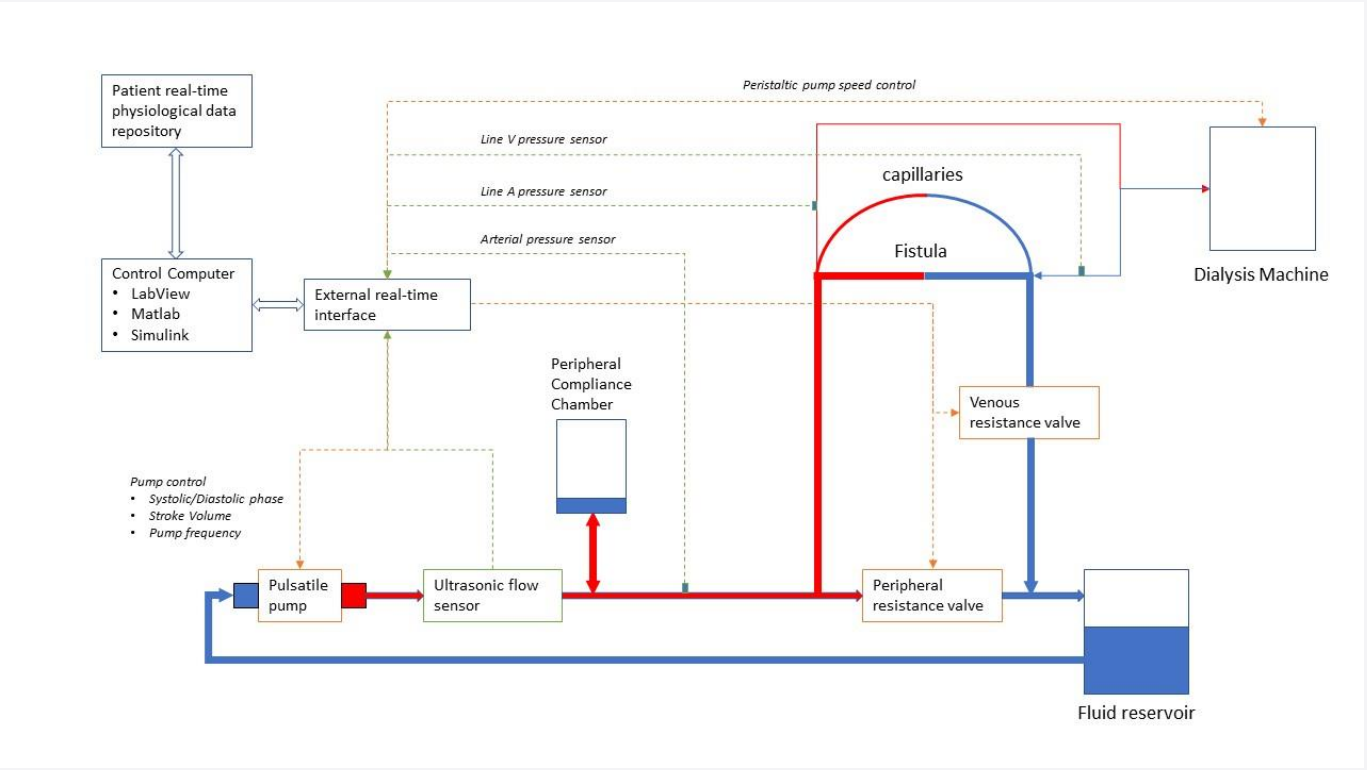


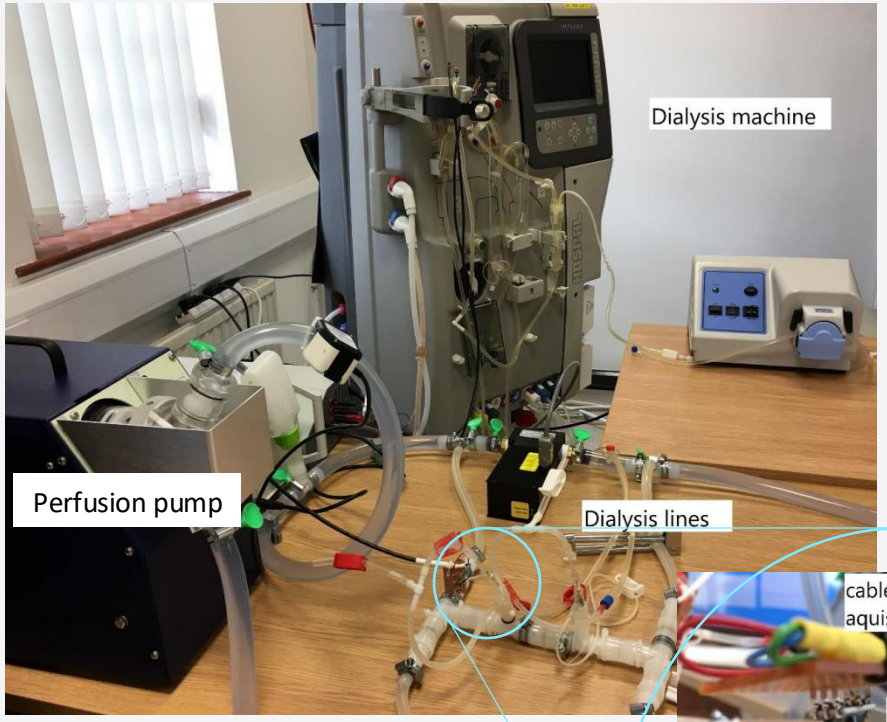

Venous air trap
Pressure sensor
Arterial line
Pressure sensor
Venous air trap
pressure sensor
connection

