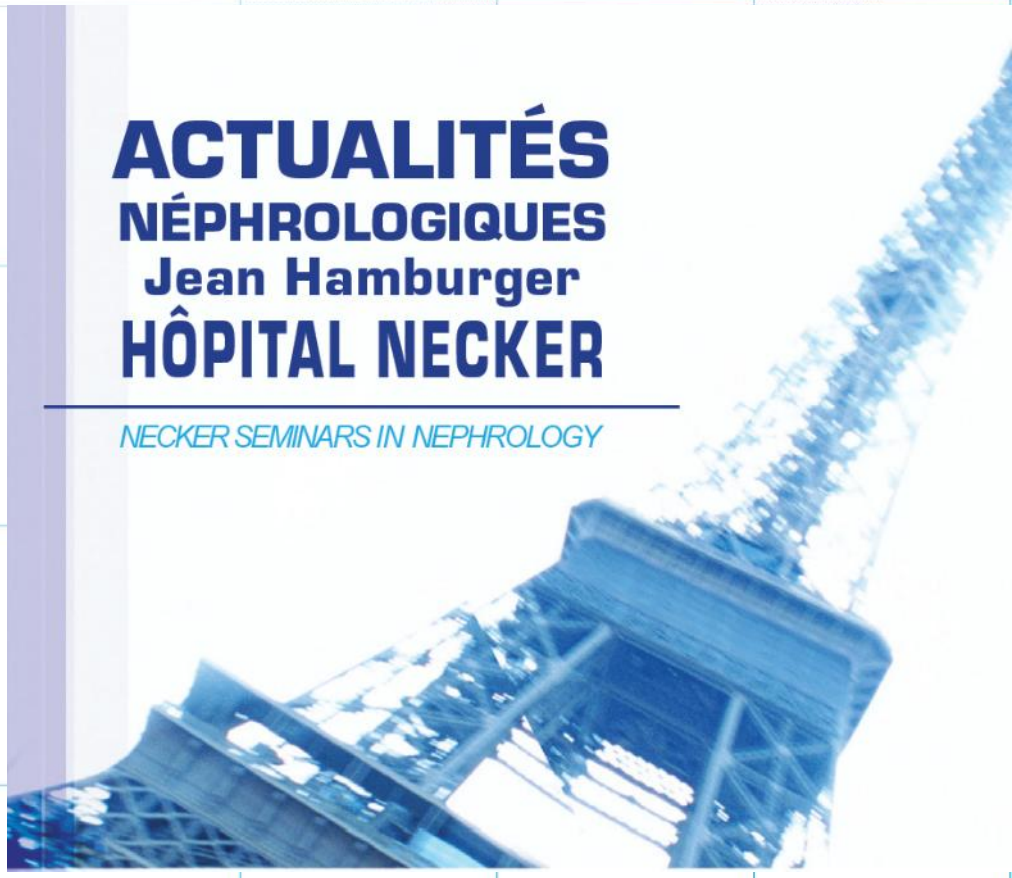
Quantifier la surcharge sodée du dialysé

Pr Sandrine Lemoine
Service de néphrologie, dialyse et physiologie rénale
Hôpital Edouard Herriot
Lyon

14 mai 2025



RÉGULATION DE L'HOMÉOSTASIE HYDRO-SODÉE EN HD

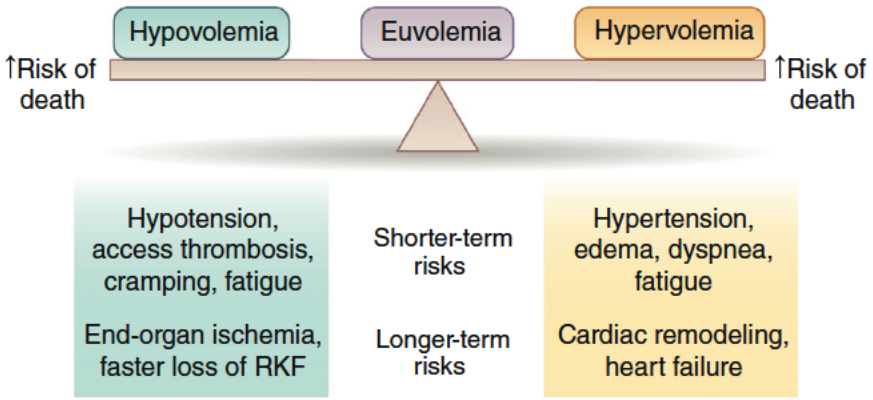
Un challenge…

- ✓ Limiter la consommation en eau et en sel
- ✓ Ultrafiltration
- ✓ Prescription dialysat en sodium

