TMP and Filter Pressure Drop

Monitoring Circuit Pressure Trends

Presentation Overview

- Importance of therapy continuity for delivery of adequate CRRT dose
- Impact of circuit down-time on CRRT therapy continuity
- Clogging and clotting as primary causes of circuit changes
- Factors affecting CRRT circuit life
- Overview of CRRT circuit hemodynamics
- Transmembrane pressure (TMP) and filter pressure drop (ΔP filter)
- TMP and pressure drop trends as indicators of filter/circuit function
- TMP and filter pressure drop troubleshooting
- Key takeaways
- References

Therapy Continuity and Circuit Down-Time

Therapy Continuity Is Important

- One of the greatest challenges of CRRT is ensuring treatment continuity[1]
- Frequent treatment interruptions can lead to significant differences between prescribed and delivered doses of CRRT, resulting in decreased therapy dosing that may have an affect on morbidity and mortality[1-2]

Randomized Study of CRRT Dose and Survival[2]

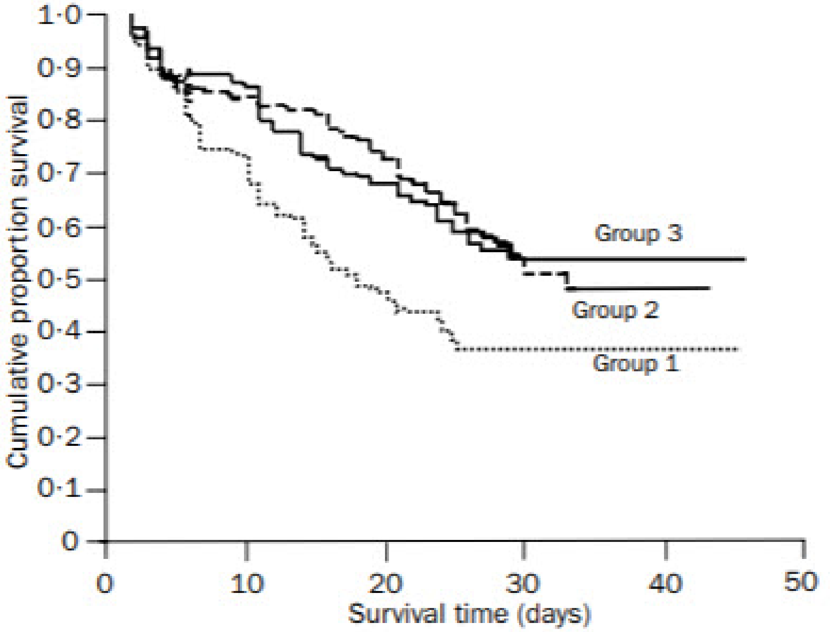


Figure 2: **Kaplan Meier estimation of survival rates in the three groups**

Group 1: 20 mL h^{-1} kg^{-1}
Group 2: 35 mL h^{-1} kg^{-1}
Group 3: 45 mL h^{-1} kg^{-1}

1. Dunn WJ & Sriram S. Crit Care Resusc. 2014 Sep;16(3):225-31.
2. Ronco C et al. Lancet. 2000 Jul 1;356(9223):26-30.

Down-Time Reduces Prescription Delivery

- Prospective study of down-time and its impact on uremic control
- 78% of down-time was due to filter clotting
- Median down-time was 3 hours, resulting in patients receiving approximately 78% of the prescribed dose
- Down-time was significantly correlated with increased plasma creatinine and urea concentrations (p < 0.0001)
- Down-time should be < 8 hours to maintain adequate treatment

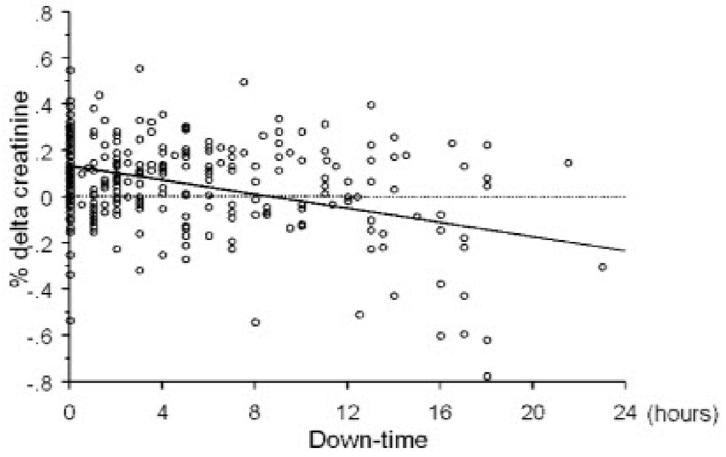


Fig. 1 Scattergram of down-time and Δ creatinine. Univariate analyses showed significant relationship between down-time and Δ creatinine ($p<0.0001$). %Δ creatinine=0.13–0.015 x down-time; R^2=0.153

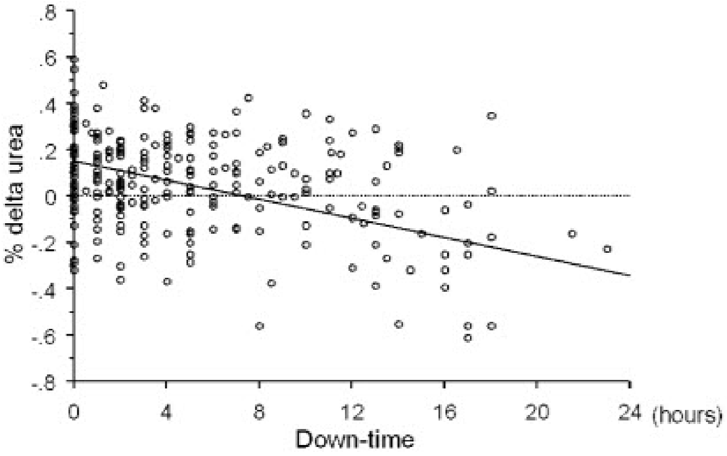


Fig. 2 Scattergram of down-time and Δ urea. Univariate analyses showed significant relationship between down-time and Δ urea ($p<0.0001$). %Δ urea=0.148–0.02 x down-time; R^2=0.219

Uchino S et al. Intensive Care Med. 2003 Apr;29(4):575–578.

Clogging, Clotting & Circuit Changes

- Most circuit changes are related to membrane clogging and clotting[1-6]
- Frequent filter changes contribute to:
  - Incomplete dose/ prescription delivery[1-6]
  - Decreased solute, fluid balance and acid-base control[2-3]
  - Increased blood loss[6]
  - Increased nursing workload[6]
  - Increased costs[6]

1. Ejaz AA et al. Nurs Crit Care. 2007 Mar-Apr;12(2):81-5.
2. Dunn WJ & Sriram S. Crit Care Resusc. 2014 Sep;16(3):225-31.
3. Fealy N et al. Crit Care Resusc. 2002 Dec;4(4):266-70.
4. Kim IB et al. Blood Purif. 2010;30(2):79-83.
5. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]
6. Zhang L et al. Blood Purif. 2016;41(4):254-63.