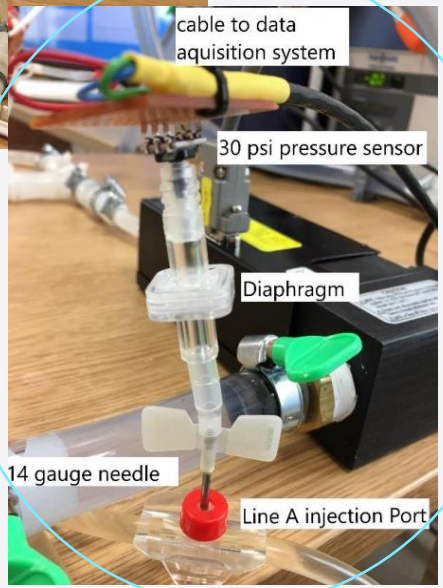

To Arterial Needle
To Dialysis Machine
0.2 micron filter
Impermeable Membrane
Pressure Sensor


Pressure monitor connected, seperated from blood by sterile membrane
Blood flow to dialysis machine
Blood flow from patient's AVF
Dialysis line
Y-connector
Needle

Ex-vivo ‘dummy patient’ system





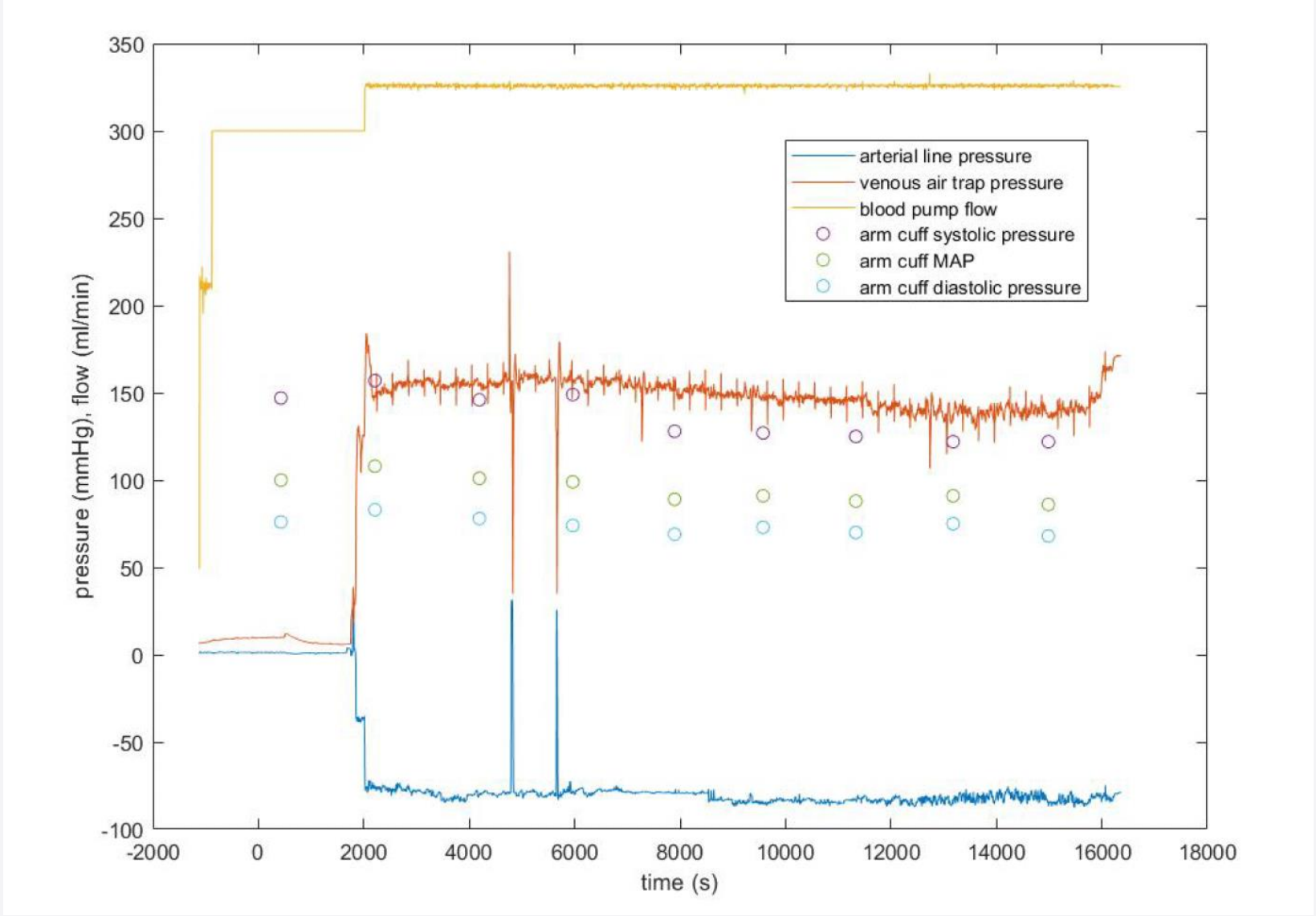


First clinical study: testing feasibility

- 11 patients
  - 58.3% male, median age 65 (IQR 48-78)
- Finapres as well as arterial pressure monitoring during single dialysis treatment