KDIGO: Pas de consensus sur la prescription du sodium en dialyse

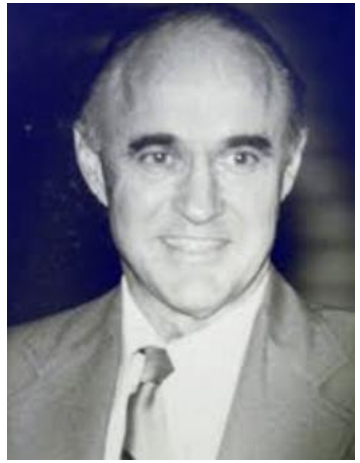
Blood pressure and volume management in dialysis: conclusions from a Kidney Disease: Improving Global Outcomes (KDIGO) Controversies Conference

Jennifer E. Flythe[1,2], Tara I. Chang[3], Martin P. Gallagher[4,5], Elizabeth Lindley[6], Magdalena Madero[7], Pantelis A. Sarafidis[8], Mark L. Unruh[9], Angela Yee-Moon Wang[10], Daniel E. Weiner[11], Michael Cheung[12], Michel Jadoul[13], Wolfgang C. Winkelmayer[14] and Kevan R. Polkinghorne[15,16,17]; for Conference Participants[18]



Flythe et al, Kidney international, 2020

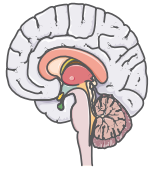
PHYSIOLOGIE DU SODIUM ET LA THÉORIE DE GUYTON



Balance sodée positive

↓

Stimulation des osmorécepteurs Centraux



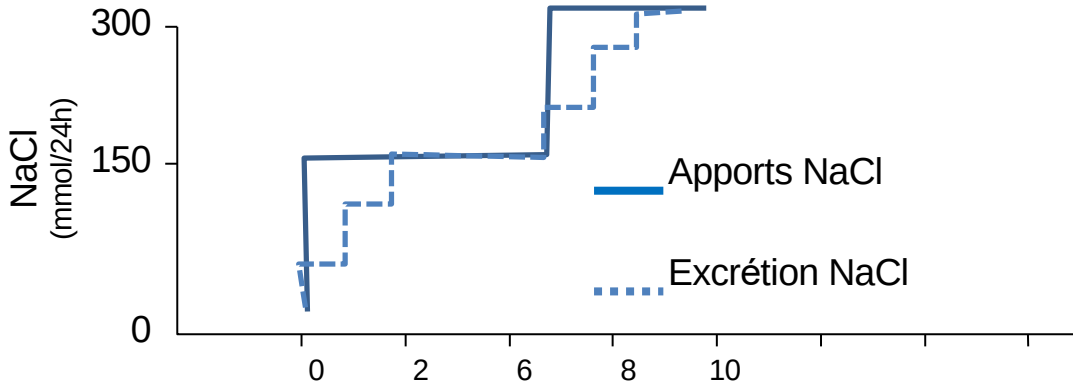
ADH → Réabsorption tubulaire d'eau

Soif → Ingestion d ’eau

Augmentation des LEC → ↑Pression artérielle

↓

↑ Natriurèse



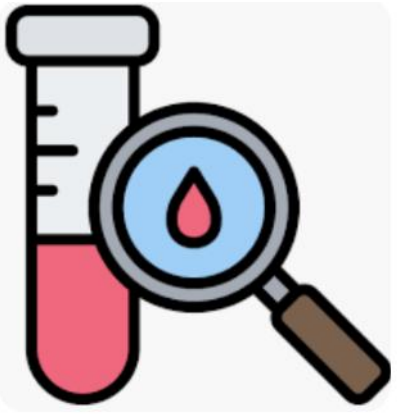
⇨ **Sodium osmotiquement actif**

COMMENT QUANTIFIER CE SODIUM OSMOTIQUEMENT ACTIF?