Factors Affecting Circuit Life[1-2]

Patient Factors	• Pathology (sepsis, inflammation, coagulopathy) • Hematocrit • Platelet function/count
Filter Characteristics	• Adsorptive vs. non-adsorptive • Surface area • Pore size and number
Catheter Properties & Placement	• Lumen diameter, length, material, coating • Location
Anticoagulation	• Anticoagulation vs. no anticoagulation • Heparin vs. regional anticoagulation
Filtration Fraction	• higher filtration fractions associated with more clogging
Vascular Access Quality	• Stasis, blood flow rate
Replacement Fluids	• Pre-dilution vs. post-dilution

1. Joannidis M & Oudemans-van Straaten HM. Crit Care. 2007;11(4):218.
2. Brain M et al. BMC Nephrol. 2017 Feb 20;18(1):69.

CRRT Circuit Hemodynamics

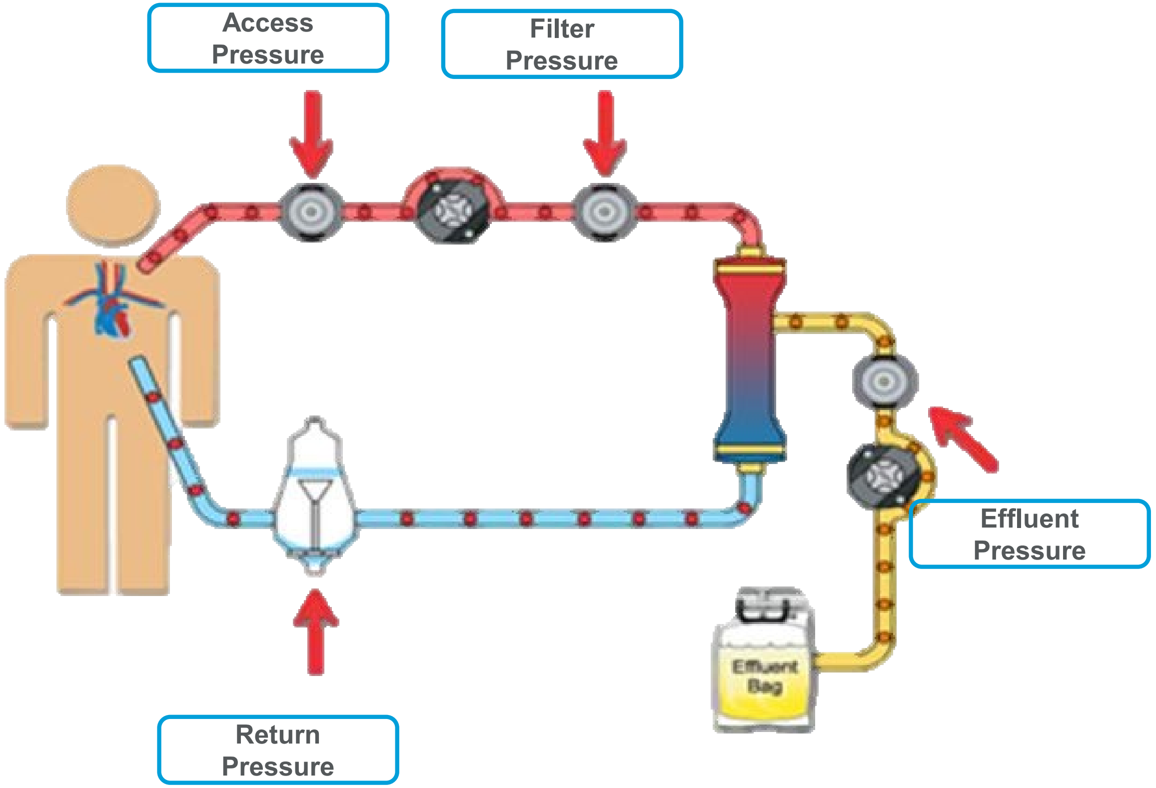
CRRT Circuit Hemodynamics

- Understanding circuit hemodynamics will enable you to[1]
  - Respond to alarms generated by CRRT devices during therapy
  - Recognize common issues like catheter dysfunction and filter clogging or clotting
- Slow or ineffective troubleshooting may result in the need for frequent circuit changes[1-2]
- Frequent circuit changes decrease therapy efficacy and increase nursing workload and CRRT costs[1-2]

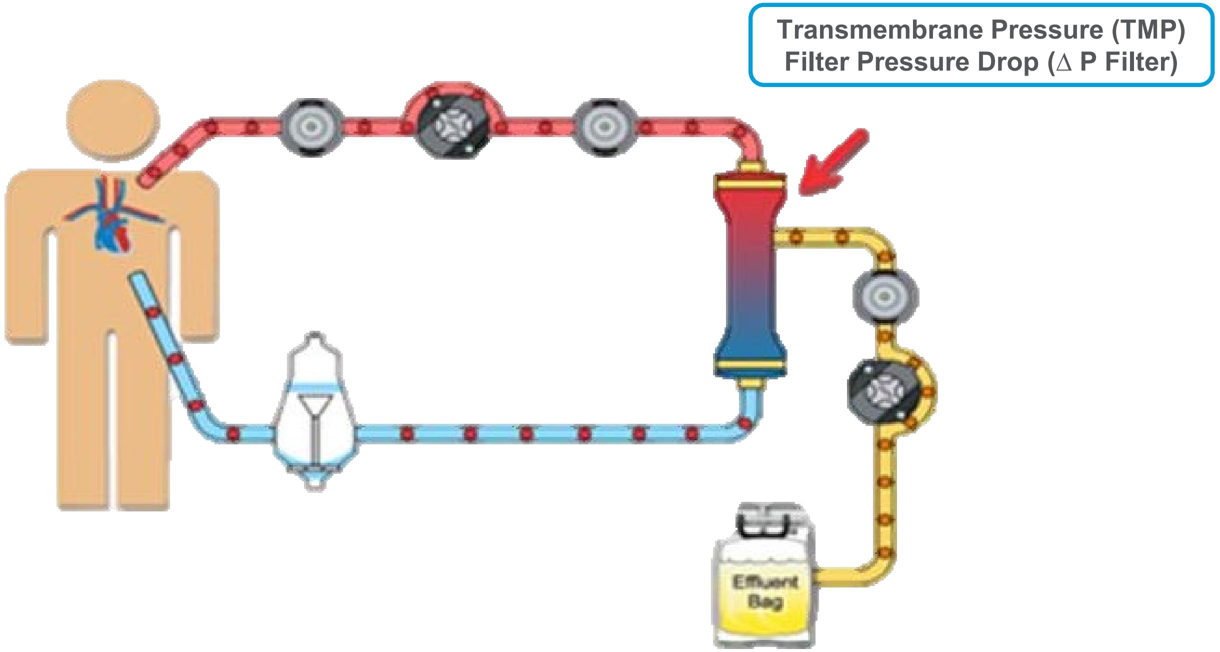
1. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]
2. Dunn WJ & Sriram S. Crit Care Resusc. 2014 Sep;16(3):225-31.

