# Peritoneal dialysis: Current limitations and future prospects

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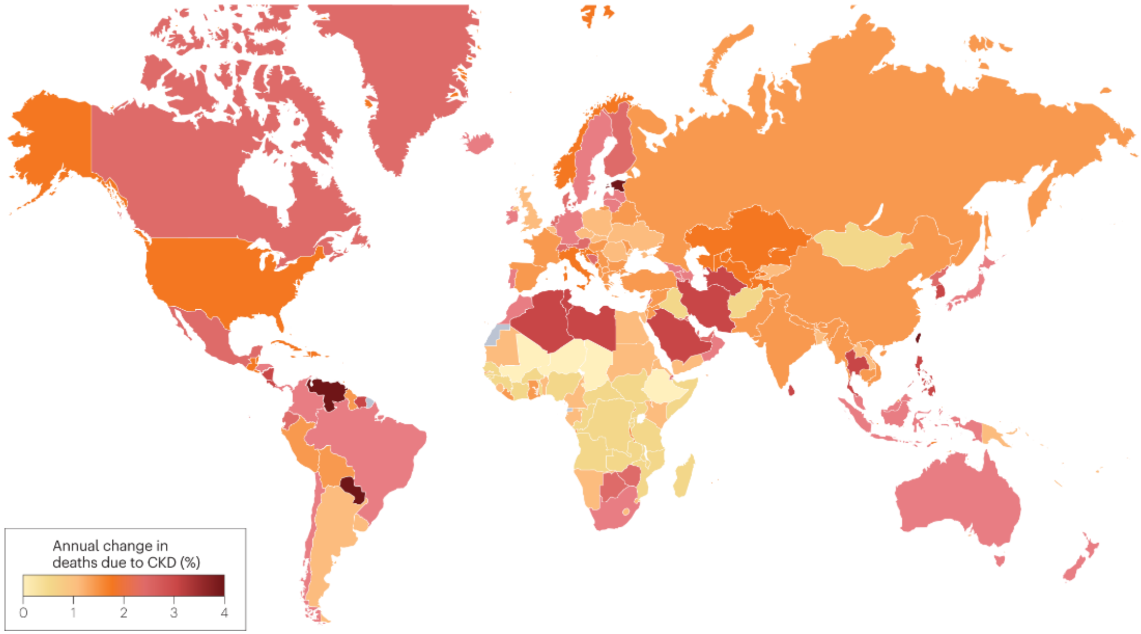
*COI*
*Consulting fees from Baxter, StadaPharma, Chiesi and Bioporto*

*Traveling support from Chiesi.*

*Research funding from Invizius and Baxter*

# Annual Increase in Predicted Deaths due to CKD 1990 - 2040




Adult CKD:
850 million, ~10% of Europeans

Pediatric CKD2-5:
2 million (out of 2 billion)
~ T1DM and 10x Cystic fibrosis

*Francis et al, Nat Rev Neph 2024*

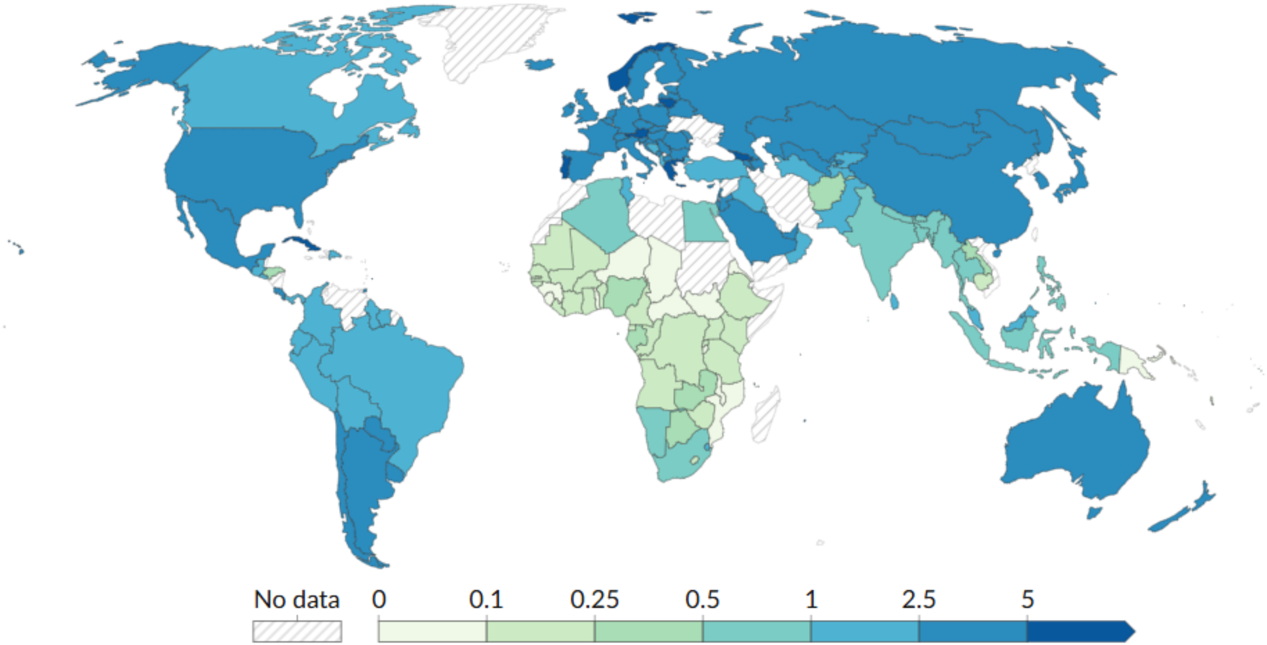
⇒ Dialysis accounts for 1-2% of national healthcare budgets in Europe
⇒ In 2030 ESKD will be the fifth leading cause of death

# Peritoneal dialysis meets critical needs

- Home-based PD with better health-related quality of life
- Clinical outcomes and early survival superior to HD
- PD requires low number of health care professionals per patient (addresses work force crisis!)
- Lower costs

=> *PD suited to cope with the increasing dialysis need*

# Resource-poor regions: *Doctors per 1,000 population (WHO 2022)*




https://ourworldindata.org/grapher/physicians-per-1000-people

ELSEVIER

The Lancet Child & Adolescent Health

Volume 9, Issue 12, December 2025, Pages 822-824

Comment

# Addressing the crisis in paediatric dialysis: a call for urgent action

Rukshana Shroff [a] ✉, Johan Vande Walle [b], Bruno Ranchin [c], Claus Peter Schmitt [d]

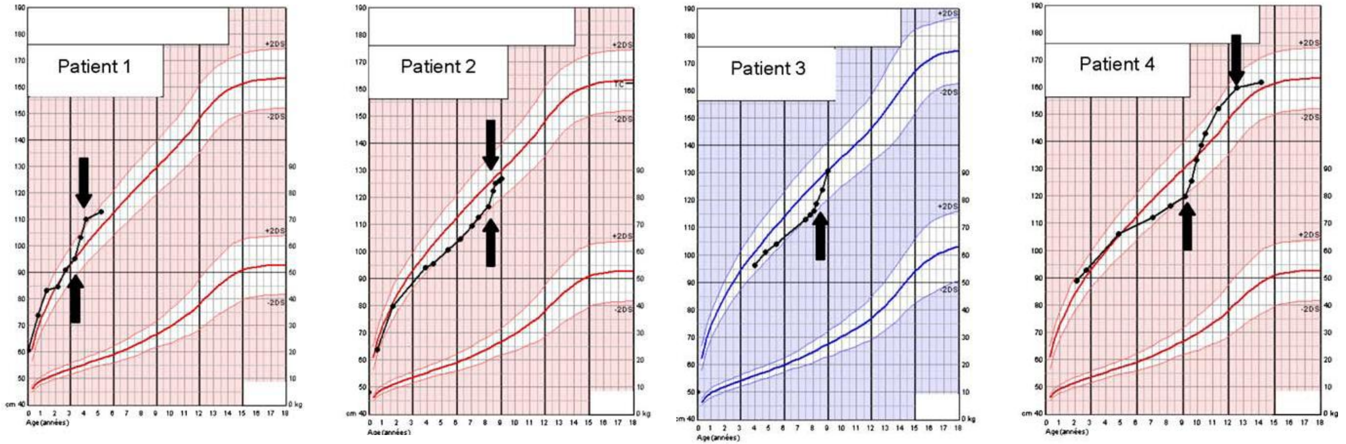
*European Union's Medical Devices Regulation (2017/745)*

=> Joline prototype
pediatric PD catheters

# PD - first choice dialysis, but unmet needs!

- No “intensified PD” option as in HD (>15 hours HD/week)
- Deterioration of long term PD membrane function
- Peritoneal infections
- NaCl and fluid overload
  (except for polyuric and formula fed children)
- Phosphate overload
  => CKD-MBD
  => CVD

# Catch up growth with daily online HDF





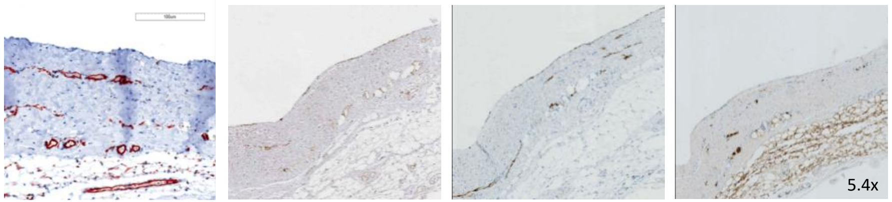
Pre-dilution mode
18 to 27 L/$m^2$
blood flow: 150 ml/min/$m^2$
6 x 3h / week
$Kt/V_{urea}$: 1.4 ± 0.1 / session
**N=20**

*Fischbach M et al, NDT 2010*

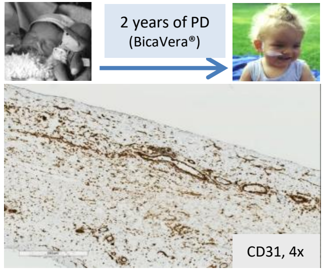
# Peritoneal Membrane Transformation with Chronic PD (low GDP PDF)

Healthy peritoneum

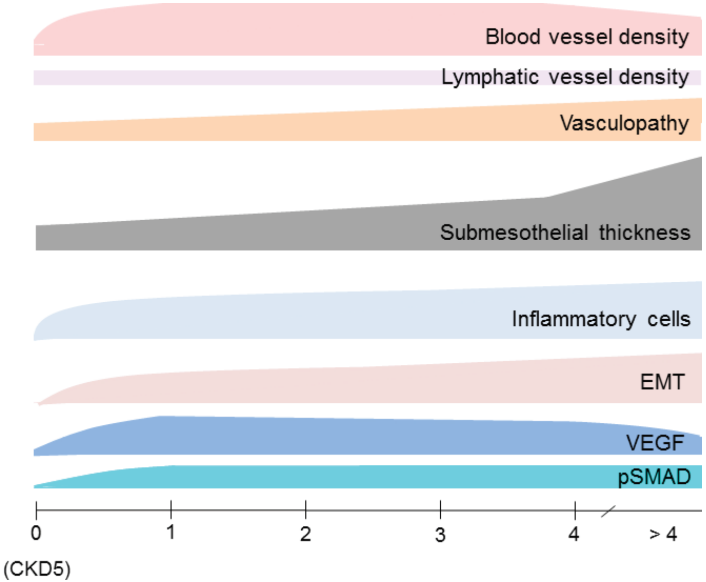
| Vessels (CD31) | Vessels (AQP1) | Lymphatics (Podoplanin) | Nerves (S 100) |
| --- | --- | --- | --- |




Peritoneum in PD




9 years of PD
(Physioneal®)

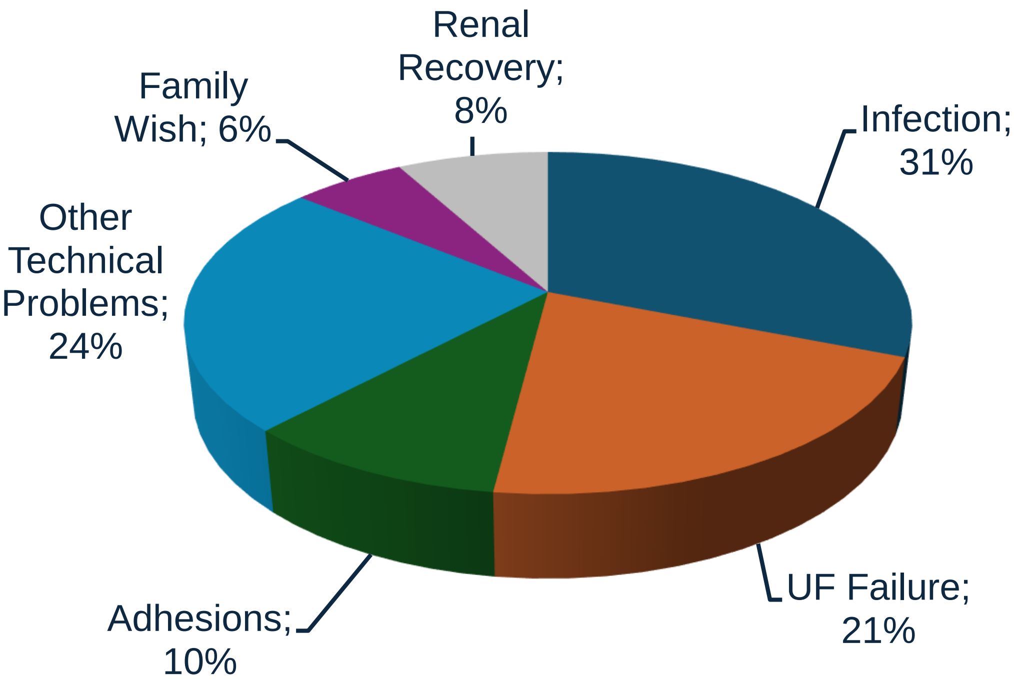

Driving force: dialysate glucose (1500-4200 mg/dl)

*Bartosova M & Schmitt CP, Front in Physiol 2019*

*Schaefer B et al, Kidney Int 2018 Schaefer B et al. Sci Rep. 2016*

# Reasons for PD Discontinuation

(other than transplantation, death, & loss of follow-up; n=323)