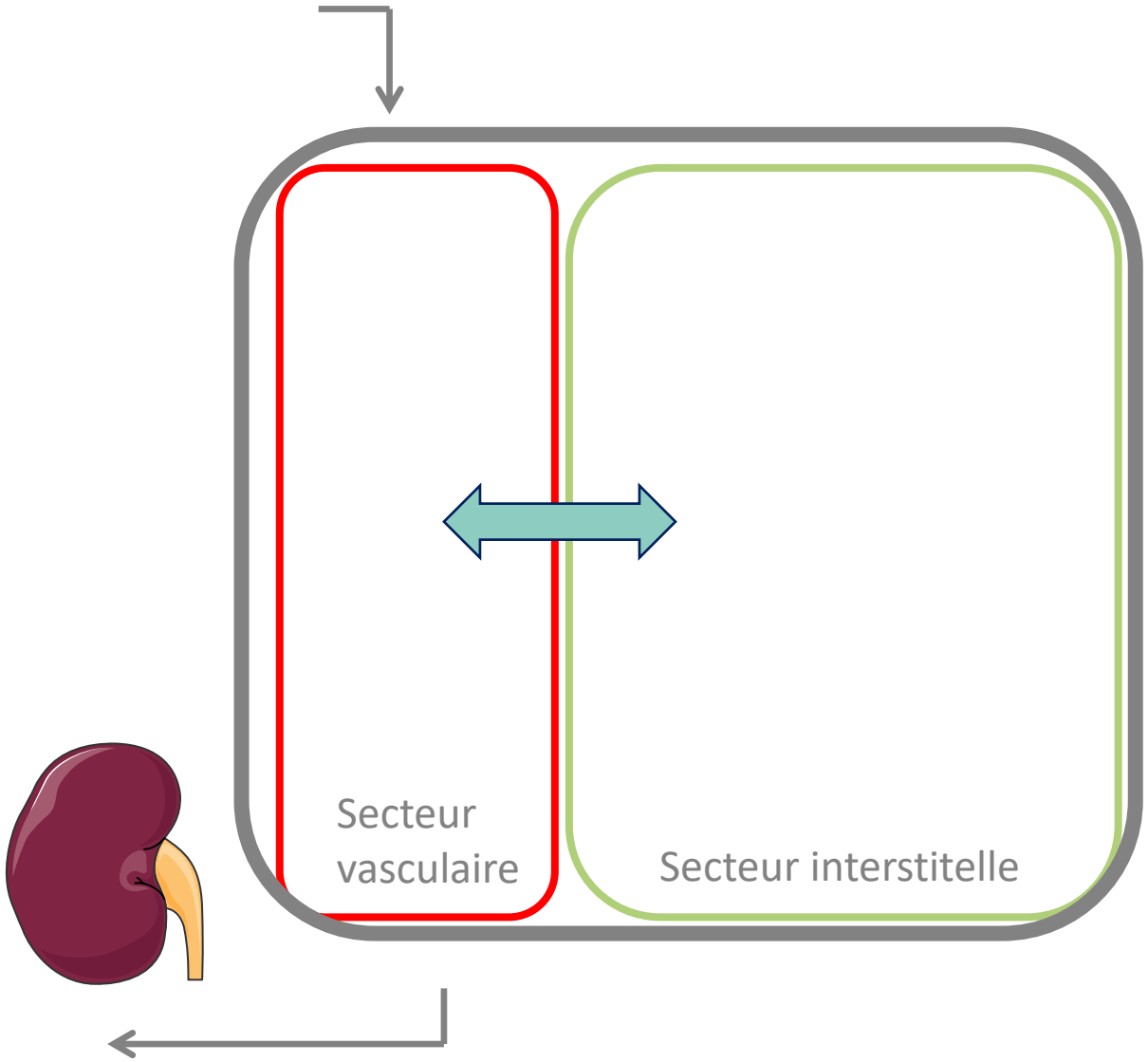
Poids sec
OMI
Pression artérielle

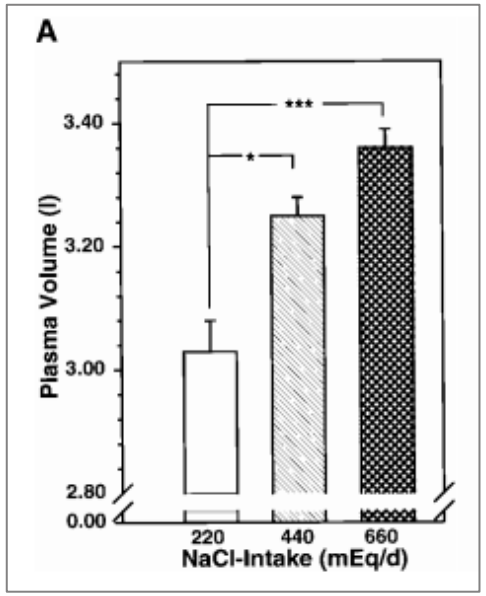
Impedancemétrie