Overview: CRRT Circuit Hemodynamics

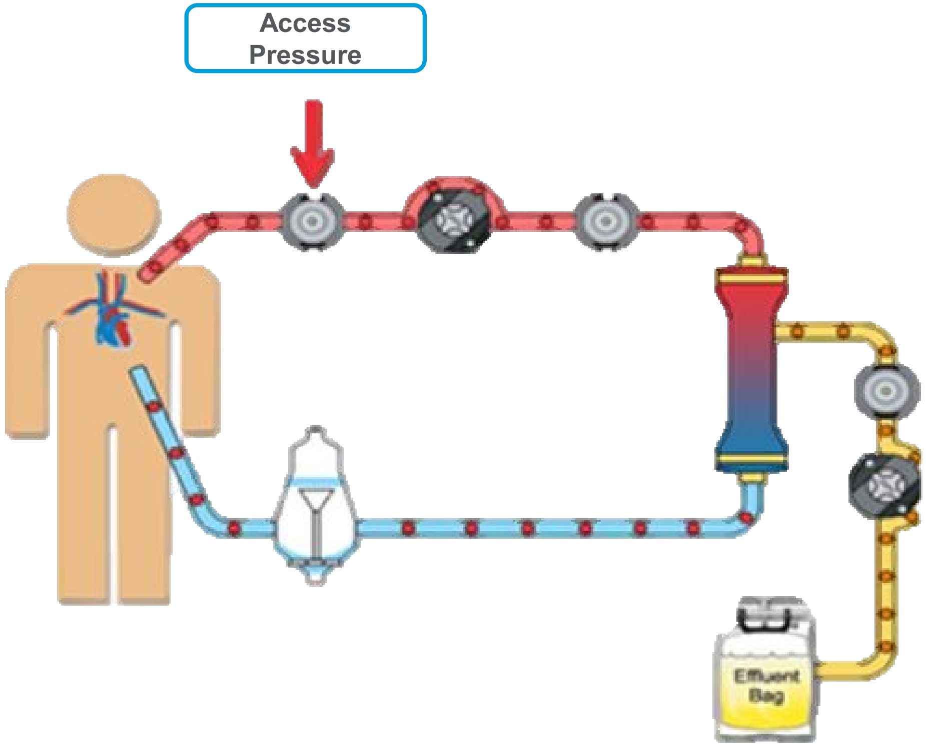
Measured Pressures



Software-Calculated Pressures



Access Pressure



Access Pressure

Pressure created by pulling blood from patient

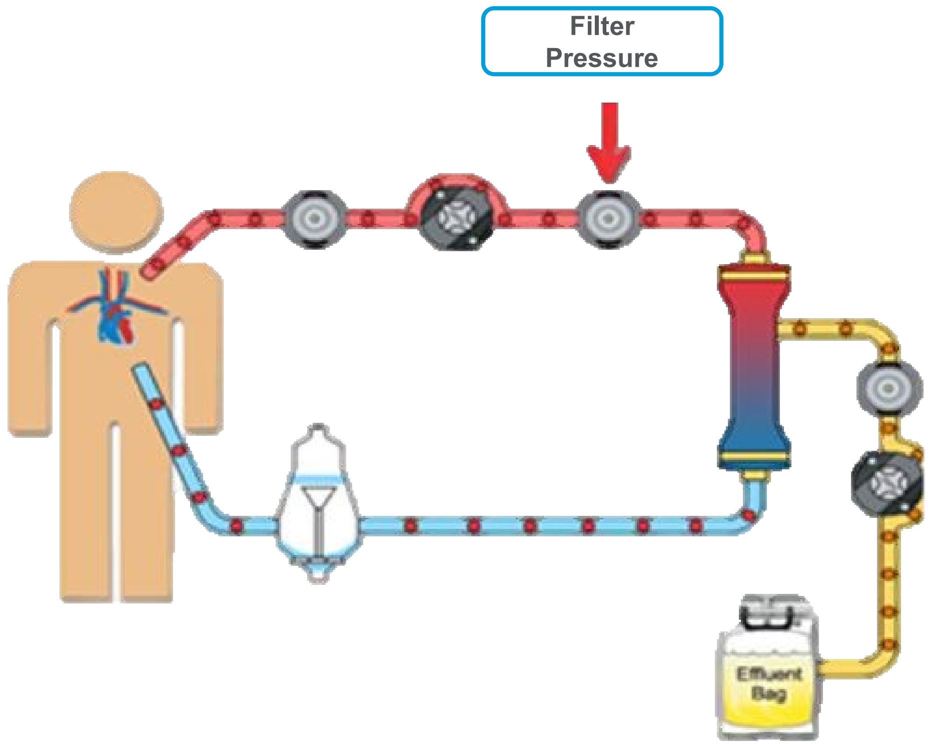
Can be negative or positive, depending on the blood source to which the access line is connected[1]

Main determinants:[2]

- Blood flow rate
- Catheter diameter, length, design
- Catheter tip position
- Catheter patency
- Patient hemodynamics
- Patient position and movements