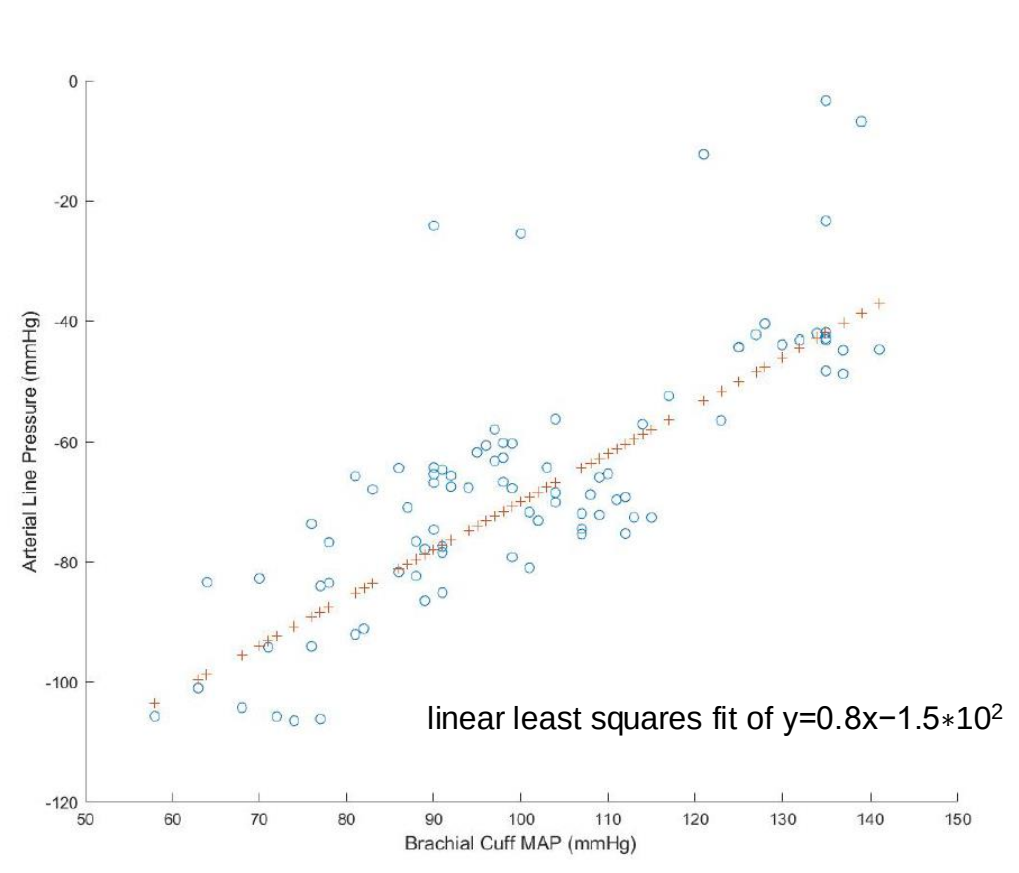
- Derived pump flow, arterial and venous line pressures, and brachial cuff pressure measurements calculated/recorded with synchronous time stamps
- Comparisons at each brachial BP reading against arterial line pressure