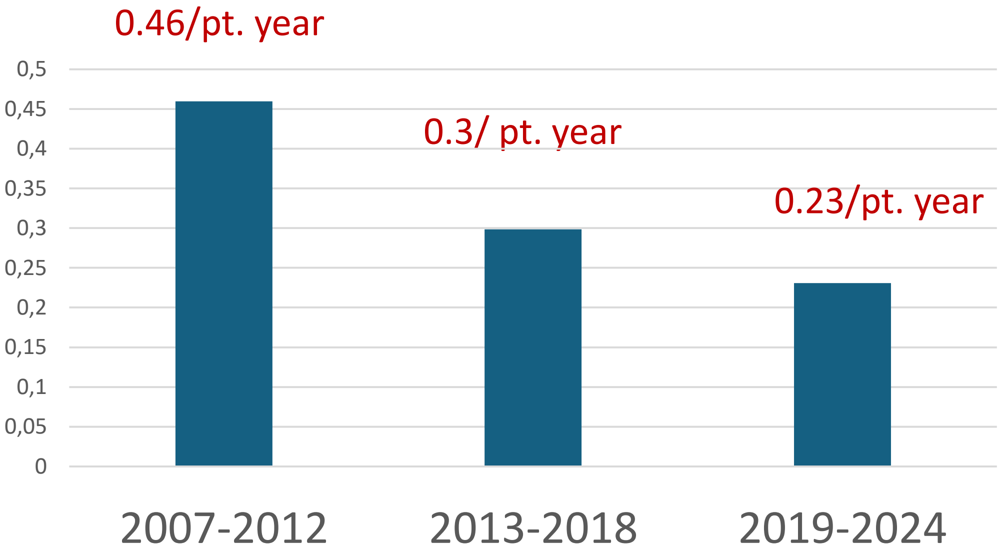



4867 PD patients in IPPN,
3200 terminated

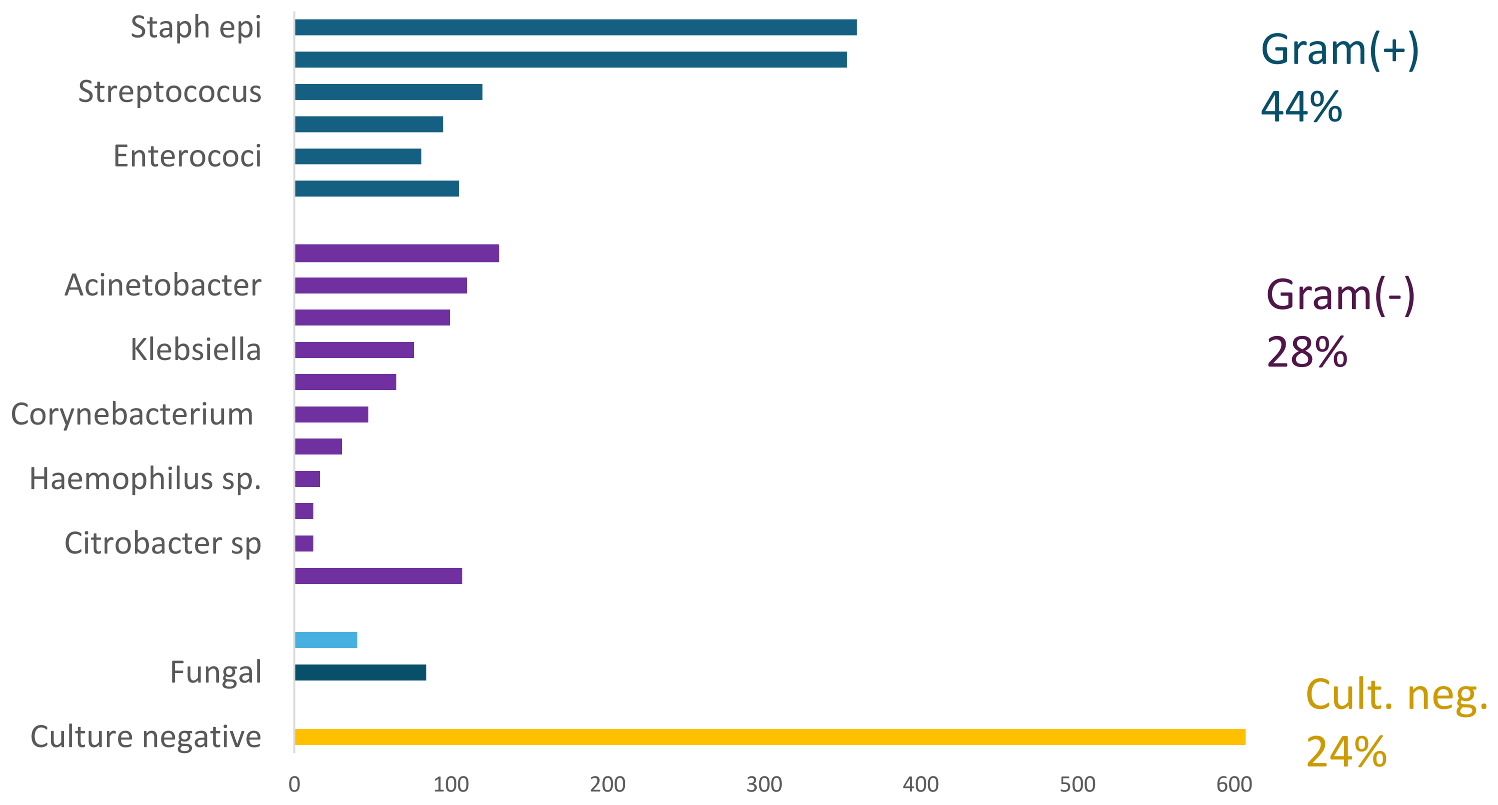
| | |
|---|---|
| Tx: | 65% |
| Death: | 9% |
| Loss to f/u & others | 15 %, |
| Rest: | 11% |

# Peritonitis Rate in IPPN registry (2007-2024)

2538 peritonitis episodes
in 1301 patients
(incl. 187 relapses)



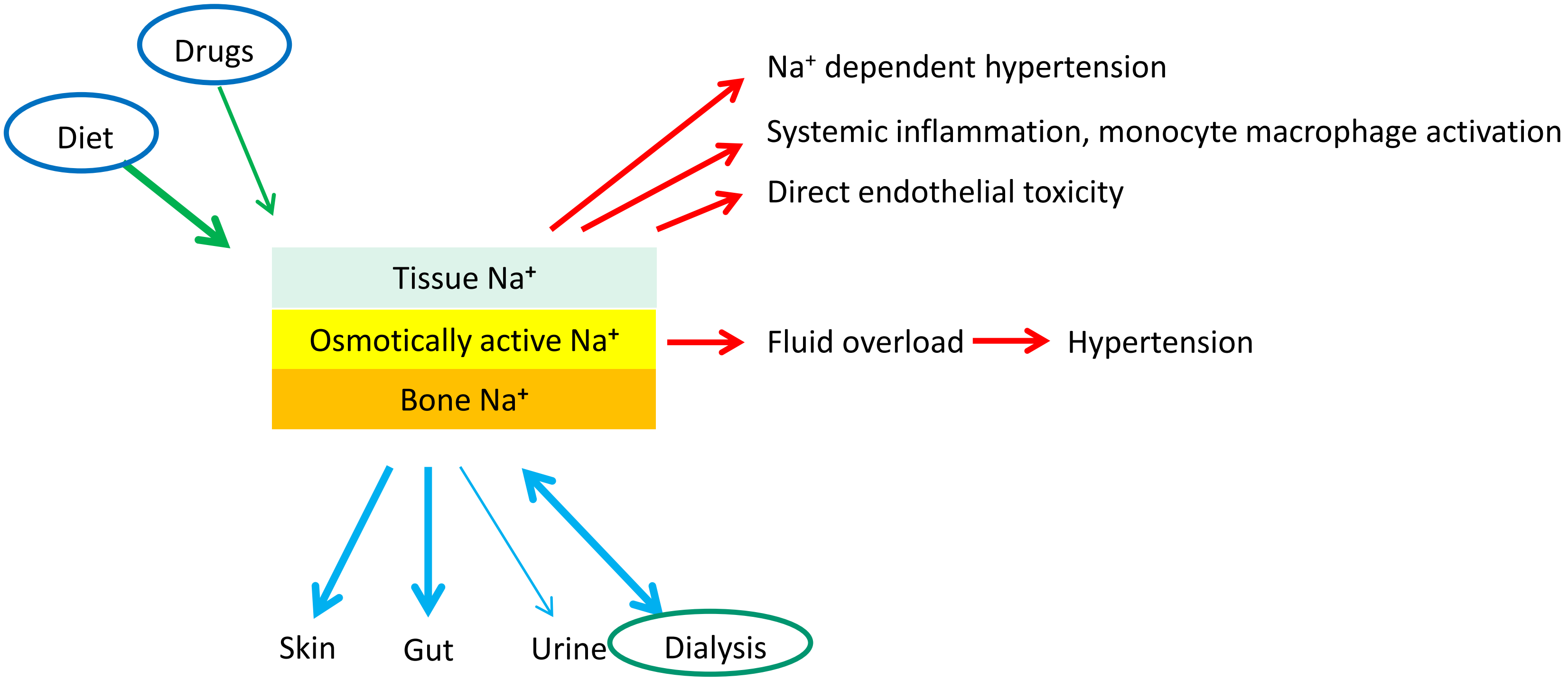
# PERITONITIS ETIOLOGY



# Guideline Impact in PD Peritonitis

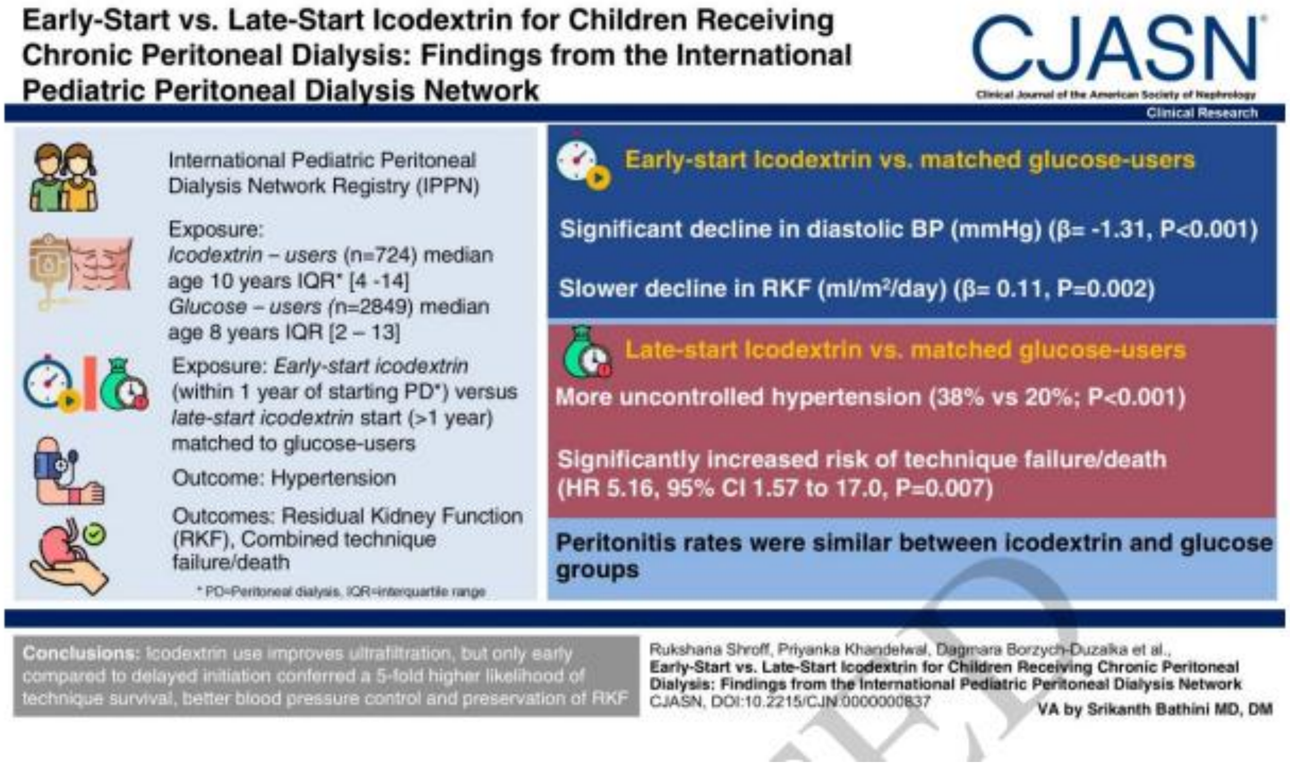
| Outcome | Guideline concordant treatment (78%) | Guideline discordant treatment (22%) | p |
|---|---|---|---|
| **Full functional recovery** | 1377 (84%) | 332 (72%) | **<0.0001** |
| **UF failure** | 67 (4%) | 27 (6%) | 0.107 |
| **Adhesions** | 14 (1%) | 5 (1%) | 0.648 |
| **Uncontrolled infection** | 32 (2%) | 18 (4%) | **0.01** |
| **Secondary fungal peritonitis** | 9 (0.5%) | 7 (1.5%) | **0.03** |
| **Permanent treatment failure** | 128 (8%) | 67 (14.5%) | **<0.0001** |
| **Death** | 8 (0.5%) | 5 (1%) | 0.150 |

# Body Sodium Overload and Consequences in Dialysis Patients

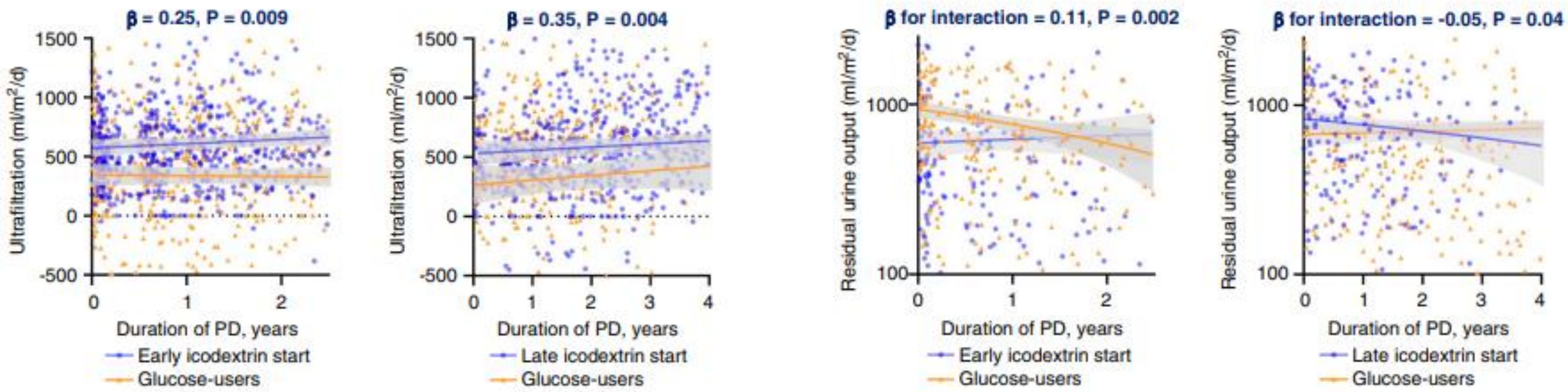



*Paglialonga F, Schmitt CP. Ped Neph 2023*

# IPPN: Hypertension/uncontrolled hypertension in 37 % of children on PD (without icodextrin)

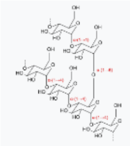


# Better UF, diastolic RR and preservation of RKF with early Icodextrin use




Khandelwal P et al Clin J Am Soc Nephrol. 2025.