1. Prismaflex Operator's Manual.
2. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]

Filter Pressure



Filter Pressure

Pressure to push blood through filter

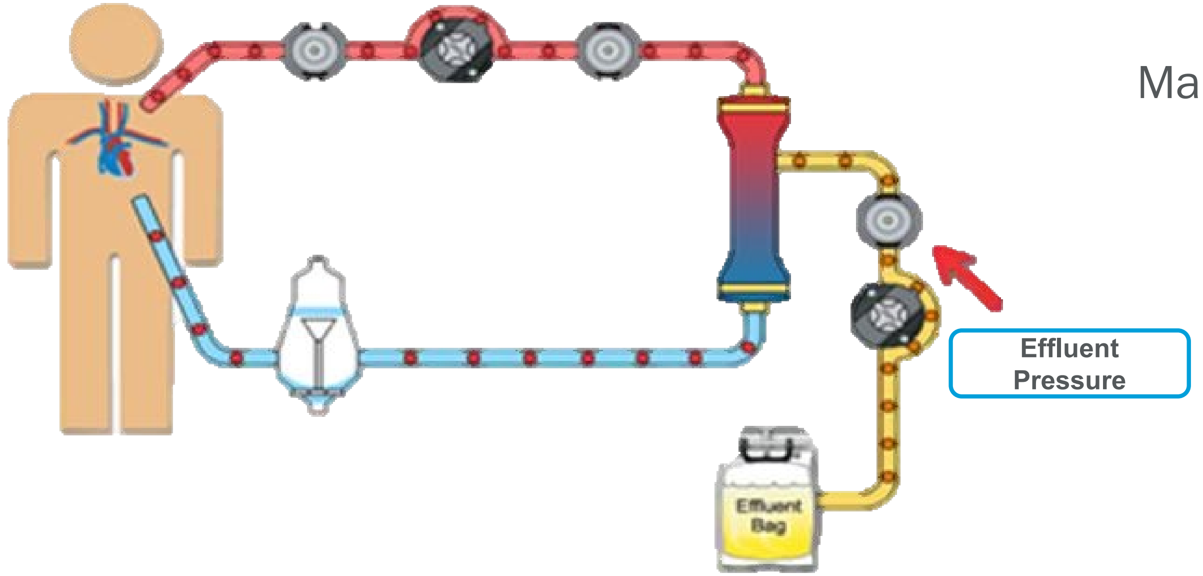
Always positive and higher than return pressure[1]

Main determinants:[2]

- Blood flow rate
- Number of patent filter capillaries
- Filter size
- Hematocrit
- Blood viscosity
- Outflow pressure (transmitted)

1. Prismaflex Operator's Manual.
2. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]

Effluent Pressure



Effluent Pressure

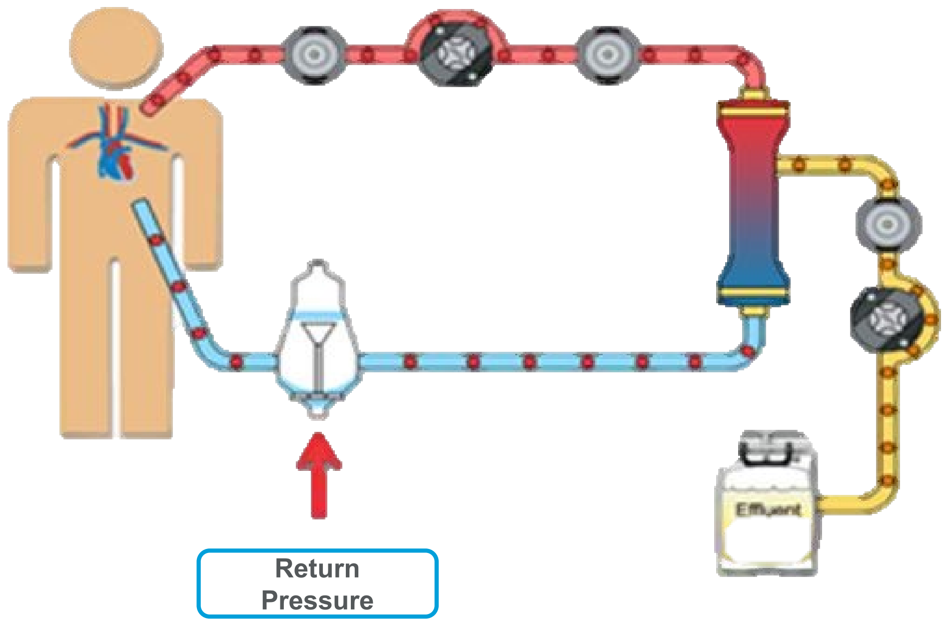
Can be either positive or negative, depending on whether fluid is being pushed or pulled from the blood compartment to the fluid compartment[1]

Main determinants:[2]

- Set ultrafiltration rate
- Membrane pore permeability

1. Prismaflex Operator's Manual.
2. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]

Return Pressure



Return Pressure

Pressure created by returning blood to patient

Always positive[1]

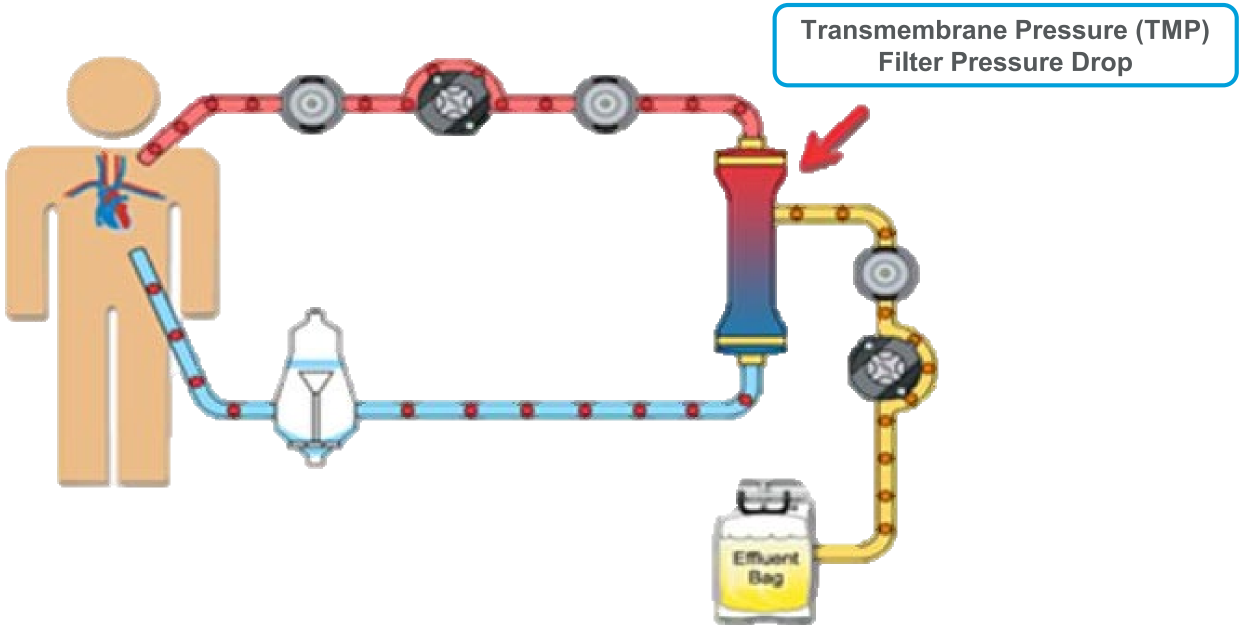
Reflects resistance/pressure needed to overcome in order to return blood to patient[2]

Main determinants:[2]

- Blood flow rate
- Catheter section, length, design
- Catheter tip position
- Catheter patency
- Patient hemodynamics
- Clotting in deaeration chamber
- Patient position and movements

1. Prismaflex Operator's Manual.
2. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]

Software-Calculated Pressures



Transmembrane Pressure (TMP)