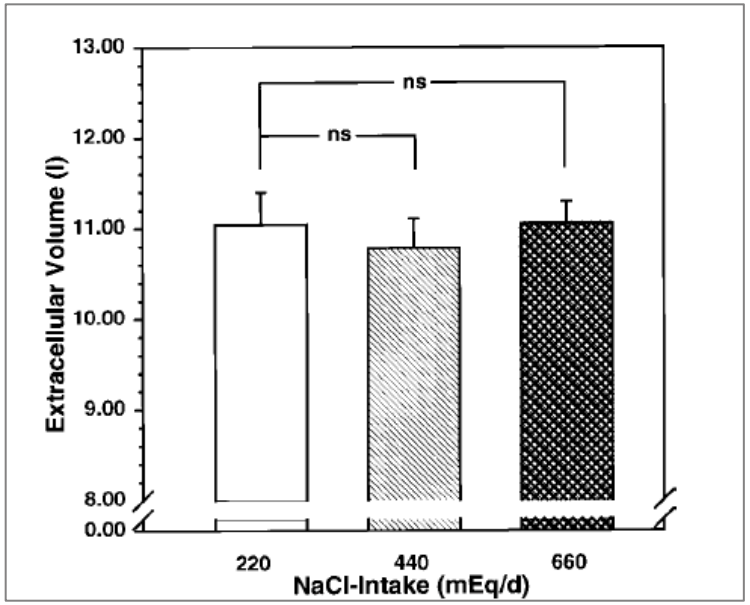
Biomarqueurs sanguins

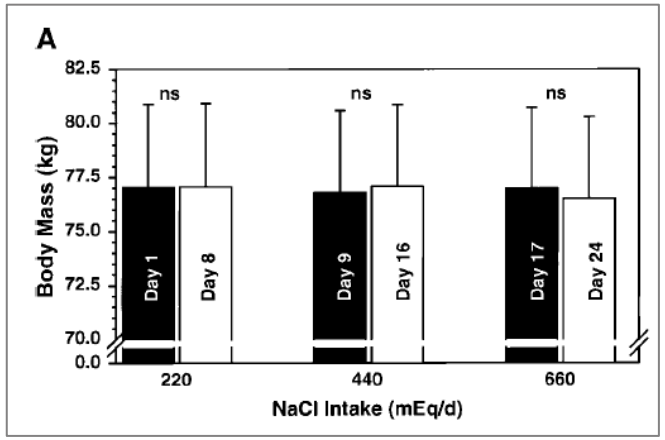


PHYSIOLOGIE DU SODIUM: EVOLUTION DU CONCEPT?