> Perit Dial Int. 2021 Feb 10;896860820982218. doi: 10.1177/0896860820982218.
Online ahead of print.

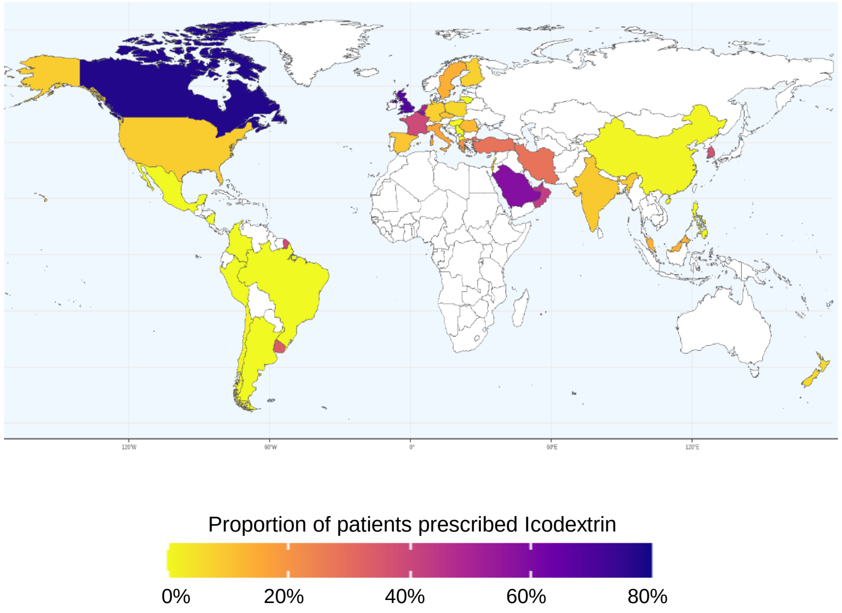


## ISPD recommendations for the evaluation of peritoneal membrane dysfunction in adults: Classification, measurement, interpretation and rationale for intervention

Johann Morelle [1], Joanna Stachowska-Pietka [2], Carl Öberg [3], Liliana Gadola [4], Vincenzo La Milia [5], Zanzhe Yu [6], Mark Lambie [7], Rajnish Mehrotra [8], Javier de Arteaga [9], Simon Davies [7]

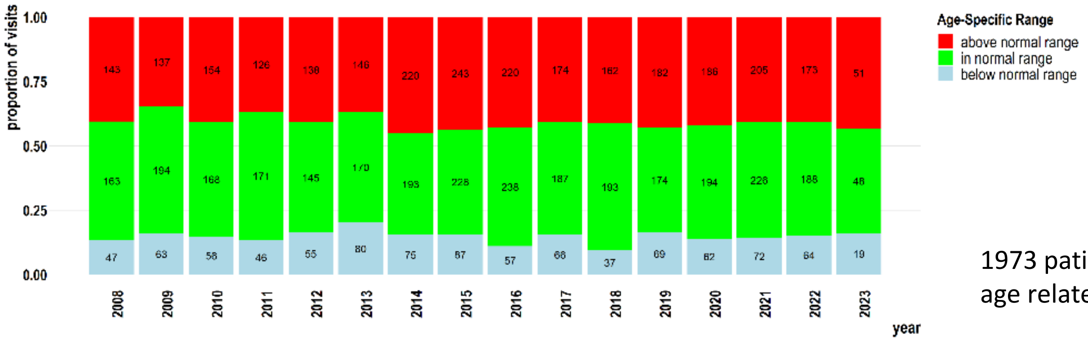
Guideline 2b: Clinical implications and mitigation of <u>fast solute transfer</u>: A faster PSTR is associated with lower survival on PD. (GRADE 1A) This risk is in part due to the lower ultrafiltration (UF) and increased net fluid reabsorption that occurs when the PSTR is above the average value. The resulting lower net UF can be avoided by shortening glucose-based exchanges, using a polyglucose solution (icodextrin), and/or prescribing higher glucose concentrations. (GRADE 1A) Compared to glucose, **use of icodextrin can translate into improved fluid status and fewer episodes of fluid overload. (GRADE 1A)**

## Global use of Icodextrin in Pediatric PD



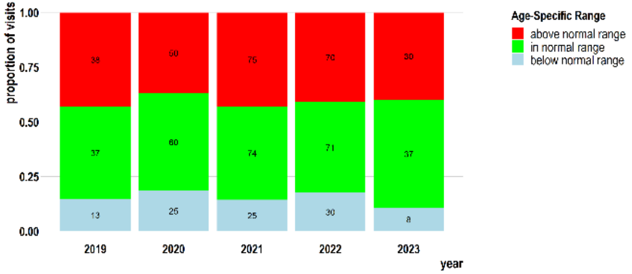
# CKD-MBD in Pediatric Dialysis: Key Performance Indicator Serum Phosphate

**IPDN**




1973 patient visits
age related normal ranges

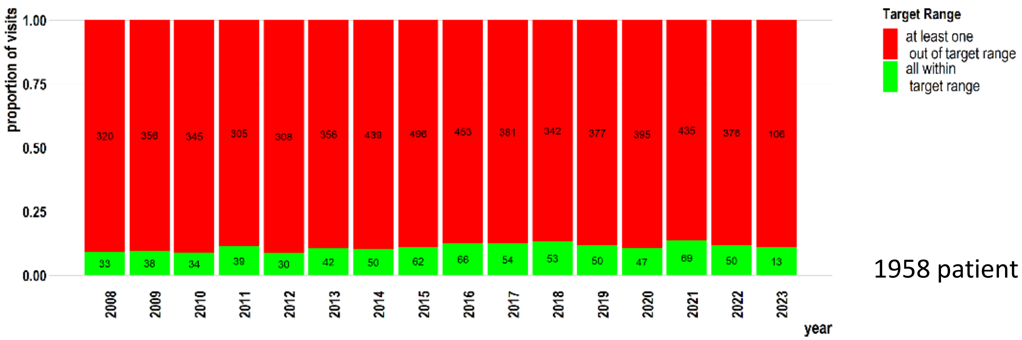
**ERKReg**




405 patient visits
age related normal ranges

# Composite Key Performance Indicator – **Serum Ca, Phos and PTH**

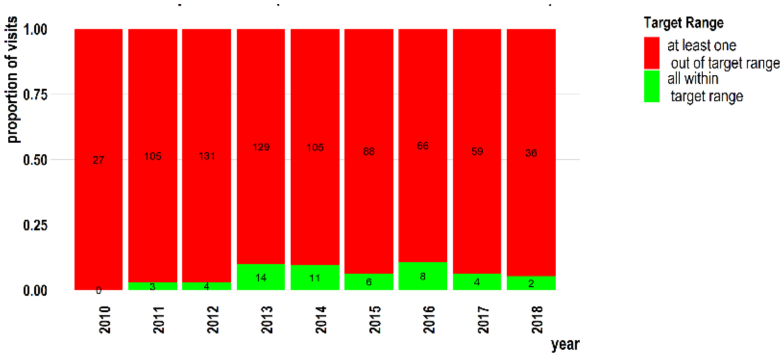
**IPDN**




1958 patient visits



**4C**




170 visits patients

We have to do better!

⇒ Understand the peritoneum
⇒ Optimize peritoneal transport function
⇒ Limit PD associated risks

# Factors affecting Peritoneal Membrane Function in PD

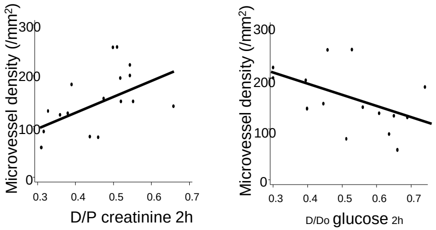
- Peritoneal microvessel density (=perfusion; independently predicts solute transport; reduced in critical AKI, increases early with low GDP-PD)
  Peritoneal fibrosis (reduces PD efficiency)

- Hereditary factors

- Peritoneal transporter function

- Peritoneal surface in contact with PD fluid
  (30-60%, depending on dwell volume)

- Intraperitoneal pressure




**MVLR Analysis 2 *hours D/P creatinine***

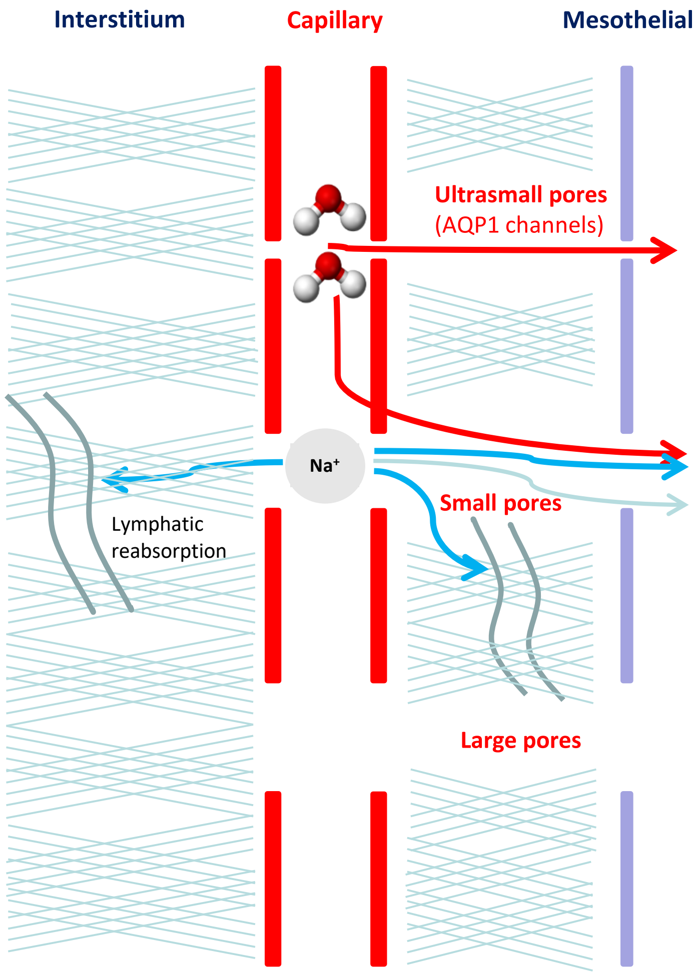
| | Coeff. | lower CI95% | upper CI95% | p-value |
|---|---|---|---|---|
| Age (years) | 0.007 | -0.002 | 0.015 | 0.115 |
| Dialytic glucoseexp. (g/m²/day) | 0.002 | -0.000 | 0.003 | 0.059 |
| **Microvessel density (/mm²)** | 0.166 | 0.069 | 0.264 | **0.004** |
| Submesothelial thickness (µm) | -0.000 | -0.001 | 0.000 | 0.111 |

**MVLR Analysis 2 *hours $D/D_0$ glucose***

| | Coeff. | lower CI95% | upper CI95% | p-value |
|---|---|---|---|---|
| Age (years) | -0.011 | -0.027 | 0.005 | 0.142 |
| Dialytic glucose exp. (g/m²/day) | -0.002 | -0.005 | 0.001 | 0.147 |
| **Microvessel density (/mm²)** | -0.203 | -0.404 | -0.003 | **0.047** |
| Submesothelial thickness (µm) | 0.001 | -0.000 | 0.001 | 0.089 |

*Schaefer B et al Kidney Int., 2018*

**Fluid reabsorption** into:
- interstitial space
- lymphatics / capillaries
  (1.2 ml/min)




PD fluid

**Selective water transport** with glucose induced osmotic pressure
⇒ $Na^+$ sieving
⇒ 40-50% of UF

**Solute ($Na^+$) and water transport** with glucose and icodextrin-induced osmotic pressure and hydrostatic pressure
=> Diffusion and UF associated convection
=> 99% of solute removal
=> 50-60% of total UF

**Large molecule transfer, protein leakage**

*Paglialonga F, Schmitt CP, Ped Neph, 2023*

> N Engl J Med. 2021 Oct 21;385(17):1570-1580. doi: 10.1056/NEJMoa2034279.