Pressure gradient across the filter membrane – difference in pressure between between blood and dialysis compartments[1]

Main determinants:[1]

- Membrane pore permeability
- Hydrostatic/oncotic pressure gradients across filter
- Rate of replacement solutions
- Blood flow rate

Filter Pressure Drop (ΔP Filter)

Difference between Return and Filter pressures

Main determinants:[1]

- Number of patent capillaries in the filter
- Patient blood viscosity

1. Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]

Transmembrane Pressure and Pressure Drop

Transmembrane Pressure (TMP)

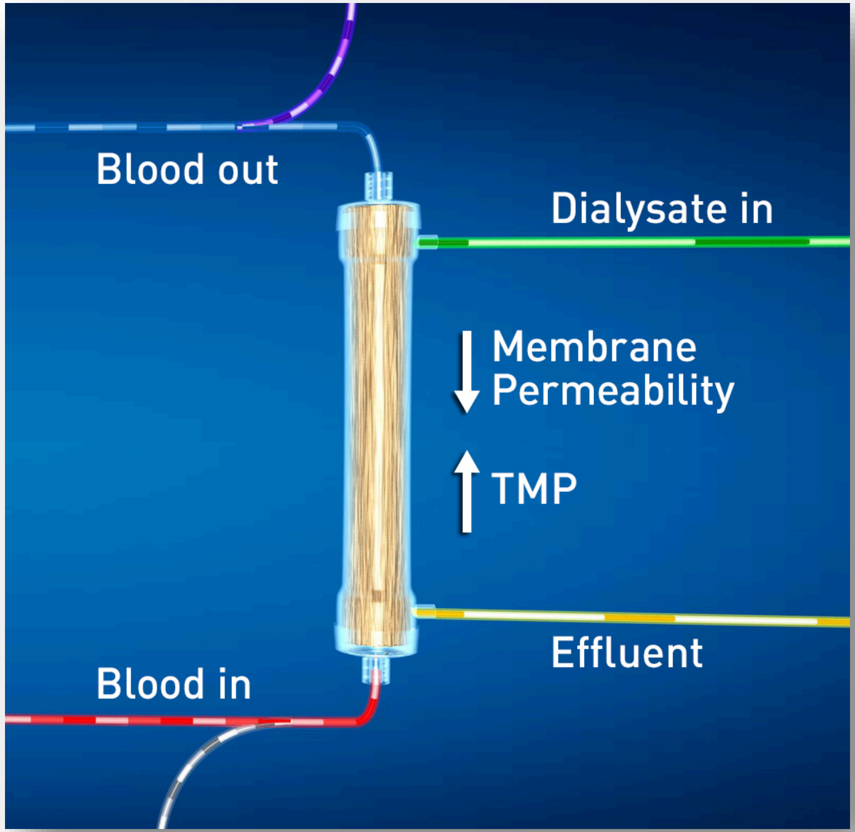
$$TMP = \frac{\text{Filter Pressure} + \text{Return Pressure}}{2} - \text{Effluent Pressure}$$

Transmembrane Pressure (TMP) is the pressure exerted on the filter membrane during CRRT[1]

- Reflects the pressure difference between the blood and fluid compartments of the filter

During treatment, permeability of the membrane decreases due to protein coating (clogging), causing TMP to increase

- TMP above +300 mmHg will produce the "Advisory: TMP Too High" alarm
- If the TMP increases beyond the membrane capacity that is product dependent, the "Caution: TMP Excessive alarm" occurs



1. Prismaflex Operator's Manual.

Filter Pressure Drop (ΔP Filter)

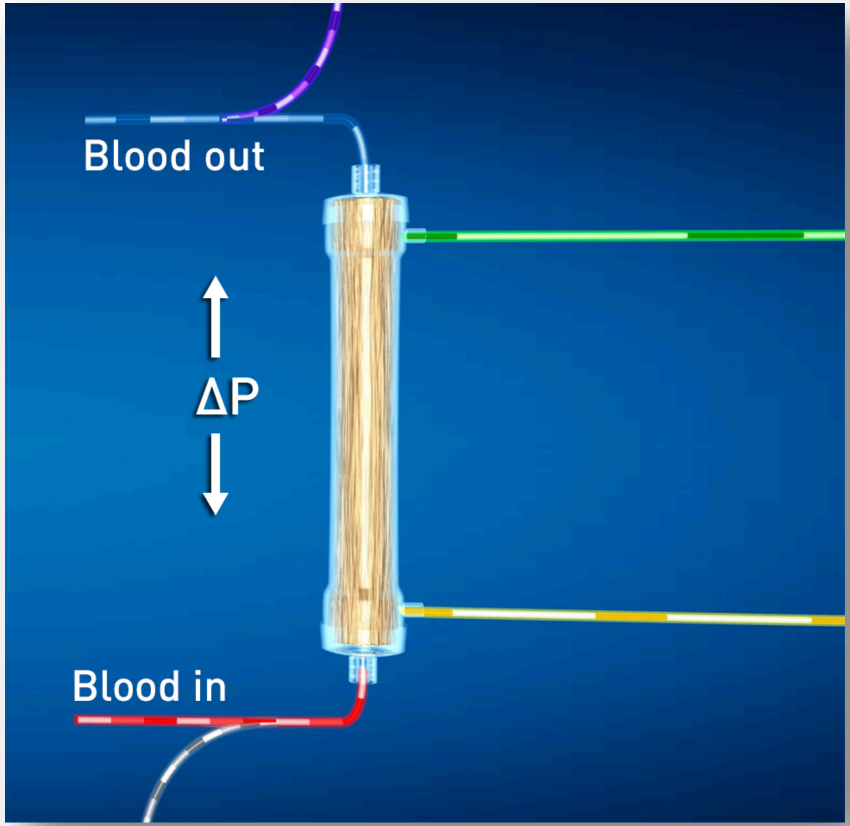
Filter Pressure Drop (ΔP Filter) = Filter Pressure — Return Pressure

ΔP Filter reflects pressure conditions in the hollow fibers

ΔP Filter is directly proportional to resistance at a given blood flow rate

Microclotting occurs in the hollow fibers during treatment, eventually leading to gross clotting and the need to change to a new set

- Clotting creates resistance to blood flow through the filter fibers and causes ΔP Filter to rise
- The amount of increase above the initial ΔP Filter contributes to the "Advisory: Filter is Clotting" alarm



1. Prismaflex Operator's Manual.

Monitoring TMP and Pressure Drop Trends

TMP & ΔP Filter: Indicators of Circuit Function

<u>TMP</u>

- A gradual rise in TMP indicates that the filter is starting to **CLOG**
  - TMP increases as filter pores clog
- <u>ΔP Filter</u>
- A gradual rise in ΔP Filter indicates that the filter is starting to **CLOT**
- ΔP Filter increases as clotting creates resistance through the hollow filter fibers