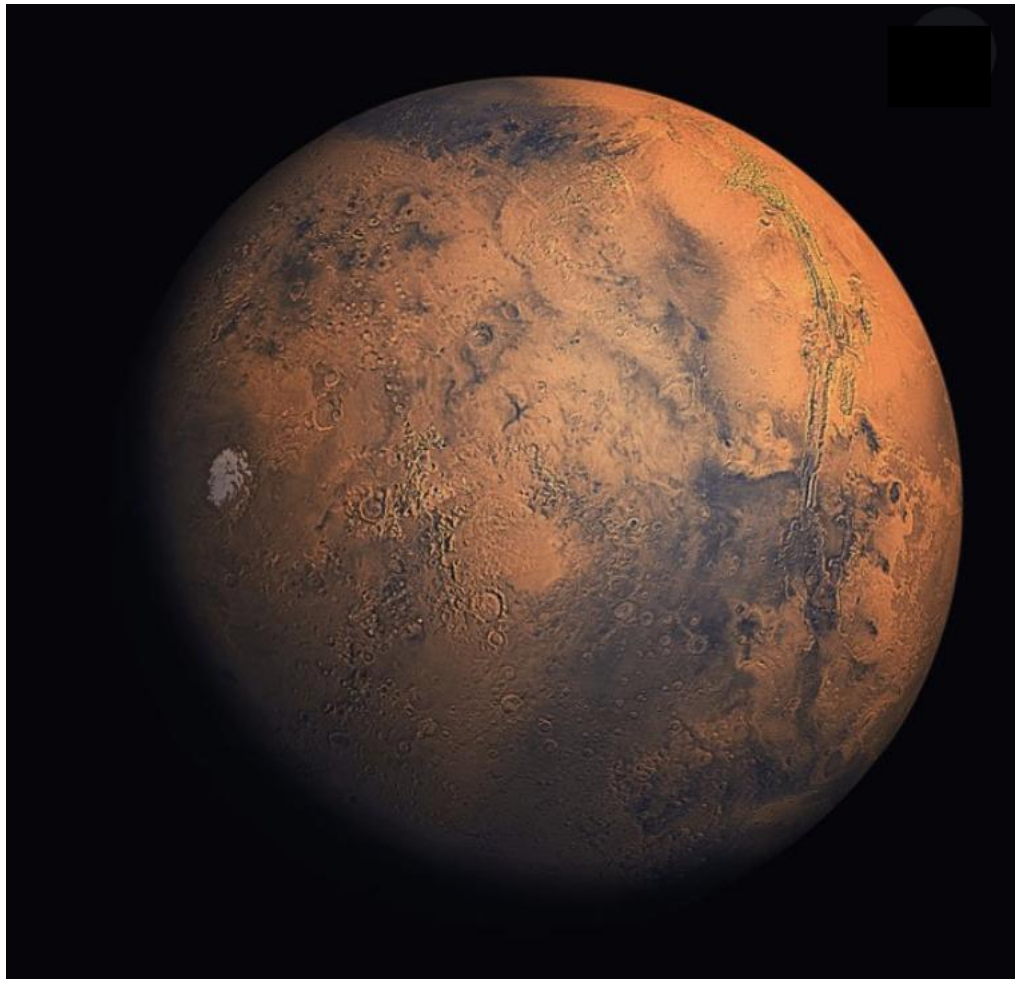




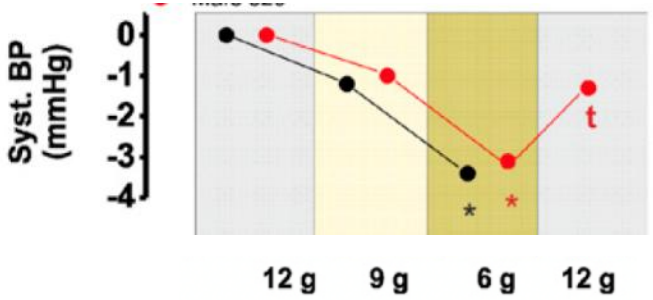


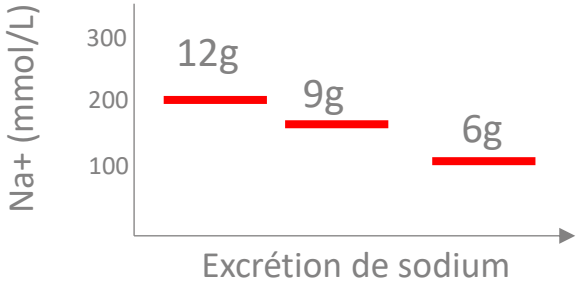
Heer et al, Am J Physiol Renal physiol, 2000; Titze, renal AJP, 2008

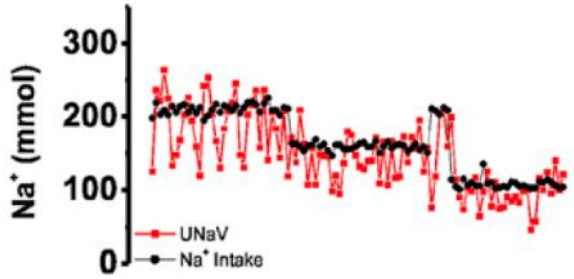
DU MARS AU SODIUM CUTANÉE …

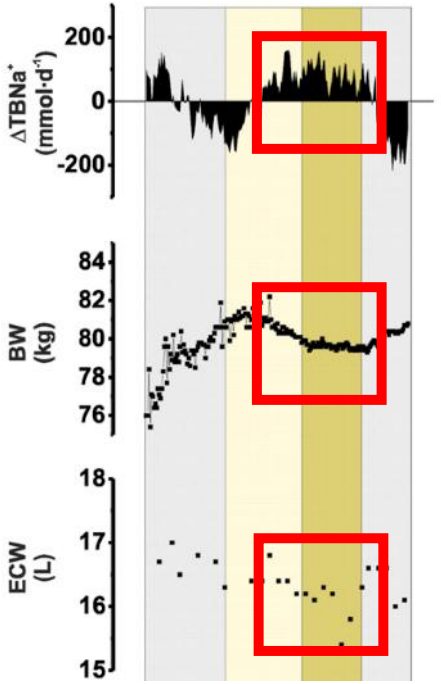


PHYSIOLOGIE DU SODIUM: EVOLUTION DU CONCEPT?