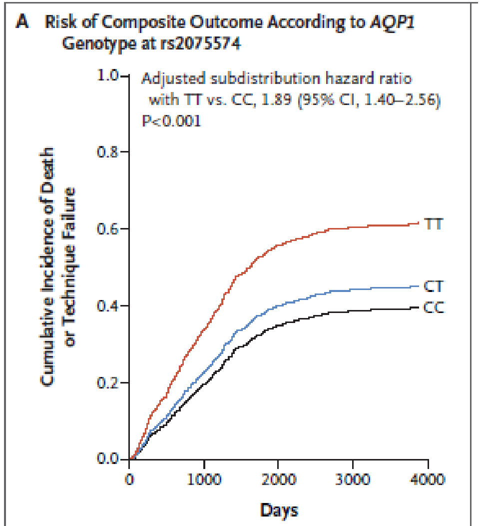
# *AQP1* Promoter Variant, Water Transport, and Outcomes in Peritoneal Dialysis

Johann Morelle [1], Céline Marechal [1], Zanzhe Yu [1], Huguette Debaix [1], Tanguy Corre [1], Mark Lambie [1], Marion Verduijn [1], Friedo Dekker [1], Philippe Bovy [1], Pieter Evenepoel [1], Bert Bammens [1], Rafael Selgas [1], Maria A Bajo [1], Annemieke M Coester [1], Amadou Sow [1], Nicolas Hautem [1], Dirk G Struijk [1], Raymond T Krediet [1], Jean-Luc Balligand [1], Eric Goffin [1], Ralph Crott [1], Pierre Ripoche [1], Simon Davies [1], Olivier Devuyst [1]

**A common variant in AQP1 associated with decreased UF and increased risk of death or technique failure**

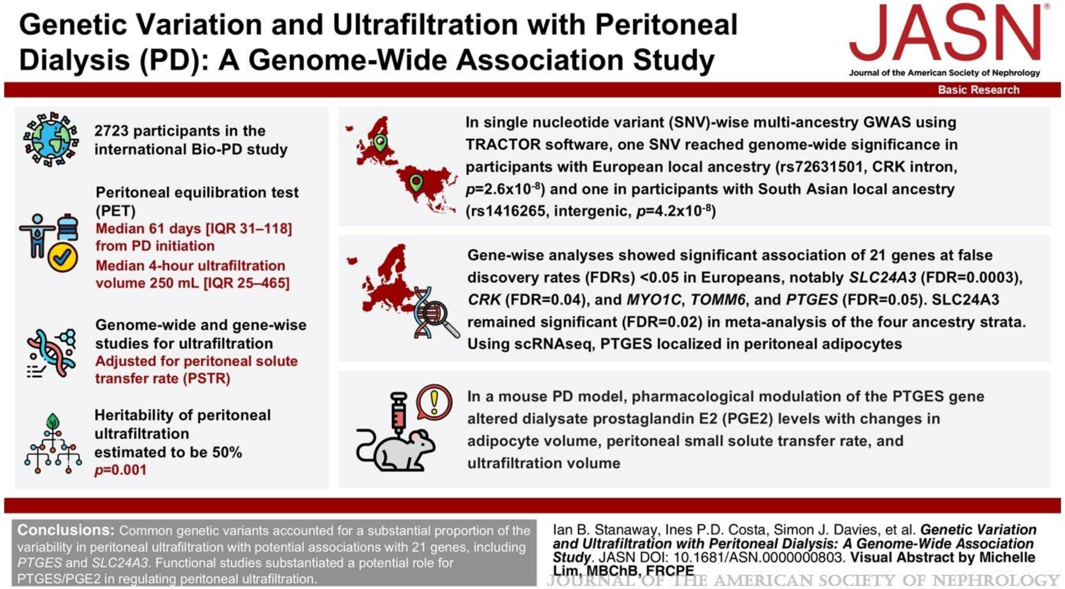
Carriers of the TT genotype at rs2075574 (10 to 16% of patients) had lower UF than carriers of the CC genotype (35 to 47% of patients):
- 506±237 ml vs. 626±283 ml (discovery phase; P = 0.007)
- 368±603 ml vs. 563±641 ml (validation phase; P = 0.003)

TT carriers had:
- a higher risk of death/technique failure than CC carriers
- a higher risk of death from any cause (24% vs. 15%, P = 0.03).

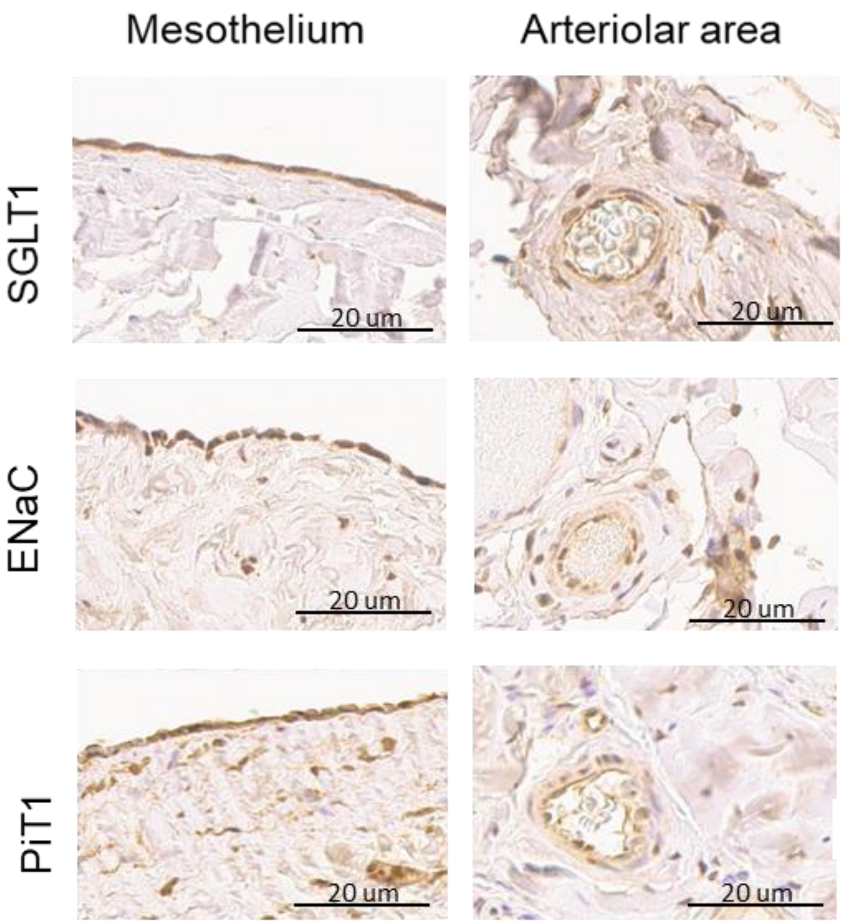


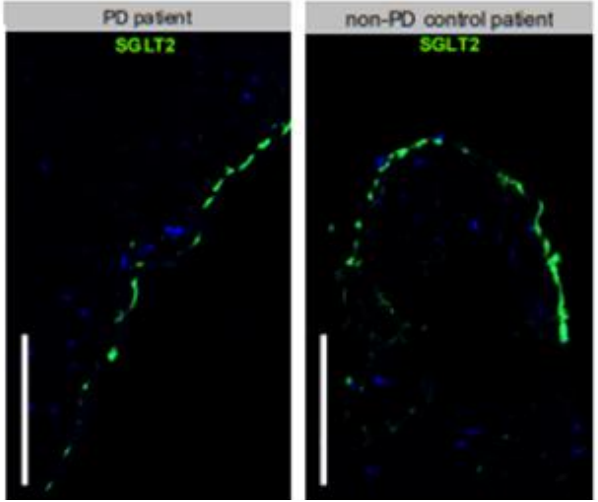

No. at Risk

| | | | | | |
|---|---|---|---|---|---|
| TT | 114 | 42 | 5 | 4 | 0 |
| CT | 400 | 168 | 32 | 3 | 0 |
| CC | 384 | 160 | 25 | 6 | 0 |

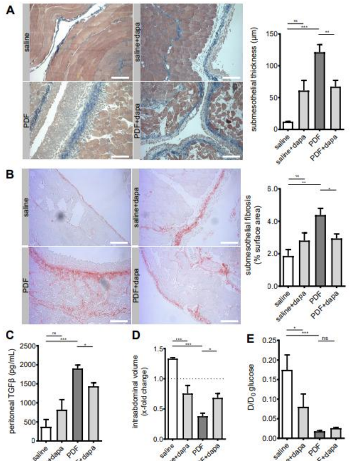


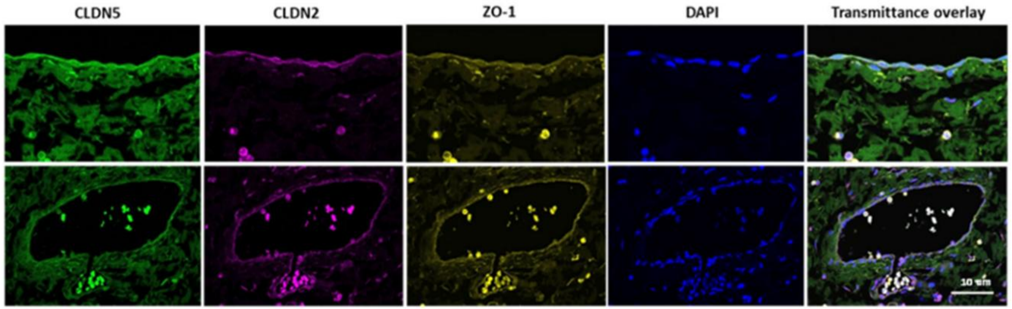

- Hereditary of highly variable UF: 50%
- SLC24A3: Transport of inorganic cations/anions and amino acids/oligopeptides
- Prostaglandin E2 synthase




Dapagliflozin in Mice PD

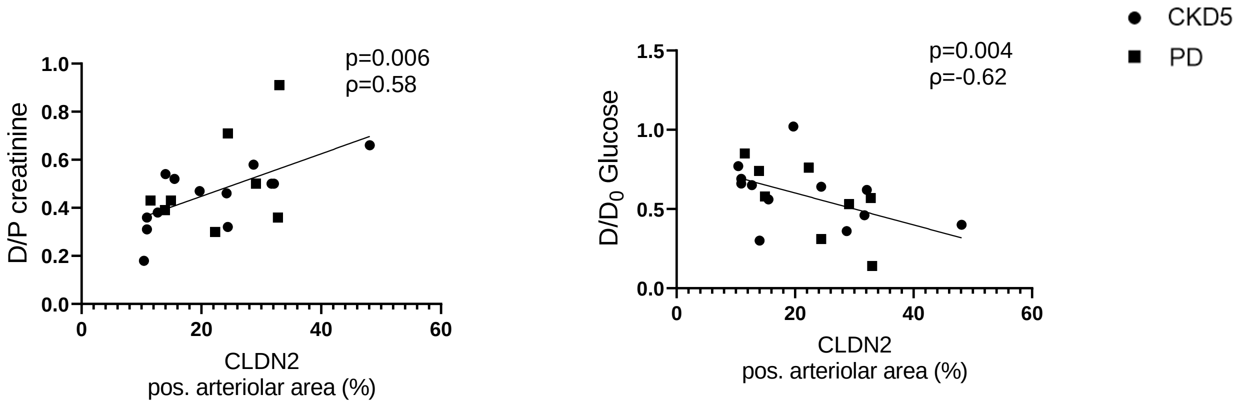



Sealing claudins (CLDN1, CLDN3, CLND5)
Pore-forming claudins (CLDN2, CLDN4, CLDN15)
Occludin   Tricellulin ...

*Levai E et al., Sci Re***p** *2023*
*Balzer MS et al Biomolecules 2020*

# Vascular Claudin-2 abundance predicts peritoneal small solute transport




D/P creatinine

| | Multivariable Analysis | |
|---|---|---|
| | **Coeff. (95% CI)** | **p-value** |
| Microvessel density (/ mm²) | 0.000 (-0.001, 0.001) | 0.413 |
| Age (years) | -0.007 (-0.018, 0.004) | 0.218 |
| Arteriolar CLDN2 (% pos. area) | 0.006 (-0.001, 0.013) | **0.086** |

$D/D_0$ glucose

| | Multivariable Analysis | |
|---|---|---|
| | **Coeff. (95% CI)** | **p-value** |
| Microvessel density (/ mm²) | 0.000 (-0.001, 0.001) | 0.664 |
| Age (years) | 0.004 (-0.011, 0.018) | 0.600 |
| Arteriolar CLDN2 (% pos. area) | -0.010 (-0.018, -0.001) | **0.036** |

*Levai E et al., Sci Rep 2023*

**Table 1.** Current Evidence and Ongoing Trials With SGLT-2 Inhibitors in Peritoneal Dialysis in Humans.

| Study | Design | Participants | Intervention | Primary outcome |
|---|---|---|---|---|
| Hamdan et al[23] | Prospective interventional cohort study (pre-post) | Prevalent PD patients (N = 20) | Dapagliflozin 10 mg daily for 30 days | Changes in PET parameters |
| PRESERVE (NCT05250752) | Prospective interventional cohort study (pre-post) | PD patients (N = 10) | Dapagliflozin 10 mg daily for 3 days | D4/D0 ratio |
| EMPA-PD (NCT05671991) | Crossover randomized study[a] | PD patients with residual urine output ≥400 mL/24 h (N = 30) | Empagliflozin 25 mg (single dose) or placebo | Total glucose absorption |
| EMPOWERED[24] (jRCTs051230081) | Crossover randomized study | PD patients with heart failure (N = 36) | Empagliflozin 10 mg or placebo for 8 weeks | Change in daily UF volume from baseline |
| CANARY (NCT05715814) | Single-arm, open-label study | PD patients with residual renal function[b] | Empagliflozin 25 mg daily for 2 weeks | Change in measured GFR from baseline |
| RENAL LIFECYCLE (NCT05374291) | Randomized controlled trial | PD patients with residual urine output >500 mL/24 h (N = 100)[c] | Dapagliflozin 10 mg daily or placebo | Mortality or heart failure hospitalization |

*Note.* SGLT-2 = sodium-glucose co-transporter 2; PD = peritoneal dialysis; N = number of participants; PET = peritoneal equilibration test; D4/D0 = ratio of 4 hours to 0 hours dialysate glucose; UF = ultrafiltration; GFR = glomerular filtration rate.

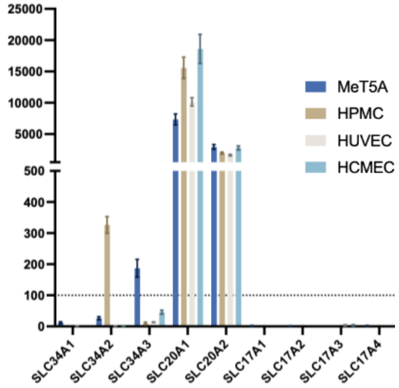
[a]This study will be followed by an open-label extension phase with empagliflozin 10 mg once daily for 8 weeks for all participants.