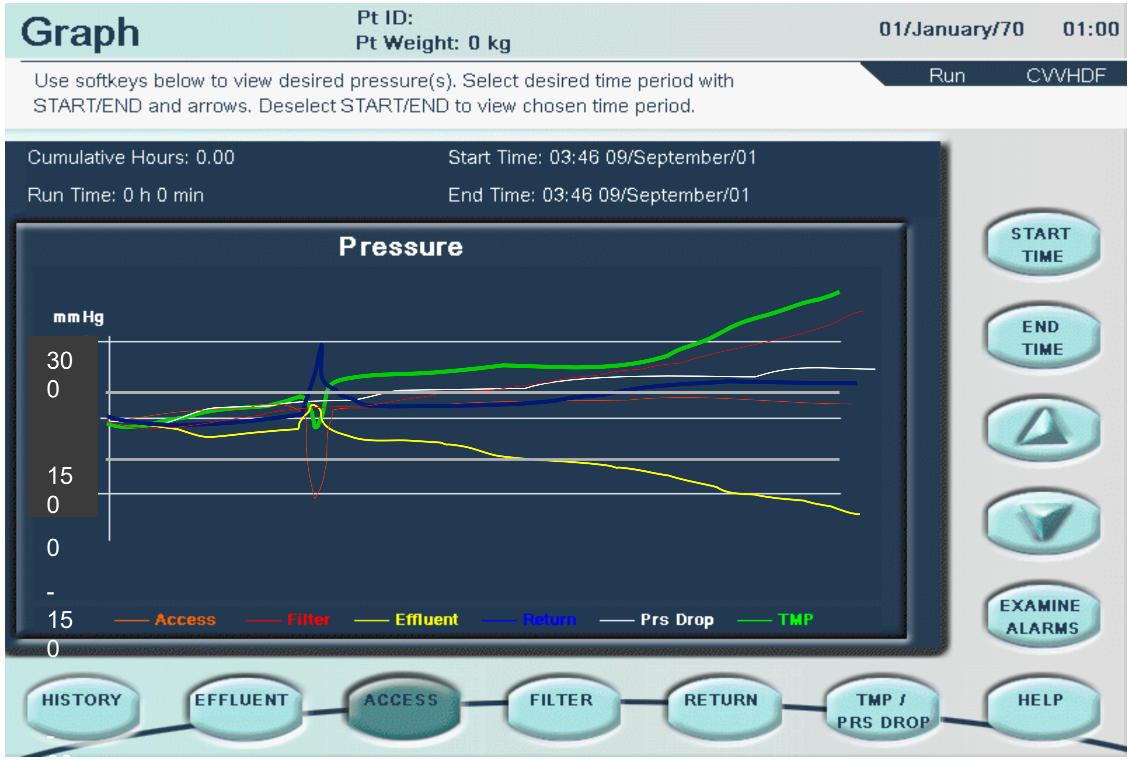
<u>ΔP Filter</u>

- A gradual rise in ΔP Filter indicates that the filter is starting to **CLOT**
  - ΔP Filter increases as clotting creates resistance through the hollow filter fibers

1. Prismaflex Operator's Manual.

What Do TMP and ΔP Filter Trends Tell You?

- Straight lines = therapy is running and filter is efficient
- Gradual increase in TMP (green line) = filter is most likely CLOGGING
- Gradual increase in ΔP Filter (white line) = filter is most likely CLOTTING
- The faster the increase, the faster the filter is degrading
- Abrupt peaks and troughs indicate therapy or blood pump has stopped
  - Access or return issues, changing a bag, etc.



Remember…

The operating points for TMP and Pressure Drop are recalculated during treatment

Software sets the initial TMP value when initial pressure operating points are established

- TMP value is subsequently reset each time the blood flow, patient fluid removal or replacement solution rates are changed, as well after self-test

Software sets the initial ΔP Filter value when the initial pressure operating points are established

- ΔP Filter value is subsequently reset each time the blood flow rate is changed

Troubleshooting: TMP and ΔP Filter

TMP and ΔP Filter Troubleshooting

	Potential Cause†	Potential Intervention†
High TMP	Membrane clogging	• Plan circuit replacement • Increase blood flow rate • Decrease replacement rate
	Filter clotting	• Plan circuit replacement • Increase blood flow rate • Increase pre-filter replacement rate
	Catheter malfunction	• Check access
High Filter Pressure Drop	Filter clotting	• Plan circuit replacement • Increase blood flow rate • Increase pre-filter replacement rate
	Insufficient anticoagulation	• Optimize anticoagulation

Ejaz AA et al. Nurs Crit Care. 2007 Mar-Apr;12(2):81-5.
Michel T et al. Curr Opin Crit Care. 2018 [Epub ahead of print]

† *Adapted from Ejaz et al. (2007) and Michel et al. (2018)*

Key Takeaways

Key Takeaways

- Circuit pressure trends may be used to monitor circuit function and guide interventions to prolong circuit patency and preserve treatment continuity
- Variations in CRRT modalities and prescriptions make establishing absolute pressure guidelines difficult
- Pressure trends and patterns are more clinically relevant than absolute numbers
- TMP and pressure drop provide important information regarding filter clogging and clotting
- Membrane clogging due to protein and red cell deposition is associated with a slow and continuous rise in TMP
- Circuit clotting also leads to a rise in TMP (due to loss of surface membrane of clotting fibers); this may be progressive, but can often be sudden
- A slow and continuous rise of filter pressure drop is an indicator of filter clotting (fiber occlusion)
- It is important to keep in mind that the operating points for TMP and pressure drop are recalculated during therapy

References

References

Brain M, Winson E, Roodenburg O, McNeil J. Non anti-coagulant factors associated with filter life in continuous renal replacement therapy (CRRT): a systematic review and meta-analysis. BMC Nephrol. 2017 Feb 20;18(1):69.

Dunn WJ, Sriram S. Filter lifespan in critically ill adults receiving continuous renal replacement therapy: the effect of patient and treatment-related variables. Crit Care Resusc. 2014 Sep;16(3):225-31.

Ejaz AA, Komorski RM, Ellis GH, Munjal S. Extracorporeal circuit pressure profiles during continuous venovenous haemofiltration. Nurs Crit Care. 2007 Mar-Apr;12(2):81-5.

Gambro. Prismaflex Operator’s Manual (for use with software versions 7.xx). Order Number G5039110. 2005-2014.

Holt AW, Bierer P, Bersten AD, Bury LK, Vedig AE. Continuous renal replacement therapy in critically ill patients: monitoring circuit function. Anaesth Intensive Care. 1996 Aug;24(4):423-9.

Joannidis M, Oudemans-van Straaten HM. Clinical review: Patency of the circuit in continuous renal replacement therapy. Crit Care. 2007;11(4):218.