→ Augmentation du contenu corporel en sodium

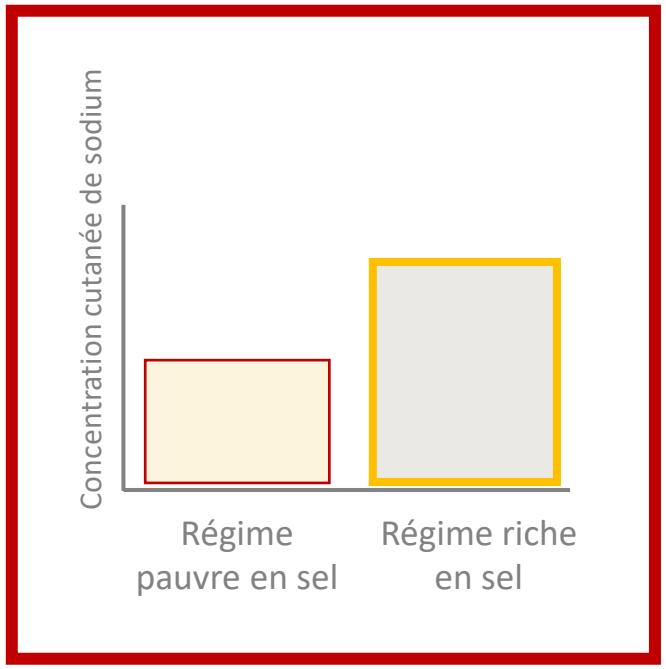
→ Pas de variation de poids

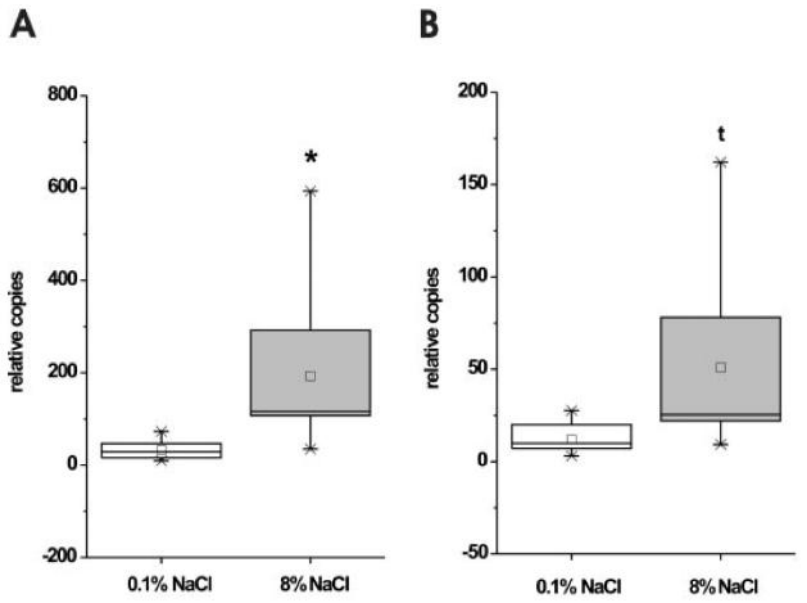
→ Pas de variation du secteur extra-cellulaire