Typical output for example patient

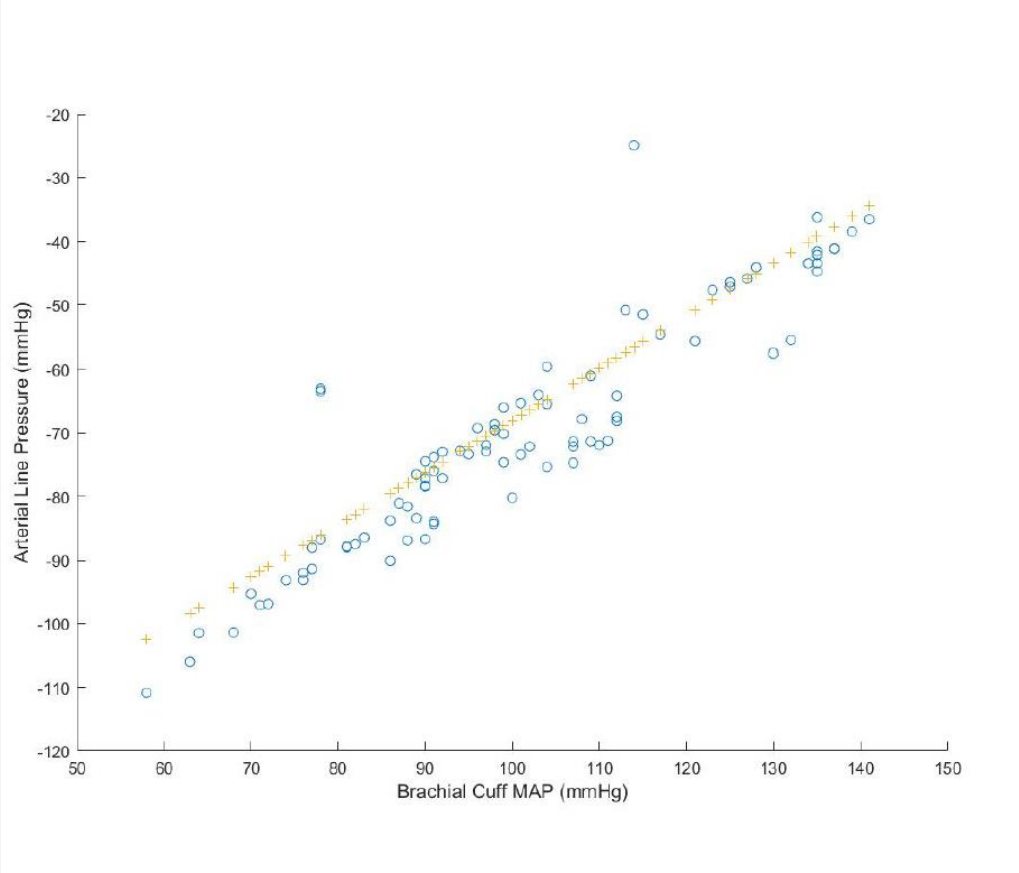


Arterial line pressure correlated with brachial BP

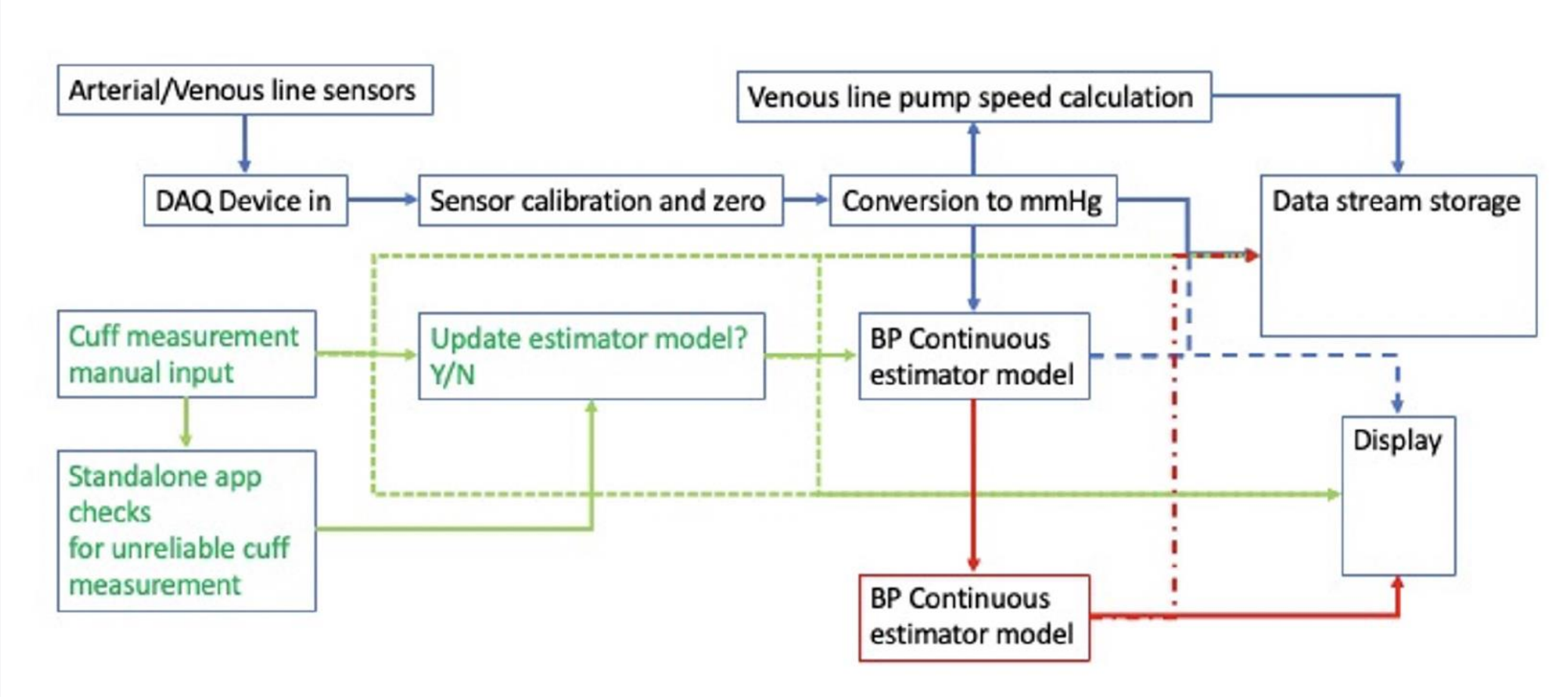
Uncorrected



Data corrected for time-varying effects



Need for model to update with cuff BP measurements



Initial model updated to include last brachial cuff measurement using Kalman filtering

Second clinical study (DIAMONDS)

Aims:

- *obtain non-invasive continuous intradialytic blood pressure recordings in a cohort of haemodialysis patients*
- *develop an algorithm for real-time prediction of intradialytic hypotension*

- Prospective observational study
- Prevalent HD patients, including those prone to IDH, studied over three consecutive treatments
- Comparison of moving average (5-sec period) estimated BP immediately prior to systolic BP from cuff measurement

Participant characteristics

42 study sessions in 21 participants

Age (years)	71 ± 11
Male [n (%)]	12 (57)
Diabetes [n (%)]	7 (33)
Cardiovascular disease [n (%)]	11 (52)
Dialysis vintage (months)	20.0 (IQR 12.5 to 63.5)
Antihypertensive medication	
Angiotensin converting enzyme inhibitors [n (%)]	3 (14)
Calcium channel blockers [n (%)]	3 (14)
Beta blockers	7 (33)
Fistula blood flow (QA)	598 (390 to 1096)
Vascular access type	
Brachiocephalic arteriovenous fistula [n (%)]	10 (48)
Radiocephalic arteriovenous fistula [n (%)]	10 (48)
Radio/brachiocephalic arteriovenous fistula [n (%)]	1 (4)
Needle gauge	
2x14g [n (%)]	15 (71)
2x15g [n (%)]	6 (29)

Results: population

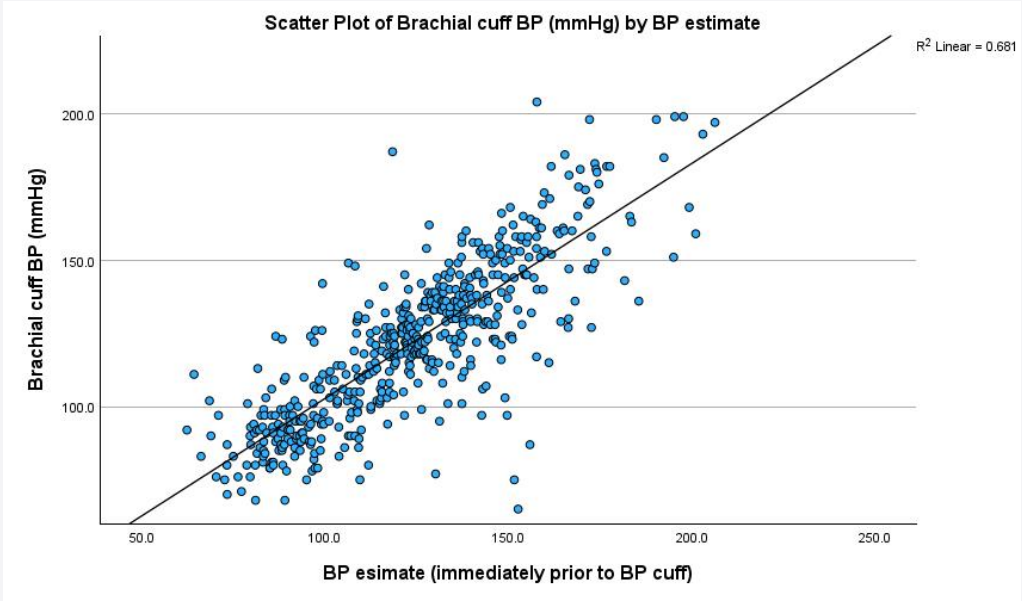
- 42 treatments, 525 data comparison points
- Good correlation between cuff BP and BP estimator (r=0.83, p<0.001)
- Mean absolute difference:

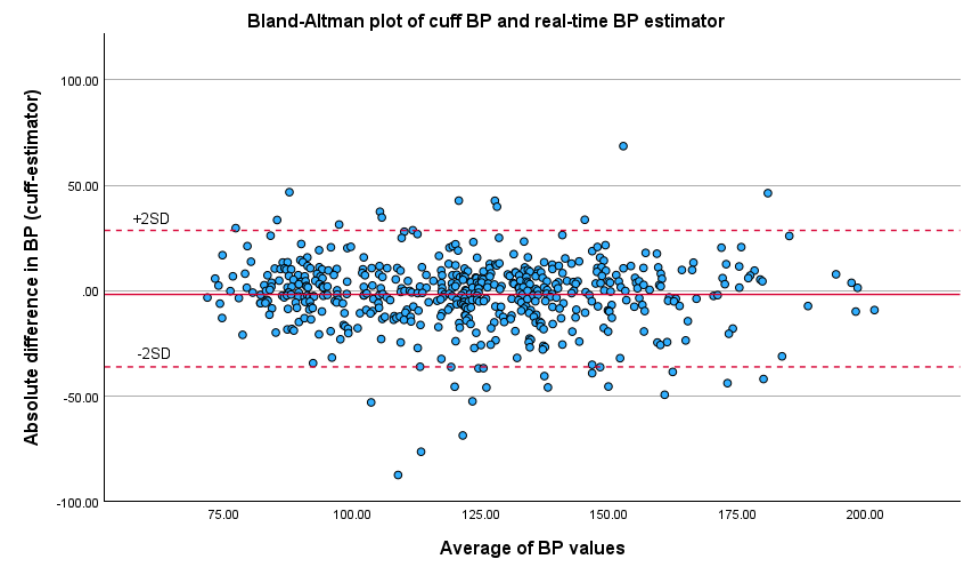
  11 ± 12mmHg (*negatives inversed*)

  (-1.9 ± 16mmHg negatives unchanged)