Kakajiwala A, Jemielita T, Hughes JZ, Windt K, Denburg M, Goldstein SL, Laskin B. Membrane pressures predict clotting of pediatric continuous renal replacement therapy circuits. Pediatr Nephrol. 2017 Jul;32(7):1251-1261.

Kim IB, Fealy N, Baldwin I, Bellomo R. Premature circuit clotting due to likely mechanical failure during continuous renal replacement therapy. Blood Purif. 2010;30(2):79-83.

Michel T, Ksouri H, Schneider AG. Continuous renal replacement therapy: understanding circuit hemodynamics to improve therapy adequacy. Curr Opin Crit Care. 2018 Sep 20. doi: 10.1097/MCC.0000000000000545. [Epub ahead of print]

Ronco C, Bellomo R, Homel P, Brendolan A, Dan M, Piccinni P, La Greca G. Effects of different doses in continuous veno-venous haemofiltration on outcomes of acute renal failure: a prospective randomised trial. Lancet. 2000 Jul 1;356(9223):26-30.

Uchino S, Fealy N, Baldwin I, Morimatsu H, Bellomo R. Continuous is not continuous: the incidence and impact of circuit "down-time" on uraemic control during continuous veno-venous haemofiltration. Intensive Care Med. 2003 Apr;29(4):575–578.

Zhang L, Baldwin I, Zhu G, Tanaka A, Bellomo R. Automated electronic monitoring of circuit pressures during continuous renal replacement therapy: a technical report. Crit Care Resusc. 2015 Mar;17(1):51-4.

Zhang L, Tanaka A, Zhu G, Baldwin I, Eastwood GM, Bellomo R. Patterns and Mechanisms of Artificial Kidney Failure during Continuous Renal Replacement Therapy. Blood Purif. 2016;41(4):254-63.

Baxter

Thank you

The PRISMAFLEX Control Unit is intended for:
- Continuous Renal Replacement Therapy (CRRT) for patients weighing 20 kilograms or more with acute renal failure and/or fluid overload.
- Therapeutic Plasma Exchange (TPE) therapy for patients weighing 20 kilograms or more with diseases where removal of plasma components is indicated.

USMP/MG120/19-0012 05/19

Backup Slides:
Studies of CRRT Pressure Trends

Study: Monitoring Circuit Function

- Study to identify causes of circuit cessation and determine predictive monitors of circuit function
  - 5 consecutive CVVHD patients, 41 consecutive filters
- Filter clotting accounted for 63% of circuit cessation
- Filter clotting was associated with a rise in TMP and decreased circuit function (decrease in molecular clearance)
- An increase in TMP of ≥ 26 mmHg predicted imminent circuit failure due to clogging

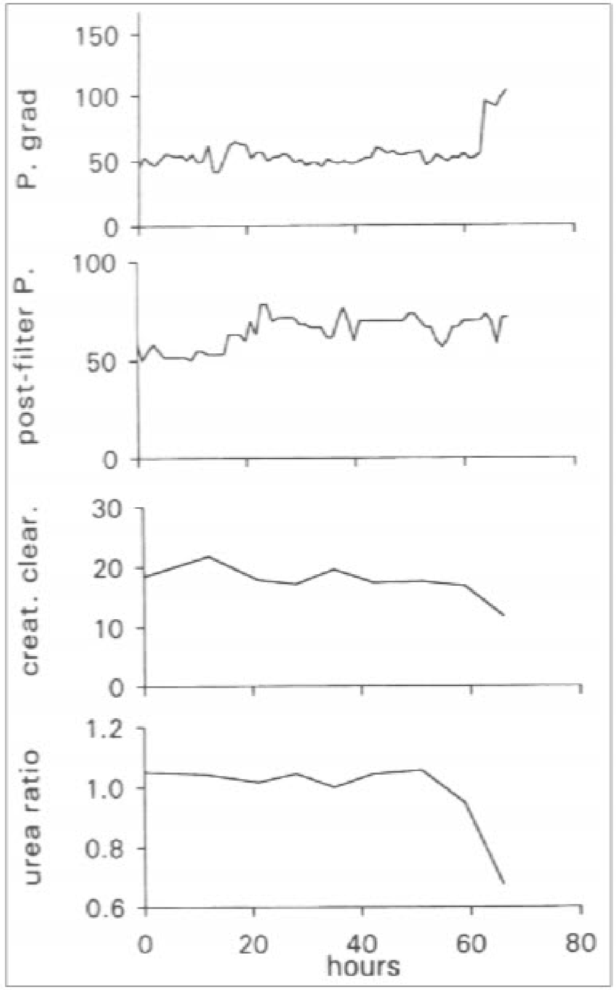
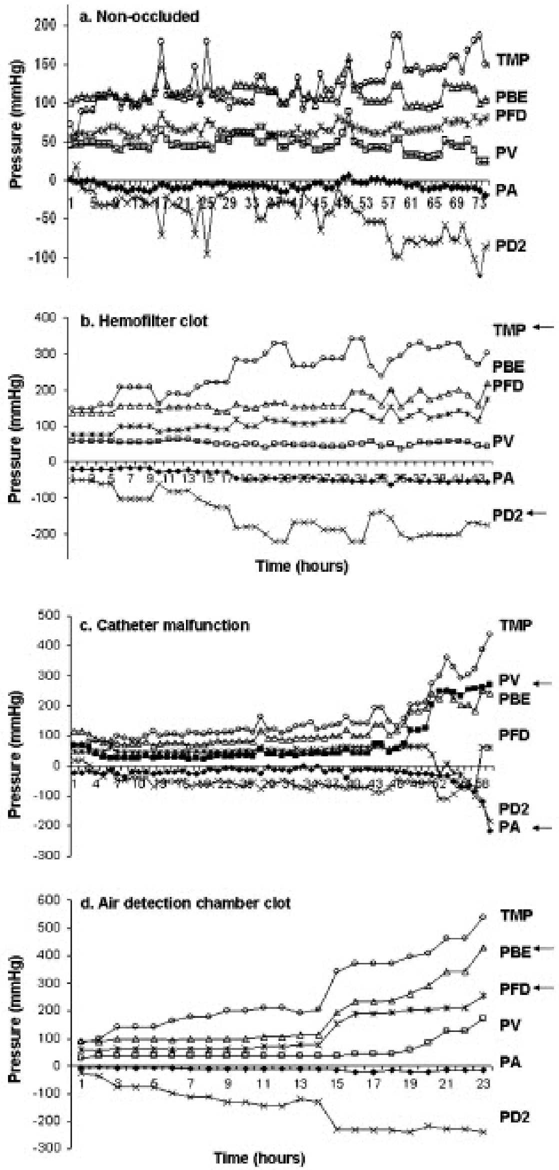


FIGURE 2: Circuit cessation in patient due to haemofilter clotting is demonstrated: rapid terminal rise in the pressure gradient across the haemofilter (P-Grad) without change in post-filter pressure and the accompanying fall in creatinine clearance (creat. clear.) and urea ratio.