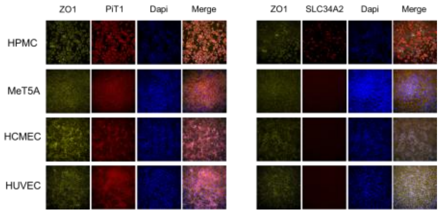
[b]Defined as a urine output of at least 250 mL/24 h and a measured glomerular filtration rate of at least 2 mL/min/1.73 $m^2$.

[c]Substudy of the main trial (which will include participants with an estimated GFR ≤ 25 mL/min/1.73 $m^2$).

# Molecular mechanisms of peritoneal phosphate transport

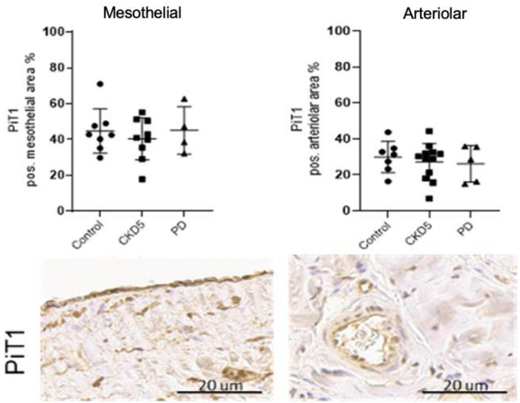
## Mesothelial / endothelial cells



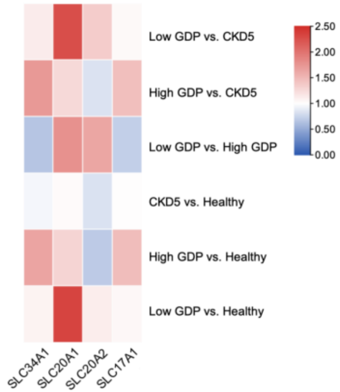

PiT1, PiT2 (SLC20A1 & SLC20A2) abundant
SLC34A2 HPMC specific
SLC34A3 MeT5A specific.

## Parietal peritoneum

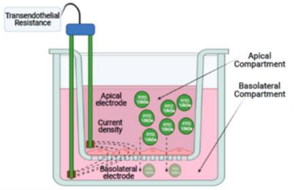



PiT1 abundant in peritoneal mesothelial and endothelial cells

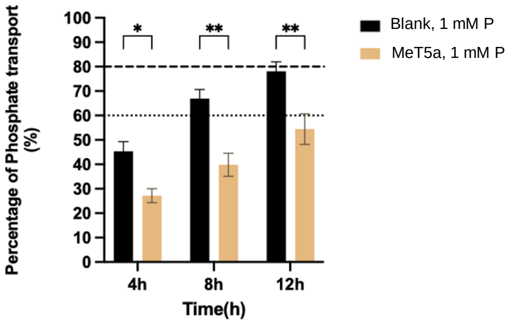
## Human arterioles

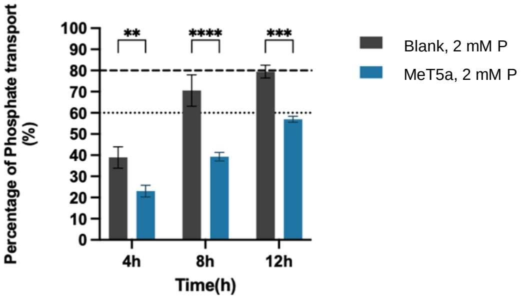



Arteriolar PiT1 upregulated with low GDP PD

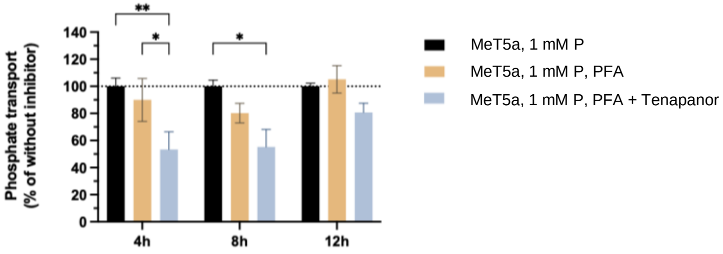



## Mesothelial cells - a barrier to P transport




## Inhibition of mesothelial P transport



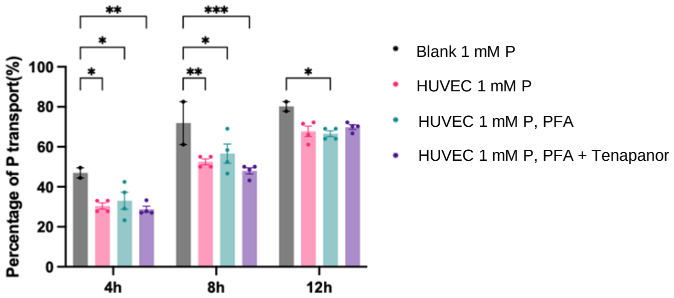

1mM P vs. 1mM P+PFA+Tenapanor *** 0.0008
1mM P+PFA vs. 1mM P+PFA+Tenapanor * 0.0112

PFA: Blocker of *transcellular* SLC20/34 P transporter families
Tenapanor: NHE3 blocker, inhibiting *paracellular* P transport

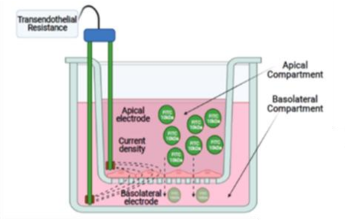
Zhiwei Du

INVIZIUS

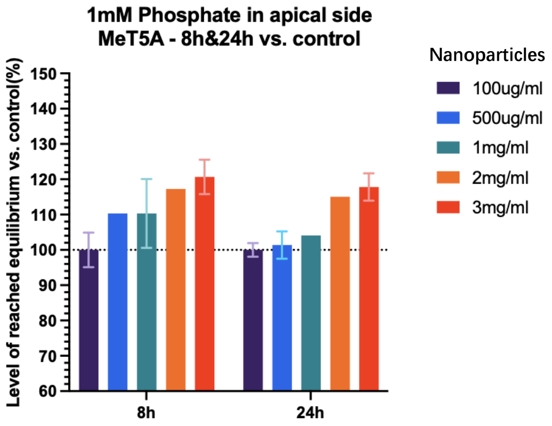
## Low HUVEC P barrier, no inhibition



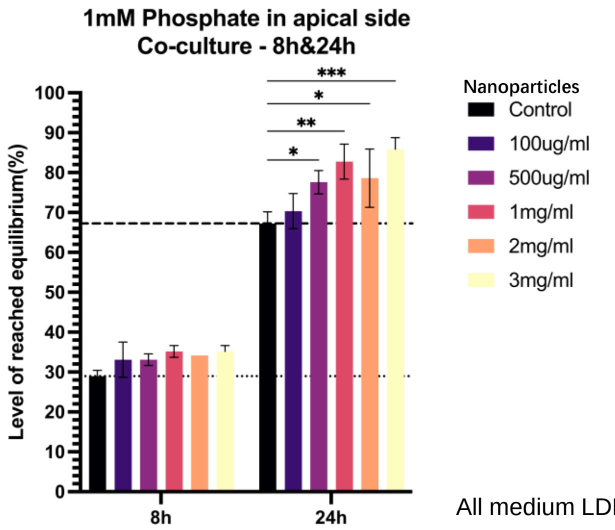
# Nanoparticles increase phosphate transport across mesothelial/endothelial co-barrier




MeT5A




MeT5A + HUVEC




All medium LDH < 30(U/L)

*Du Z, Zalosczyc A et al in prep.*

# The mesothelium – an ignored barrier to solute transport

## Human data

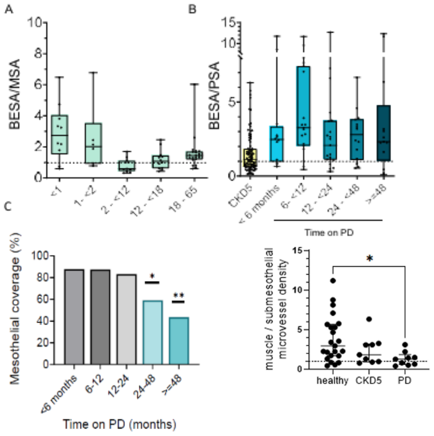



**Fig 1** Peritoneal mesothelial over blood endothelial surface area and parietal peritoneal mesothelial coverage in children with normal renal function, with chronic kidney disease (CKD5) and with time on PD.

## Cell barrier/transport studies

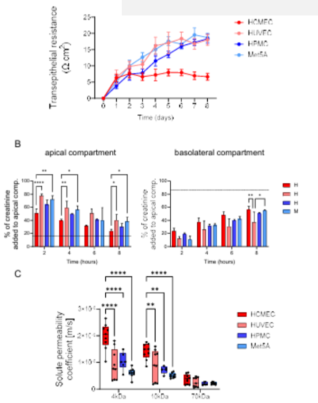
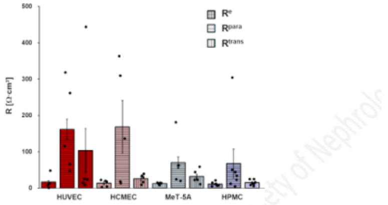



**Fig 4** Transepithelial resistance (TER) and creatinine transport (0.11 kDa) and 4-, 10-, and 70-kDa dextran permeability of mesothelial and endothelial cell monolayers.




**Suppl. Figure 4** Two-path impedance spectroscopic data of the four different cell lines.

## Mice data

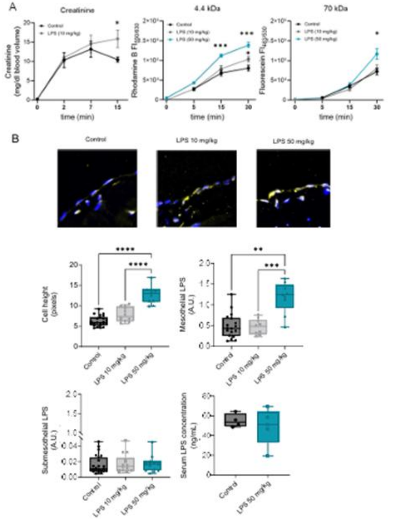
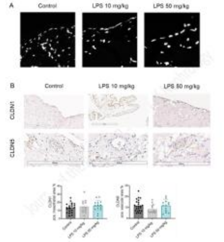



**Fig 5** Peritoneal creatinine and dextran absorption with short term LPS exposure in mice.



**Suppl. Figure 5** Mesothelial morphology and peritoneal abundance of CLDN1 and CLDN5 after 30-minute LPS exposure in mice.

## Cell expression profiles

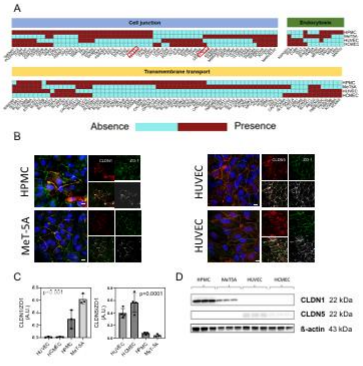



**Fig 2** Cell type specific expression of tight junction proteins CLDN1 and CLDN5.

## Single TJ clustering

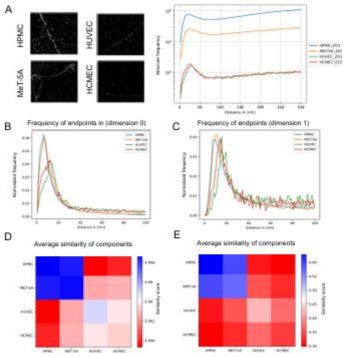



**Fig 3** Single ZO-1 molecules are more abundant and clustered in the cell membrane of mesothelial cells then endothelial cells.

*Marinovic I et al, Function 2025*

# Factors affecting Peritoneal Membrane Function in PD

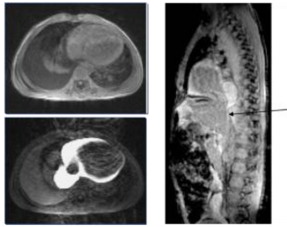
- ✓ Peritoneal microvessel density (=perfusion; independently predicts solute transport; reduced in critical AKI, increases early with low GDP-PD)
  Peritoneal fibrosis (reduces PD efficiency)
- ✓ Hereditary factors
- ✓ Peritoneal transporter function
- Peritoneal surface in contact with PD fluid
  (30-60%, depending on dwell volume)
- Intraperitoneal pressure

# Optimize Dwell Volume by Intraperitoneal Pressure Measurement (IPPM)

- Individual, optimized recruitment of peritoneal surface area (transporters) in growing children

- Low pressure: - suboptimal clearance/UF
  High pressure: - back filtration (UF loss, toxin reabsorption)
  - risk of hernia and leaks, GER
  - dyspneae / ↓ ventilation (in AKI)

- Patients do not estimate IPP correctly, facts needed

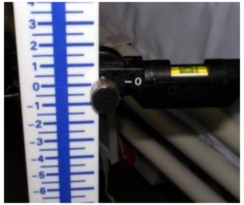


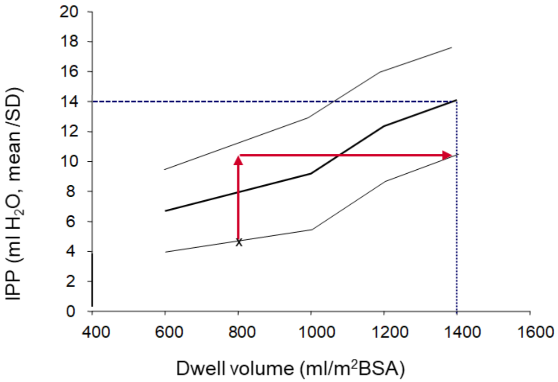
*Borzych B, Schmitt CP, Ped Neph, 2008*

*Dufek S et al, Ped Neph, 2015*

# IPP-Measurement

- “Simple” procedure
- Introduced in the 90’s by Durand PY (adults) and Fischbach M (children) in France
- Description in Fischbach M et al, Ped Nephrol 2003






| | |
|---|---|
| < 2 years: | < 8-10 cm $H_2O$ |
| > 2 years: | ≤ 14 cm $H_2O$ |

*German SOP, GPN, 2024*

# Factors influencing IPP

- Intraperitoneal dialysate volume per BSA (linear increase)
- Age: IPP/m² lower in neonates and infants (greater elasticity of the fragile abdominal wall?).
- BMI: higher intra-abdominal fat. BMI predicts IPP with good accuracy
- Sex: IPP in male > females (higher abdominal wall tone?), inconsistent data
- Organ size: hepato-splenomegaly, polycystic kidneys...
  In adults height normalized kidney mass correlates with IPP
- Posture: IPP > in upright than supine position, highest when sitting
- PD vintage: IPP declines with time after PD catheter insertion and further over months to years
- PD fluid composition: Higher IPP/dwell volume with acidic, high GDP PD fluids
- Pain, constipation…

=> Complex, multifactorial setting

*Zaloszyc A et al, submitted*

Scientific evidence on impact of IPPM on patient outcome?