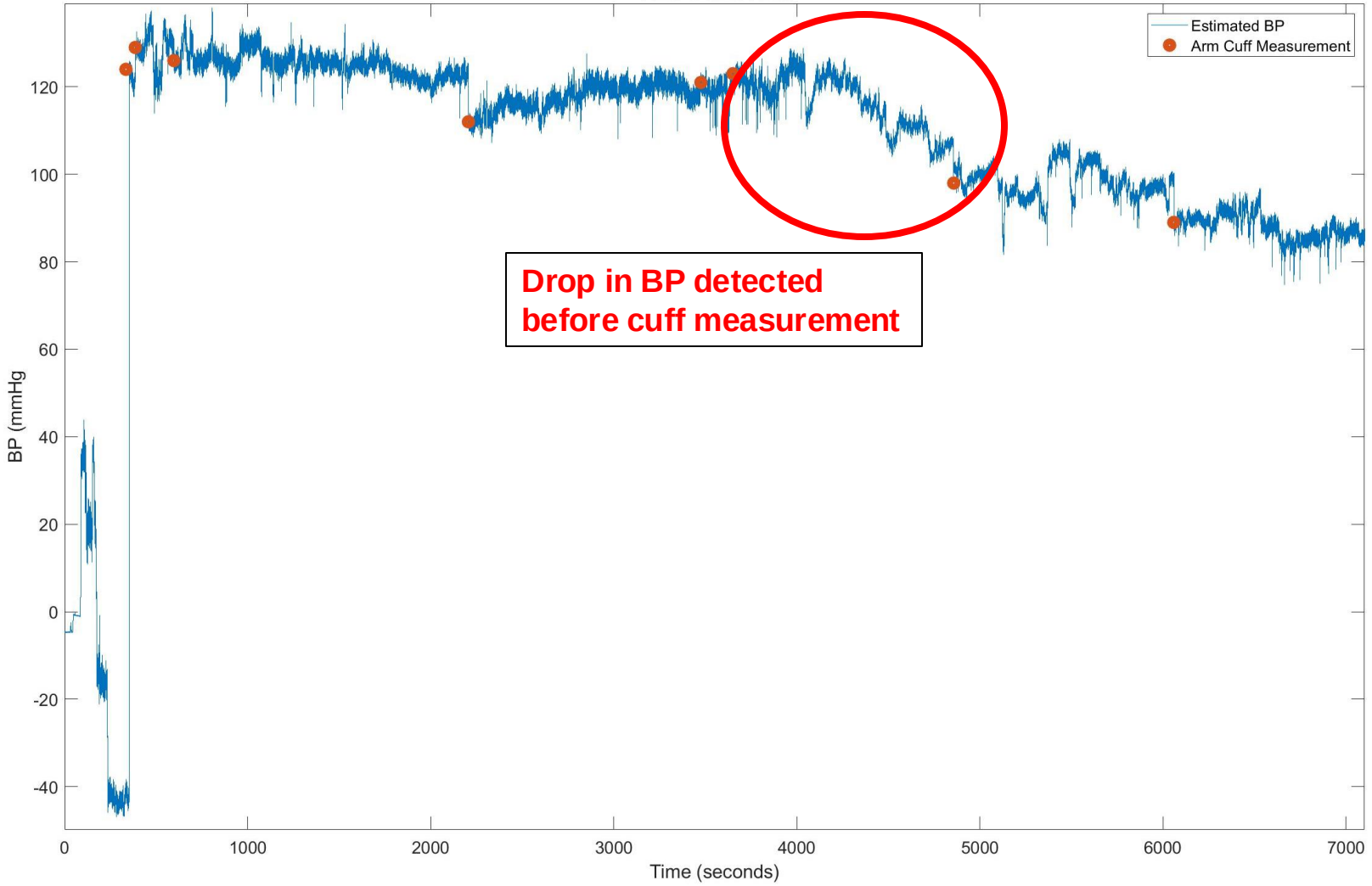
- P10*: 66.1%
- P30*: 95%

** % of estimator values within 10/30% of cuff value*

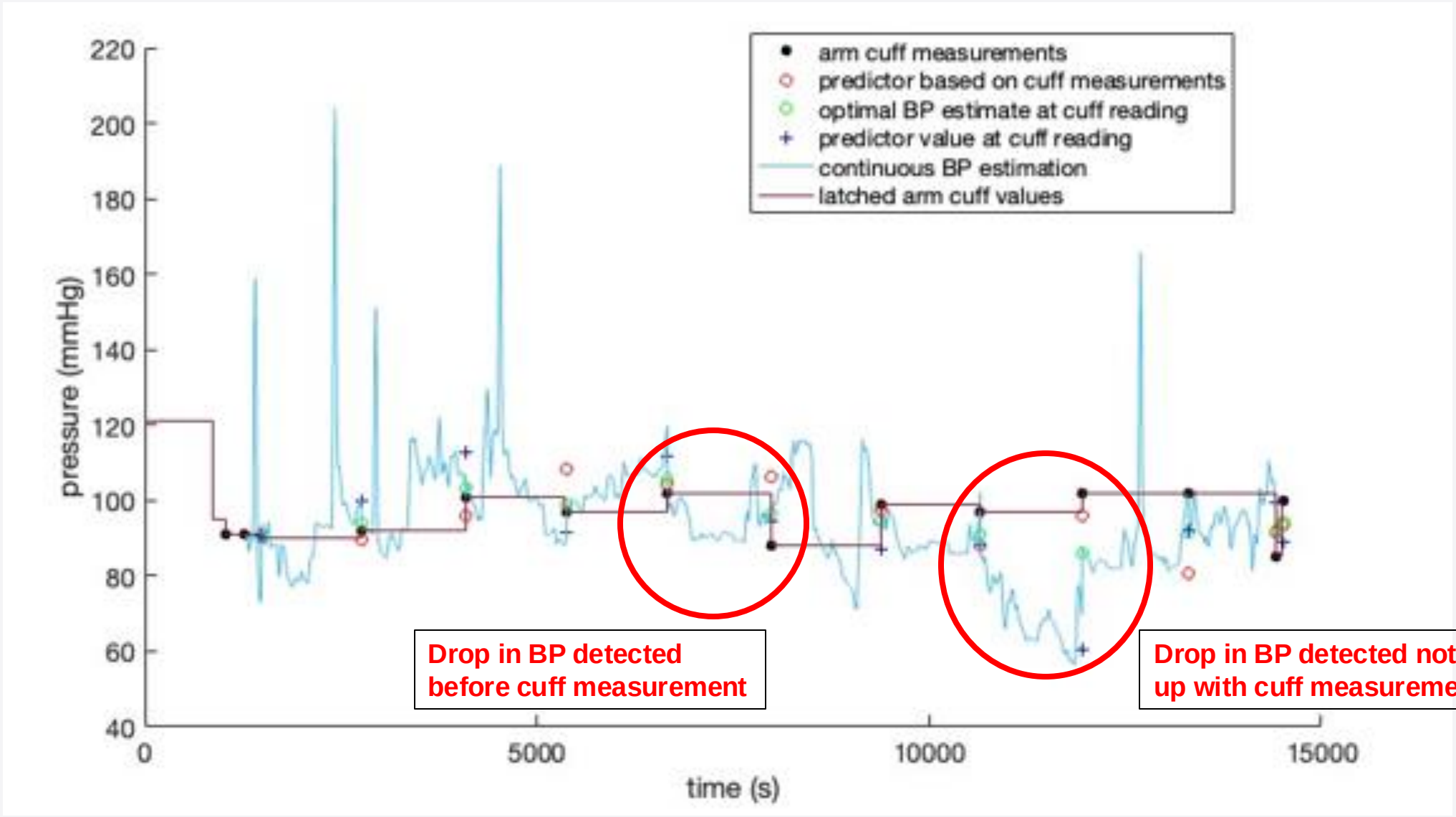




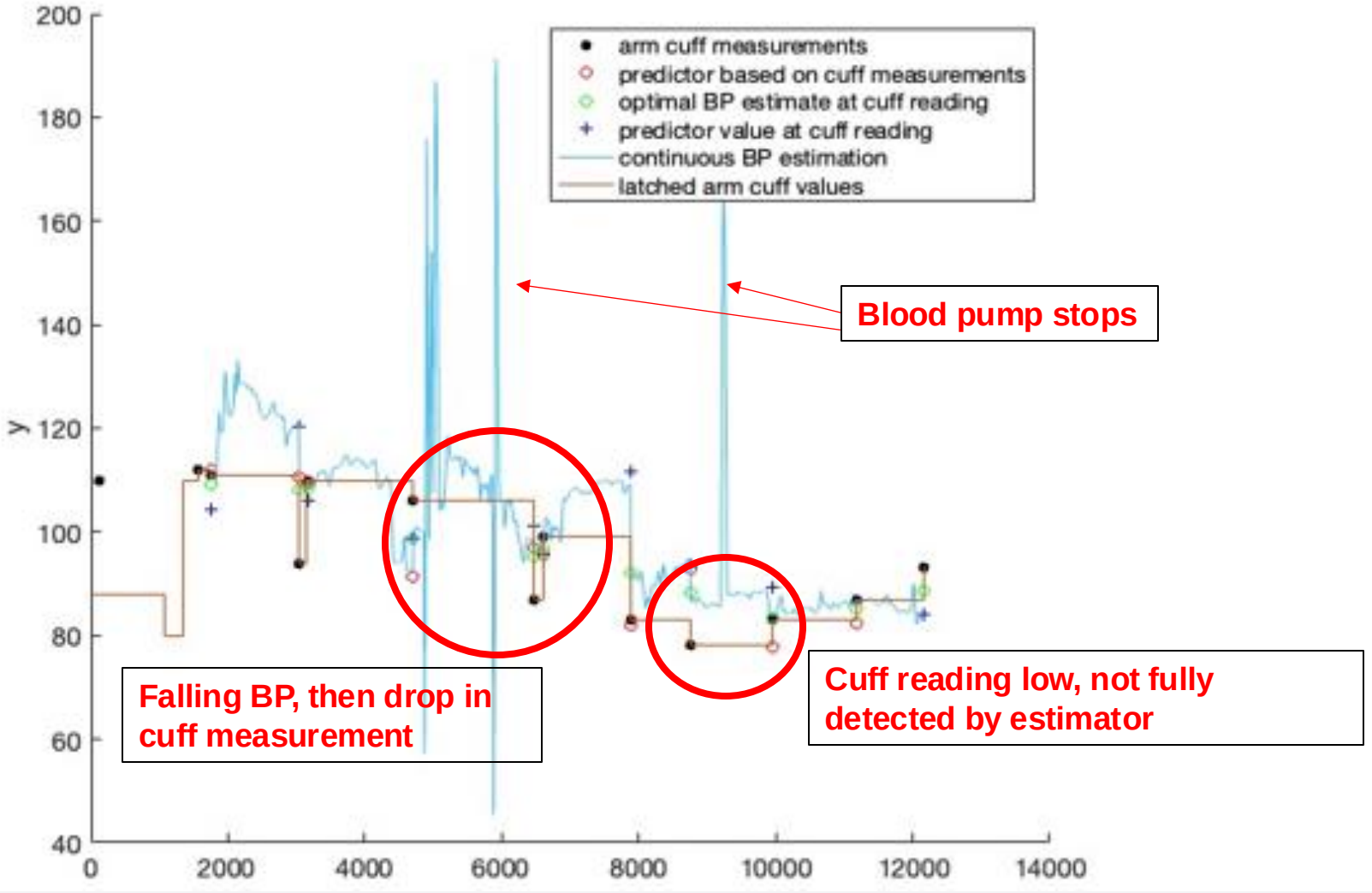
Individual treatment data: example 1



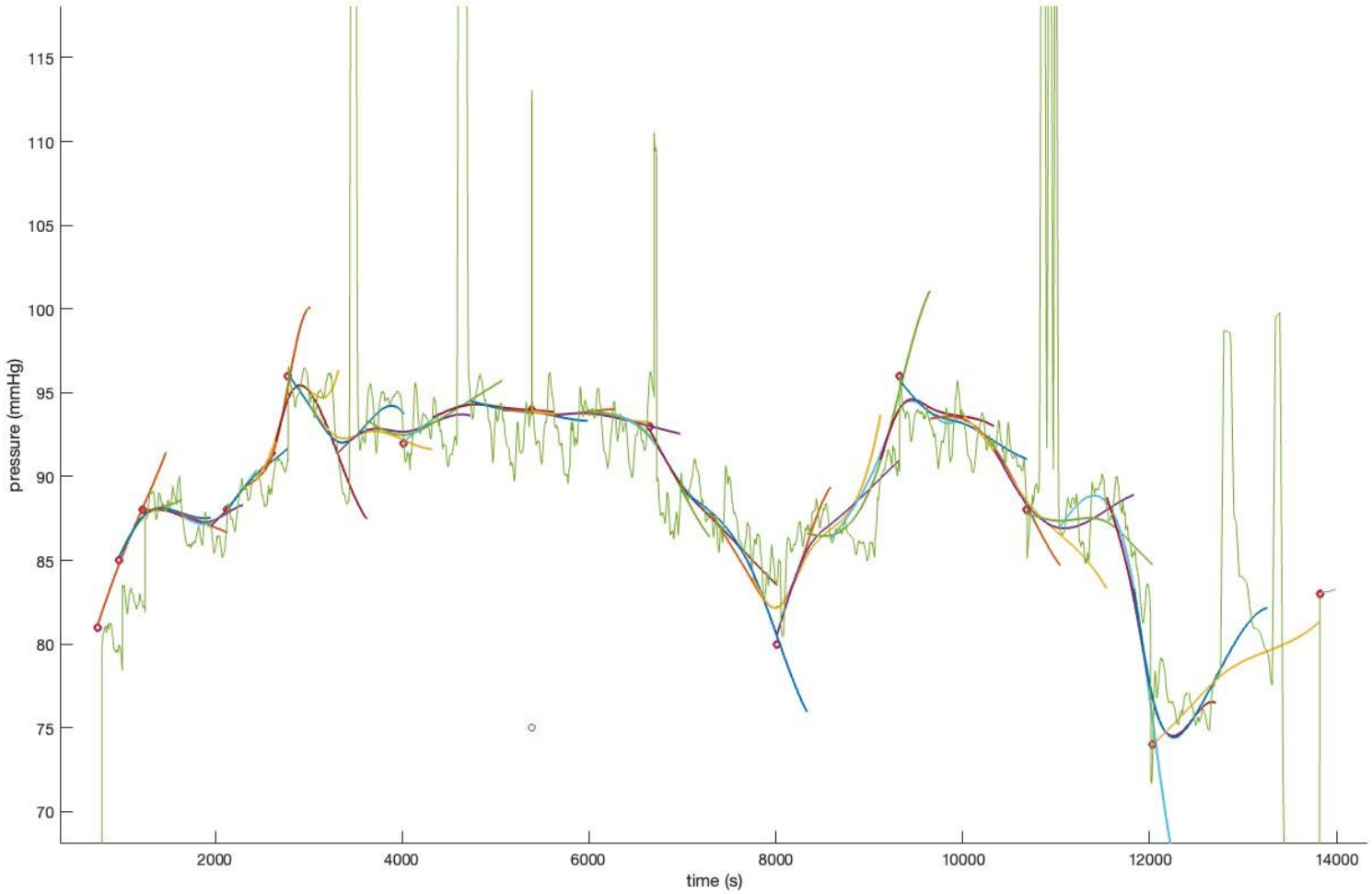
Individual treatment data: example 2



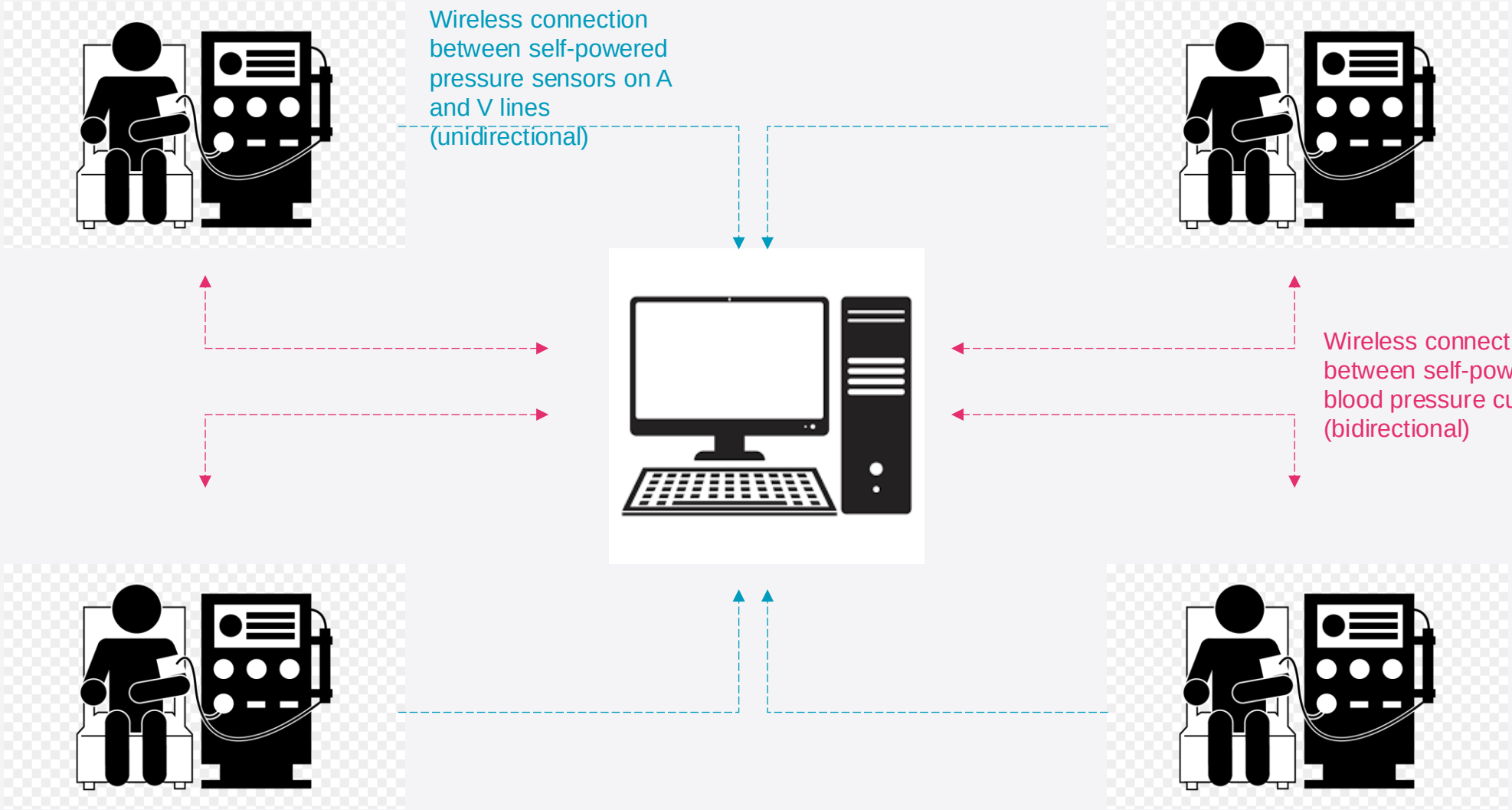
Individual treatment data: example 3