Holt AW et al. Anaesth Intensive Care. 1996 Aug;24(4):423-9.

Study: Pressure Profiles During CVVH

- Retrospective review of 91 CVVH cases
- Causes of circuit disruption
  - Filter clotting 46%
  - Catheter degradation/ malfunction 36%
  - Routine 72-hour filter change 33%
  - Deaeration chamber clotting 4%
- Distinct pressure patterns in patent and disrupted circuits
  - Pressures in patent circuits remained flat or close to initial values
  - Pressures in non-patent circuits varied depending on the cause of disruption
- Circuit changes due to filter clogging were distinguished by deviation of transmembrane and effluent pressures from baseline

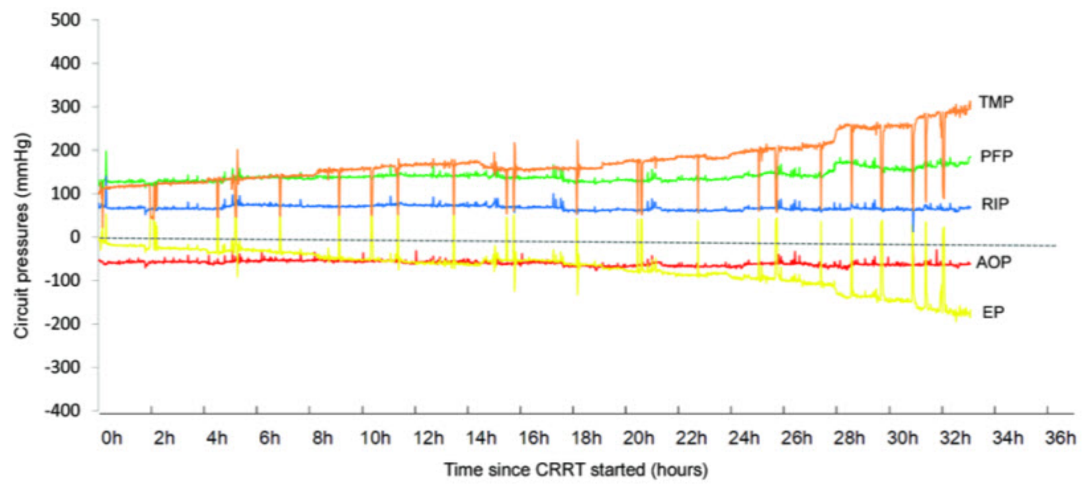


Ejaz AA et al. Nurs Crit Care. 2007 Mar-Apr;12(2):81-5.

Study: Circuit Pressures during CRRT

- Continuous recording of circuit pressures in single CRRT treatment
- The filter clotted at 33 hours with a high TMP (313 mmHg)
- TMP and filter pressure (PFP) progressively increased (TMP, 104–313 mmHg; PFP, 131–185 mmHg)
- Reduction in effluent pressure (EP) (absolute Δ = −168 mmHg) reflects the increasing negative pressure due to constant ultrafiltrate demand across a clogging membrane

Figure 3. Dynamic changes of circuit pressures during continuous renal replacement therapy (CRRT)



TMP = transmembrane pressure. PFP = prefilter pressure. RIP = return inflow pressure. AOP = access outflow pressure. EP = effluent pressure. The process of clotting becomes more obvious after about 20 hours, when the increase in TMP shows a steeper gradient.

Zhang L et al. Crit Care Resusc. 2015 Mar;17(1):51-4.

Study: TMP and ΔP Predict Clotting

- Retrospective analysis of 26 children treated with 79 CRRT circuits
- 64.6% circuits underwent unplanned filter change
- Each 1-mmHg increase in TMP or filter pressure was independently associated with 1.5% and 1.5% higher risk of clotting, respectively ($p < 0.001$)

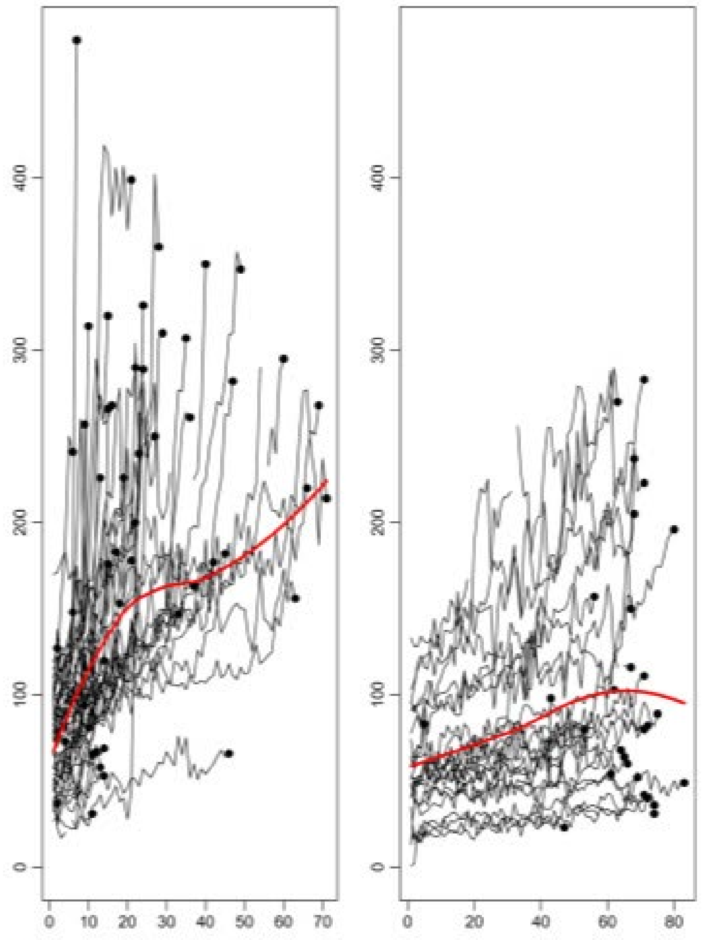


Fig. 2.
Changes in hourly transmembrane pressures (*TMP*) (*y-axis*) over time (*x-axis*, in hours) in circuits that clotted prematurely (*left panel*) as compared to circuits that lasted 3 days (*right panel*). *Black dots* indicate when a circuit clotted. *Red line* is a lowess line indicating overall trend. In circuits clotting prematurely, the transmembrane pressures increased steadily over time. In circuits lasting 3 days, the transmembrane pressures appeared to be more constant, with hourly values mostly <200 mmHg

Kakajiwala A et al. Pediatr Nephrol. 2017 Jul;32(7):1251-1261.