# IPP - Predictor of PD Outcome (HD-Switch/Death)?

54 adult patients on APD

IPP: 18.8 ± 5.2cm $H_2O$

PD: 5.5 (2-19) months

3 Hydrothoraces

11 AW-Hernia

4  x GE reflux

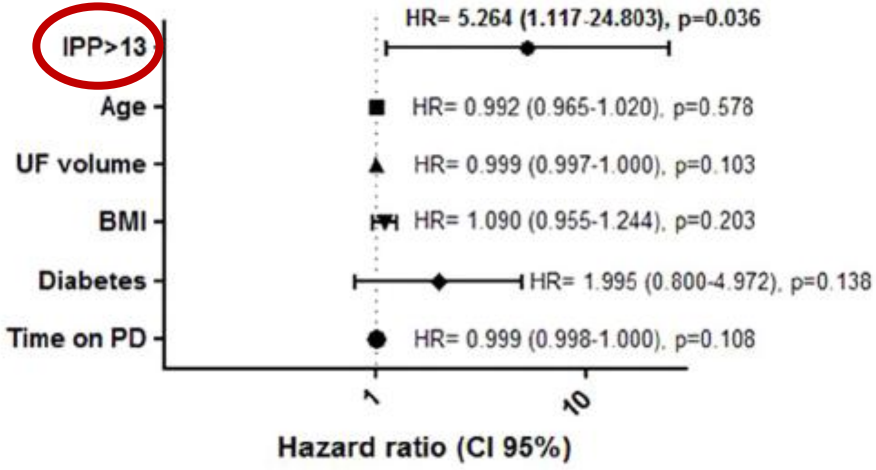



Figure 1 — Multivariate analysis of predictors of death or switch to hemodialysis. IPP = intraperitoneal pressure; UF = ultrafiltration; BMI = body mass index; PD = peritoneal dialysis; HR = hazard ratio; CI = confidence interval.

Outerelo et al PDI 2014

Nephrol Dial Transplant (2007) 22: 1437–1444

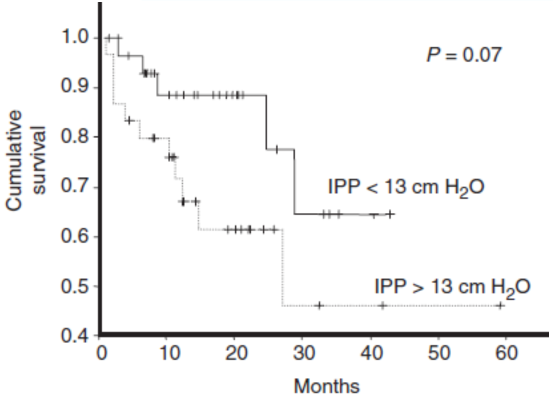
# Intraperitoneal pressure in PD patients: relationship to intraperitoneal volume, body size and PD-related complications

Agnès Dejardin[1], Annie Robert[2] and Eric Goffin[1]

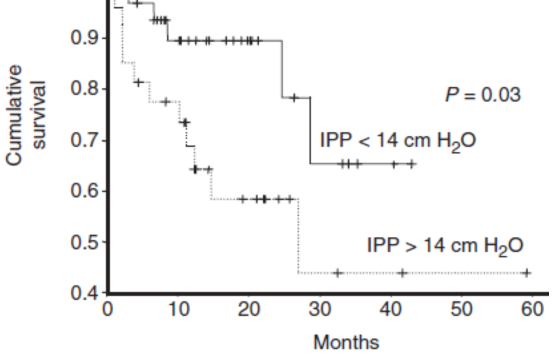
61 adult patients on PD

- Linear increase of IPP with dwell volume
- Large interindividual variability in absolute IPP
  (IPP at 2000 ml: 5 - 22.5 cm $H_2O$)
- 41% of patients with night IPP > 14 cm $H_2O$ had enteric peritonitis, 15% with night IPP <14 cm (p=0.04).
  Dwell volumes (absolute and per BSA) similar

Day time IPP and peritonitis free survival




Night IPP and peritonitis free survival



# Lower UF with high IPP?

3 studies with 49, 8 and 23 adult PD patients suggest a negative correlation of IPP with UF rate.

Castellanos LB et al.  Clinical Relevance of Intraperitoneal Pressure in Peritoneal Dialysis Patients. Perit Dial Int 2017
Durand PY et al. Intraperitoneal pressure, peritoneal permeability and volume of ultrafiltration in CAPD. Adv Perit Dial 1992
Imholz AL et al. Effect of an increased intraperitoneal pressure on fluid and solute transport during CAPD. Kidney Int 1993

*ISPD Practice Recommendations for Prescribing High-Quality Goal-Directed PD*: IPPM not mentioned.

*Brown EA et al, PDI 2020 49*

*Commentary on ISPD CPR:* IPPM in pediatric PD is a possible tool to guide adjustment in dwell volume but unclear how this is practiced in pediatric dialysis units.

*Teitelbaum I et al, AJKD 2021*

Clinical Kidney Journal, 2023, vol. 16, no. 9, 1367–1368

https://doi.org/10.1093/ckj/sfad140
Advance Access Publication Date: 22 June 2023
Editorial Comment

EDITORIAL COMMENT

# Intraperitoneal pressure in peritoneal dialysis patients: a need for treatment individualization

Ana Carina Ferreira

Nephrology Department – Centro Hospitalar e Universitário de Lisboa Central, Lisbon, Portugal; NOVA Medical School, Lisbon, Portugal

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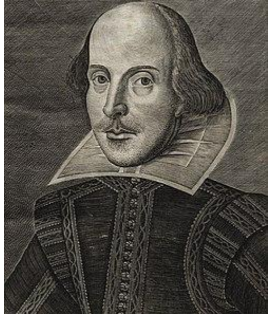
## ABSTRACT

High-quality and goal-directed peritoneal dialysis (PD) prescription should be provided to all PD patients. Prioritizing patients' goals is necessary for their quality of life, as it is assessment of volume and nutritional status, anemia and mineral and bone management, or small-solute removal. To optimize the removal of small solutes, and depending on membrane characteristics, the increase in concentration gradient difference or the increase in volume (recruitment of all peritoneal capacities) can be performed. Nevertheless, intraperitoneal volume should be tailored by measuring the intraperitoneal pressure (IPP) to avoid PD associated mechanical complications. In this editorial, a brief review on how IPP can be measured, and its implications are noted.

**Keywords:** intraperitoneal pressure, intraperitoneal volume, PD prescription, peritoneal dialysis

IPPM in clinical practice



There are enthusiasts: “great help”

and non-believer: “no evidence of benefit on clinical outcome”

# **To Be*lieve* or Not to Be*lieve***

*That is not the question…*

# European Survey on IPPM in clinical practice

- Pediatric nephrology centers of ERKNet, ESPN dialysis WG group, EPDWG and SNP invited to reply to 28 online questions

- 47 European pediatric centers from 16 countries analysed
  14 French centers (30%)

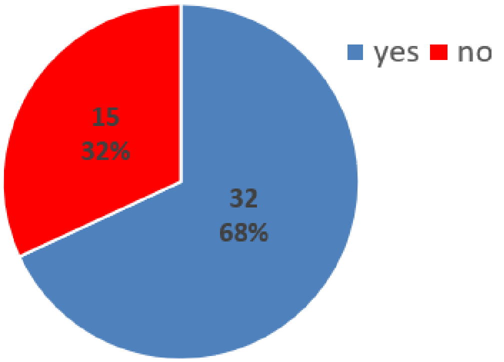
- Median patient number per center 3, range 0-30

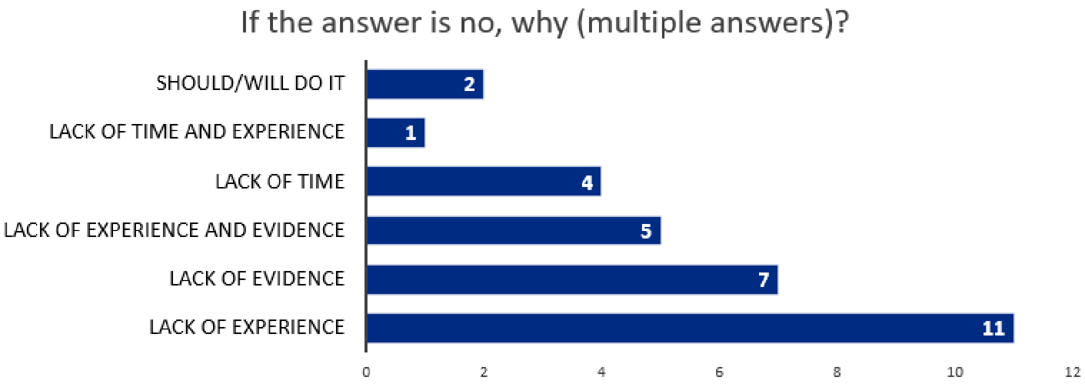
- Experience in pediatric dialysis:

| | |
|---|---|
| ≤ 5 years: | 8 |
| 6 - ≤ 10 years | 9 |
| 11-20 years | 12 |
| > 20 years | 16 |
| no reply | 2 |

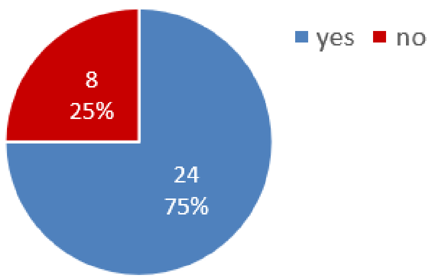
*Zaloszyc A et al, submitted*

# Implementation of IPPM in European centers



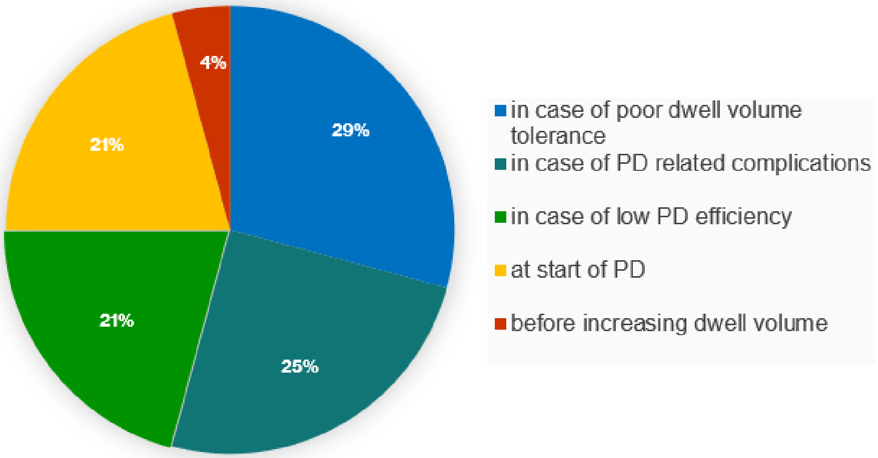



## Do you measure IPPM routinely?




## Routine IPPM measurement intervals


## If no routine IPPM, when?



# IPPM technique / PD fluid / dwell

- 12 centers use a specifically manufactured visual scale system
- 20 centers other systems (self-made scales, central venous pressure systems ...)

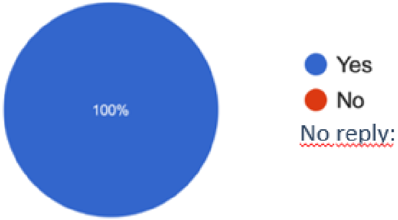
| **PD fluid type** | N (%) |
|---|---|
| Double chamber PD fluid, bicarbonate | 26 (81.1%) |
| Double chamber PD fluid, lactate | 2 (6.2%) |
| Double chamber PD fluid, mixed buffer | 6 (18.7%) |
| Icodextrin | 3 (9.4%) |
| Glucose concentration: low | 15 (46.8%) |
| Glucose concentration: medium | 7 (21.9%) |
| Glucose concentration: high | 2 (6.2%) |
| Other: patients own usual prescription/other | 2 (6.2%) |
| Single chamber acidic PD fluid | 0 |

- 53 % of centers perform single volume IPPM (mostly actual volume)
  47% perform serial measurements (e.g. 600 /1000 /1400 ml/$m^2$),
  but variable volumes applied

- 31% combine dwells with other measurement (mostly with PET)
  50% specifically measure IPP
  16% do both

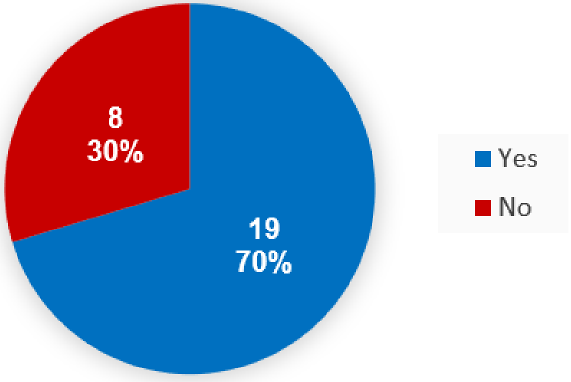
- 53% measure IPP within 10 min after infusion
  22% at the end of the dwell
  25% at both time points