Developing a real-time predictor of IDH



Next steps: build wireless prototype



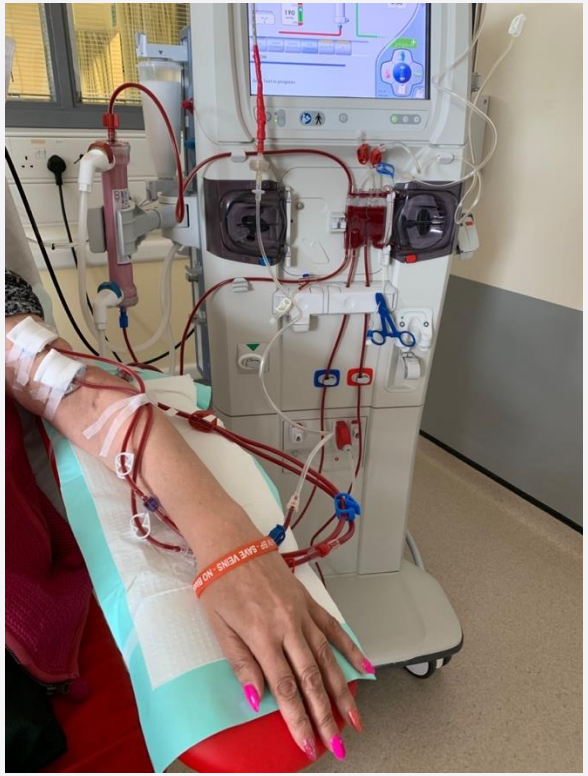
Conclusions

- Demonstrated that real-time continuous BP can be estimated using additional pressure sensors in the dialysis circuit, and without additional sensors on patient

- Case studies of benefit with earlier detection of IDH

- Foundation for individualised, real-time prediction of IDH

Next steps: *develop hardware*
validate prediction model
test targeted interventions for IDH



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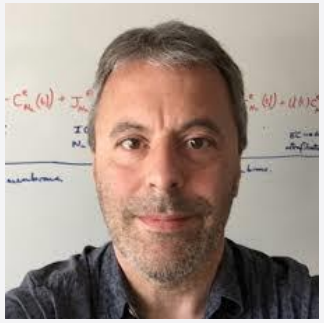
Acknowledgements: iTrend team



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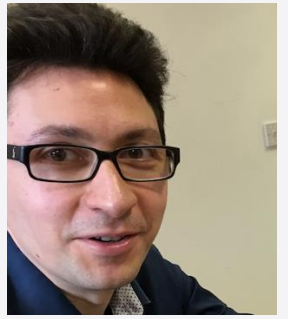

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