## Do you adapt dwell volume to IPP?

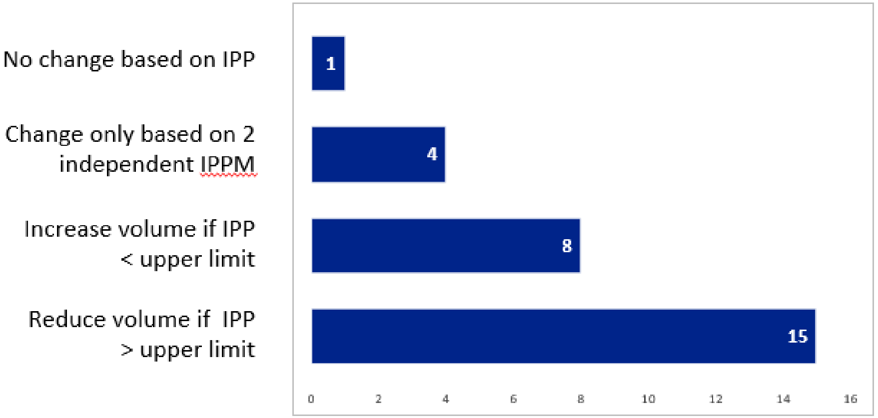



No reply: 5/32 IPPM centers

## Age/body size related upper limit of IPP?

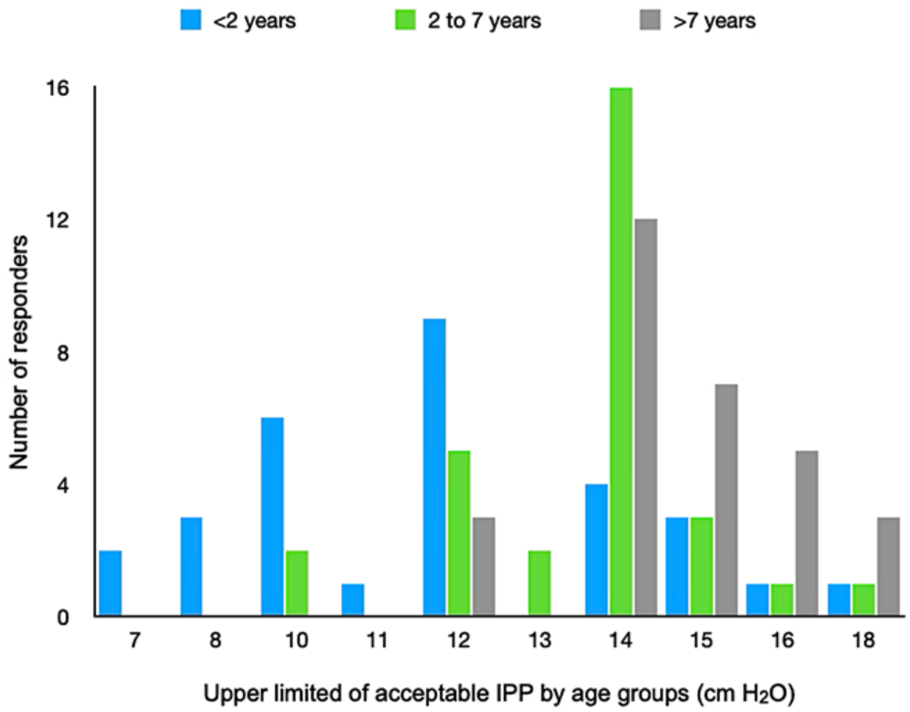



## Adaptation of PD dwell according to IPP

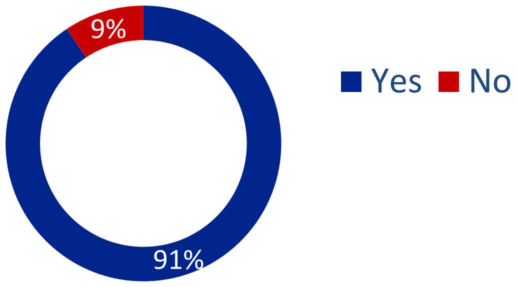



- local written protocol in 26 centres
- national standards in Spain and Germany

# Upper limit of acceptable IPPM



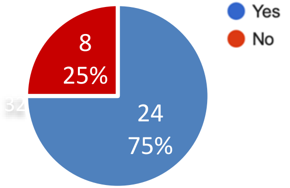
# Impact of IPPM on patient outcome?



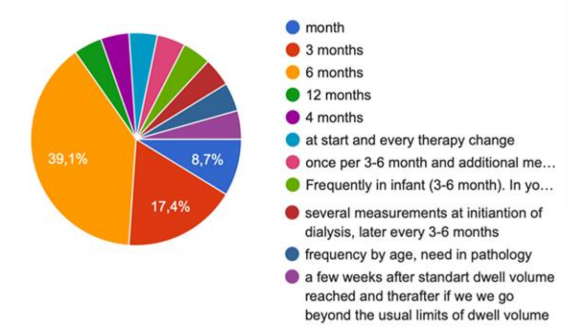

| | N = 32 (%) |
|---|---|
| It improves PD efficiency | 23 (72%) |
| It reduces PD related complications (hernia…) | 11(34%) |
| It improves compliance | 5 (16%) |
| It improves confidence of caregivers/family | 5 (16%) |
| No impact | 3 (10%) |

# IPPM – various methods, implementation and conclusions

## Routine IPPM



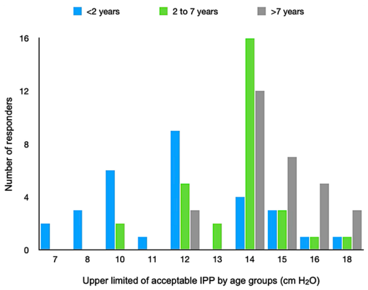

## IPPM interval



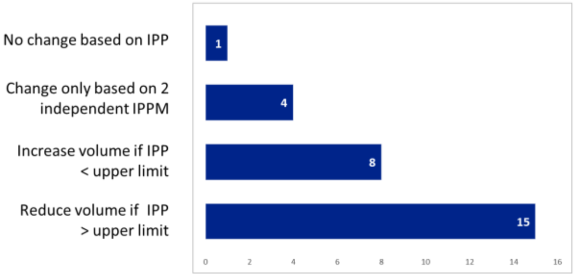

## IPPM technique

- Different devices used
- All type of dialysate fluids
- 53% perform single volume IPPM, with actual dwell volumes
  7% serial measurements, variable volumes
- 31% combined with PET
- 53% measure shortly after infusion
  22% at the end of the dwell
  25 at both time points

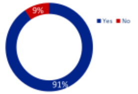
## Upper IPP limit




## Adaptation of PD dwell according to IPP




## Impact on outcome

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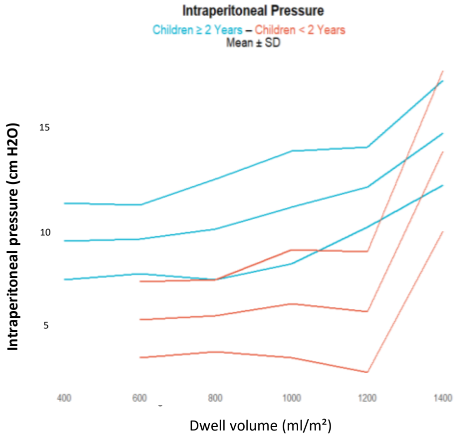
| It improves confidence of caregivers/family | 5 (16%) |
| No impact | 3 (10%) |


dreamstime.com
ID 35308557 © Steven Day

| | Dwell volume (± 50 ml/m² BSA) | Intraperitoneal pressure (cm $H_2O$) | Patients (n per volume) |
|---|---|---|---|
| **Neonates** (3-6 weeks) | 600 | 3.0 ± 2.0 | 3 |
| 45 IPPM | 800 | 4.0 ± 2.0 | 3 |
| Fischbach et al. (Adv in PD 1996) | 1000 | 7.0 ± 1.5 | 3 |
| | 1200 | 8.0 ± 2.0 | 3 |
| | 1400 | 11.0 ± 4.0 | 3 |
| **Infants** (<2 years) | 600 | 5.6 ± 1.9 | 11 |
| 133 IPPM | 800 | 5.8 ± 1.8 | 10 |
| Fischbach et al. (Adv in PD 1996); Sawaya et al. (Nephrol Ther 2025) | 1000 | 6.4 ± 2.7 | 10 |
| | 1200 | 6.0 ± 3.0 | 8 |
| | 1400 | 14.0 ± 4.0 | 8 |
| **Children** (2-18 years) | 400 | 9.5 ± 1.9 | 9 |
| 427 IPPM | 600 | 9.6 ± 1.7 | 25 |
| Fischbach et al. (Adv in PD 1996); Sawaya et al. (Nephrol Ther 2025) | 800 | 10.1 ± 2.5 | 29 |
| Zaloszyc et al. (Ped.Nephrol in press) | 1000 | 11.2 ± 2.8 | 25 |
| | 1200 | 12.2 ± 2.0 | 18 |
| | 1400 | 14.9 ± 2.6 | 14 |




- **605 IPPM in 51 children, 3 studies**
  Means of individual patients were used and in case only mean/SD were available, these were weighted for patient number.
- Dwell volumes per m² BSA used varied between studies.
- IPP was measured within 10 minutes of infusion and at the end of dwells, considering ultrafiltration. In children above 2 years IPP/m² BSA did not differ systematically when measured initially or at the end of the dwell.

*Zaloszyc A et al, submitted*

# How to proceed?

- Clinical practice points to standardize IPPM
  (based on limited evidence and good clinical experience)

  Three point measurements:
  - to detect outliers
  - to characterize abdominal elasticity / volume compliance

  Above 2 years: 600, 1000, 1400 ml/m² BSA
  Infants: 300, 600, 900 ml/m2 BSA

  Upper PP limit ≤ 14 cm H2O, infants ≤ 8-10 cm H2O

- Enter data in registry (IPPN)!
- Prospective multi-center studies
- *Automated (continuous) IPP measurement (cycler integrated)*

*Zaloszyc A et al, submitted*

# Future Prospects in IPPM

ORIGINAL ARTICLE

PHYSIOLOGICAL REPORTS 2025

## Relationship between intraperitoneal volume and intraperitoneal pressure during peritoneal dialysis—a pilot study in adult patients

**Fansan Zhu**[1] | **Laura Rosales Merlo**[1] | **Lela Tisdale**[1] | **Maricar Villarama**[2] | **Jun Yi**[3] | **Zahin Haq**[1] | **Xiaoling Wang**[1] | **Nadja Grobe**[1] | **Karsten Fischer**[3] | **Kulwinder Plahey**[3] | **Richard A. Lasher**[3] | **Paul Chamney**[4] | **Brigitte Schiller**[3] | **Peter Kotanko**[1,5]

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[2]Mount Sinai Hospital, New York City, New York, USA

[3]Fresenius Medical Care North America, Waltham, Massachusetts, USA

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[5]Icahn School of Medicine at Mount Sinai, New York City, New York, USA

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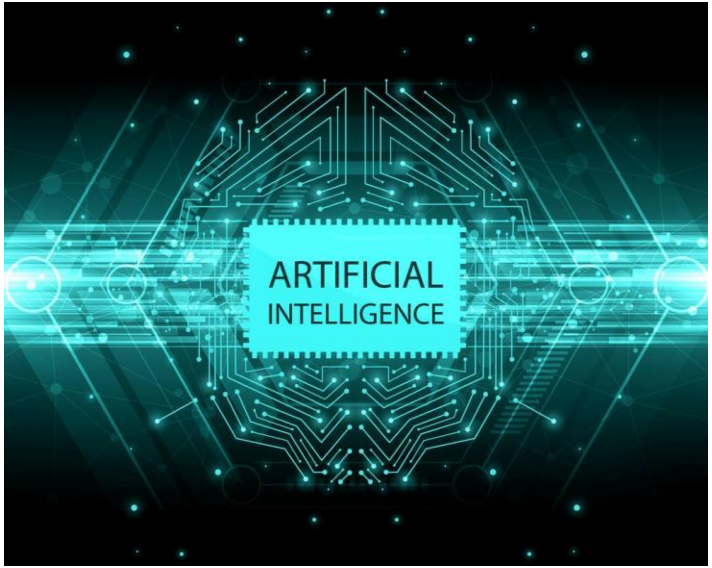
Email: fansan.zhu@gmail.com

**Abstract**

Monitoring intraperitoneal pressure (IPP) offers valuable insights into changes of intraperitoneal volume (IPV) during peritoneal dialysis (PD). This study aims to investigate the relationship between IPV and IPP during a PD dwell. Thirteen patients were studied during a 2-h dwell using 2 L of dialysate containing 2.5% dextrose. IPP was measured using a pressure sensor integrated into an automated PD cycler. IPV was monitored concurrently by segmental bioimpedance (Hydra 4200). The density ($\rho$) of the PD dialysate was measured using a meter, and the creatinine and glucose concentrations in both dialysate (D) and serum (P) were measured pre- and post-PD dwell. A physical model ($IPP = \rho \times g \times h$), was used to describe the relationship between IPP and IPV, where h is the apparent dialysate height and g is the gravitational acceleration. The change in IPP (ΔIPP, −21.2 ± 18%) was mainly determined by the change of h (Δh, −20.9 ± 18.5%), while the change $\rho$ ($\Delta\rho$, −0.34 ± 0.06%), was minor. The study demonstrated an association between ΔIPP and the ratio of D/P creatinine and $D/D_0$ glucose, suggesting that ΔIPP may reflect membrane transport characteristics. Due to its non-invasive and seamless nature, the clinical utility of PD cycler-based measurement of IPP warrants further exploration.



# International Peritoneal Biobank: Future prospects

**Children**

**446 biopsy samples**
(peritoneum omentum, 364 ped. patients)

- Previous PD treatment (18)
- Peritonitis within 4 weeks (16)
- Inadequate quality (26)

| Non-CKD | CKD5 | Low GDP PD | High GDP PD |
| --- | --- | --- | --- |
| (72) | (151) | (158) | (38) |

45 follow-up samples

Recent Tx (30 low/20 high GDP PD)

**Adults**

| 30 non CKD | 128 CKD5 | 27 Low GDP PD |
| --- | --- | --- |

# Tissue analyses with advanced technologies

Arteriolar *transcriptome* and *proteome* from patients with
- normal kidney function
- CKD5
- PD (with different fluids)
- Post KTx

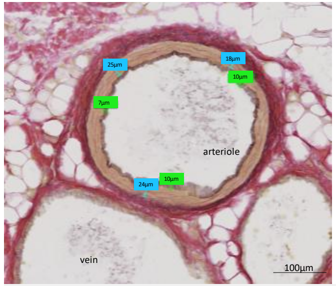
Arteriolar *Endothelial Micro-Proteome* (healthy vs CKD5)
Arteriolar *single nuclei RNAseq* (healthy vs CKD5), coop. with Nice
Arteriolar and fat tissue *lipidome (CKD5, PD, KTx)*

Peritoneal spatial transcriptome (ongoing)

Fat tissue untargeted *metabolomics* (healthy, CKD5, PD) => spatial metabolomics

High content Imaging

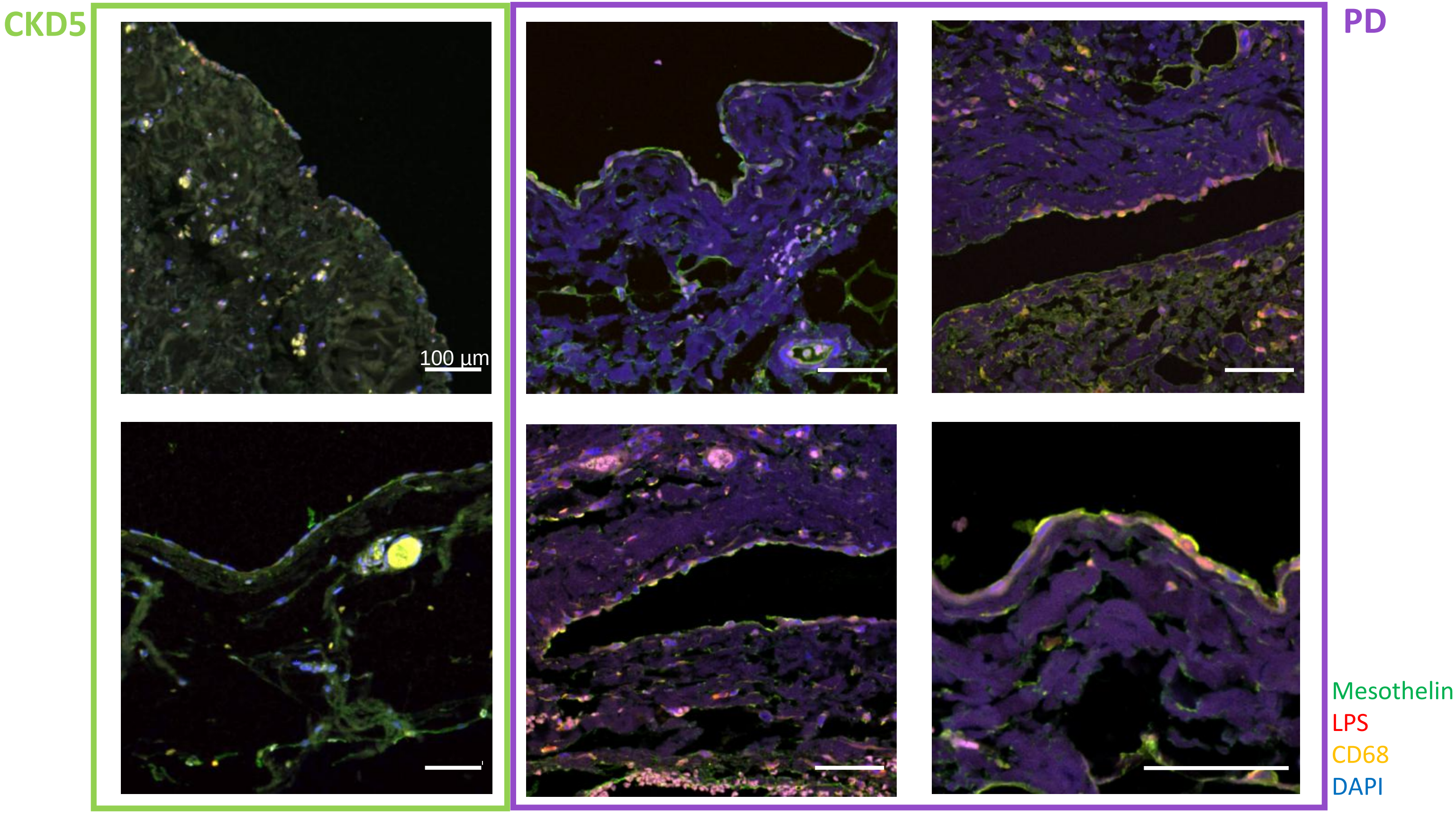
Cell models:
RNA seq: polarized endothelial (HUVEC, HCMEC) and
polarized mesothelial cell lines (MeT5A, HPMC)




Tissue (laser) microdissection

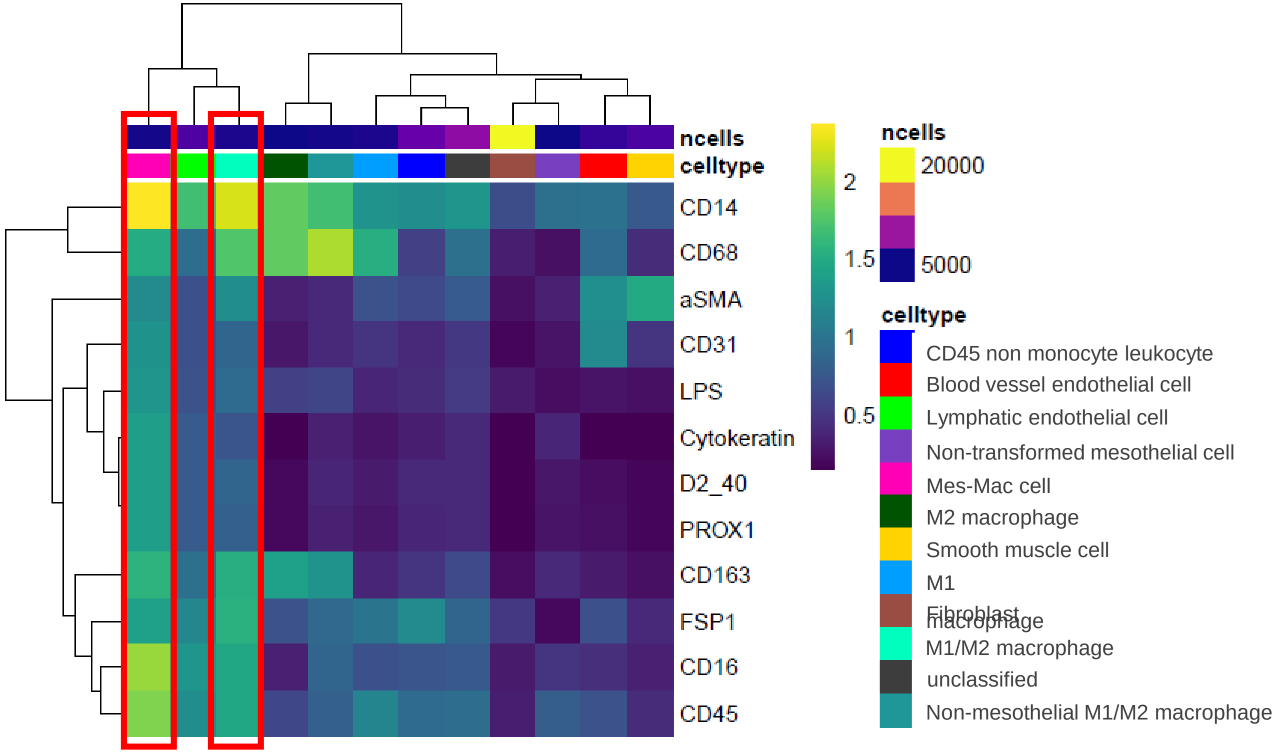
OPEN TO YOUR RESEARCH QUESTIONS!

# Novel, LPS rich peritoneal mesothelial-macrophage cell phenotype




⇒ In CKD5 and PD mesothelial cells tissues positive for LPS express macrophage markers
⇒ New mesothelial phenotype in humans (Mes-Mac)

# Peritoneal Mes-Mac Cell Molecular Expression Pattern (low-GDP PD patients)



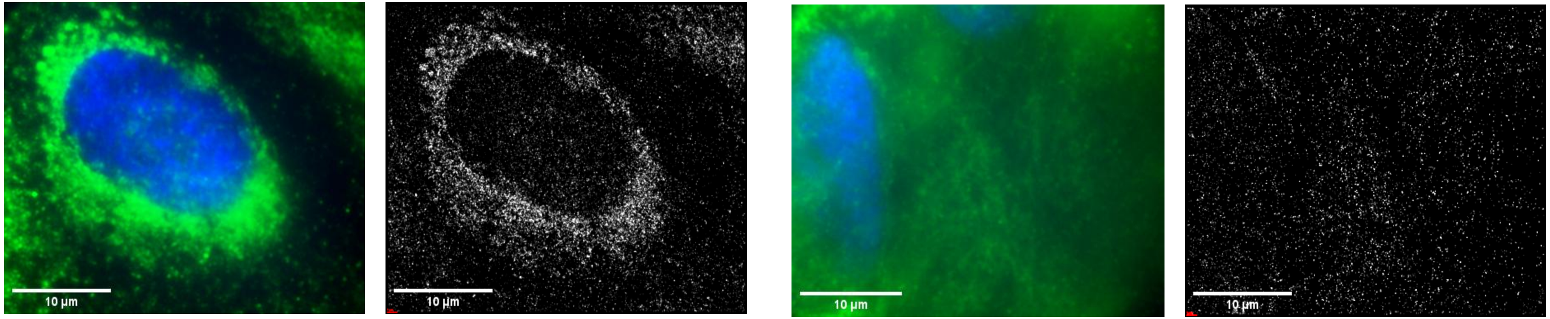

⇒ Mes-Mac cells with highest LPS signal, followed by M1/M2 macrophages

⇒ Mes-Mac cells positive for immune cell markers CD16, CD68, CD163, CD45, CD14

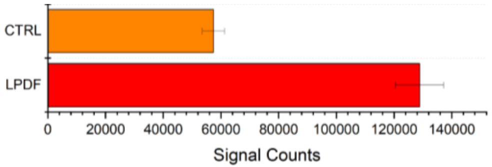
CD14: strongly on the surface of monocytes and weakly on the surface of granulocytes; also expressed by most tissue macrophages, co-receptor for LPS; CD68: macrophage marker; aSMA: activated fibroblasts, smooth muscle cells; CD31: endothelial cell; LPS: endotoxin; Cytokeratin: marker for mesothelial cells; D2-40: podoplanin; PROX1: lymphatic endothelium; CD163: monocytes and mature macrophages;

FSP1: fibroblasts; CD16: macrophage marker – natural killer cells, macrophages, subpopulation of T-cells, immature thymocytes and placental trophoblasts; CD45: human leukocytes

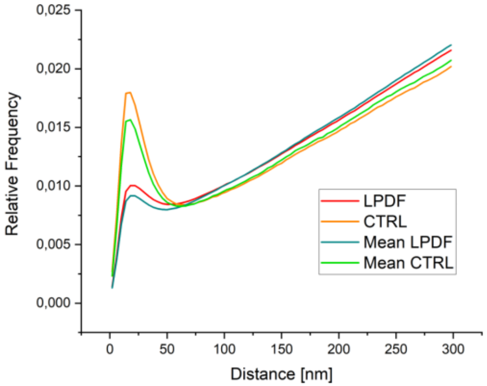
# Single endothelial glycocalyx molecule imaging, of a barrier in PD




Hyaluronan Molecule counts

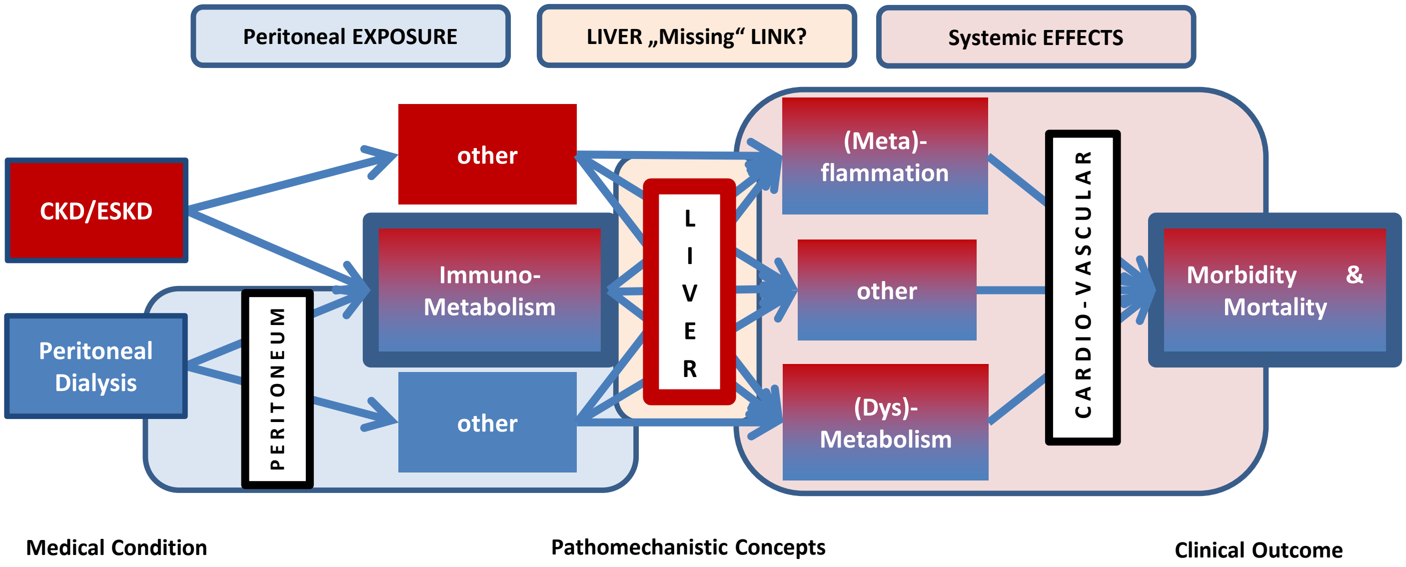



Distance distributions




⇒ PD fluid reduces hyaluronan clustering independently of higher molecule count

# Understanding the Peritoneal-Immunometabolic- Liver-Metaflammation- CVD axis to develop next generation PD fluids



# Thank you!

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HORIZON 2020

MARIE CURIE ACTIONS

Baden-Württemberg Stiftung WIR STIFTEN ZUKUNFT

IMPROVE-PD New frontiers in Peritoneal Dialysis