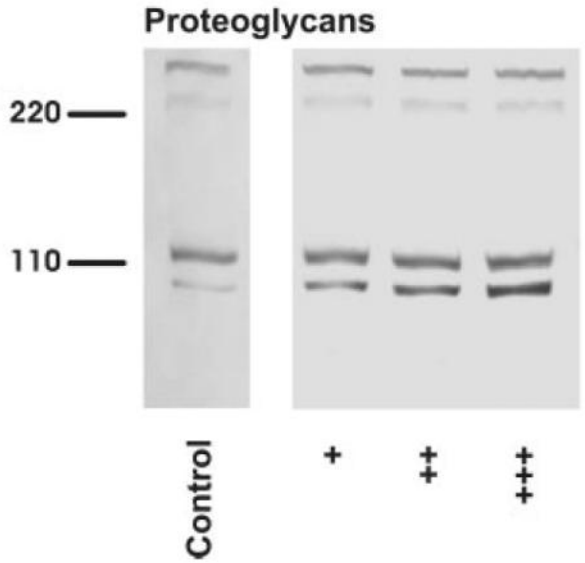
→ Sodium non-osmotiquement actif suspecté

Rakova N, Juttner K, Dahlmann A, et al. Long-term space flight simulation reveals infradian rhythmicity in human Na(fl) balance. Cell metabolism 2013

PHYSIOLOGIE DU SODIUM: EVOLUTION DU CONCEPT?



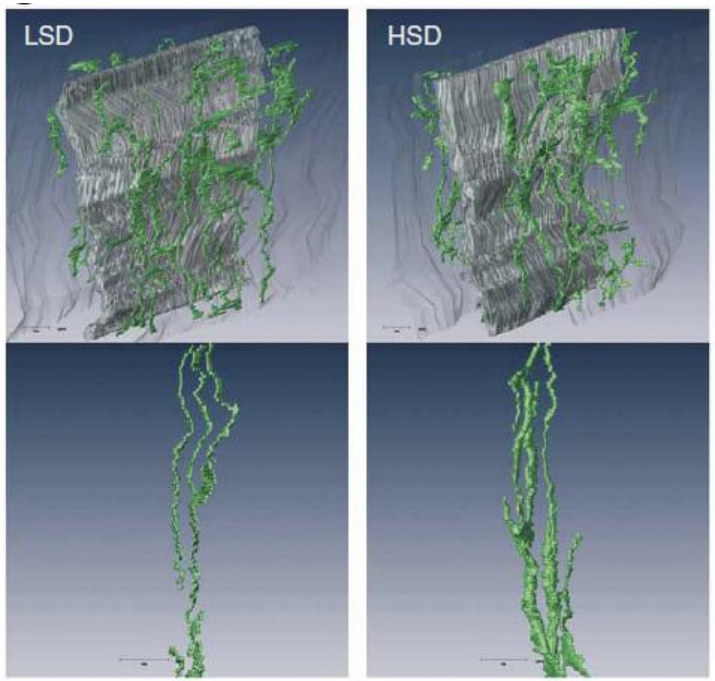




J Titze, renal AJP, 2004 –

PHYSIOLOGIE DU SODIUM: EVOLUTION DU CONCEPT?

Régime riche en sodium augmente la densité des capillaires lymphatique



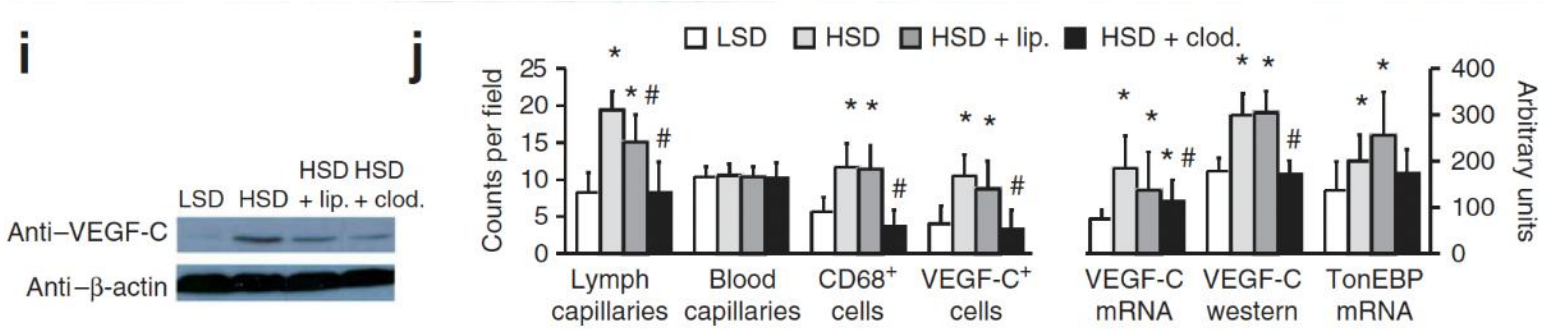


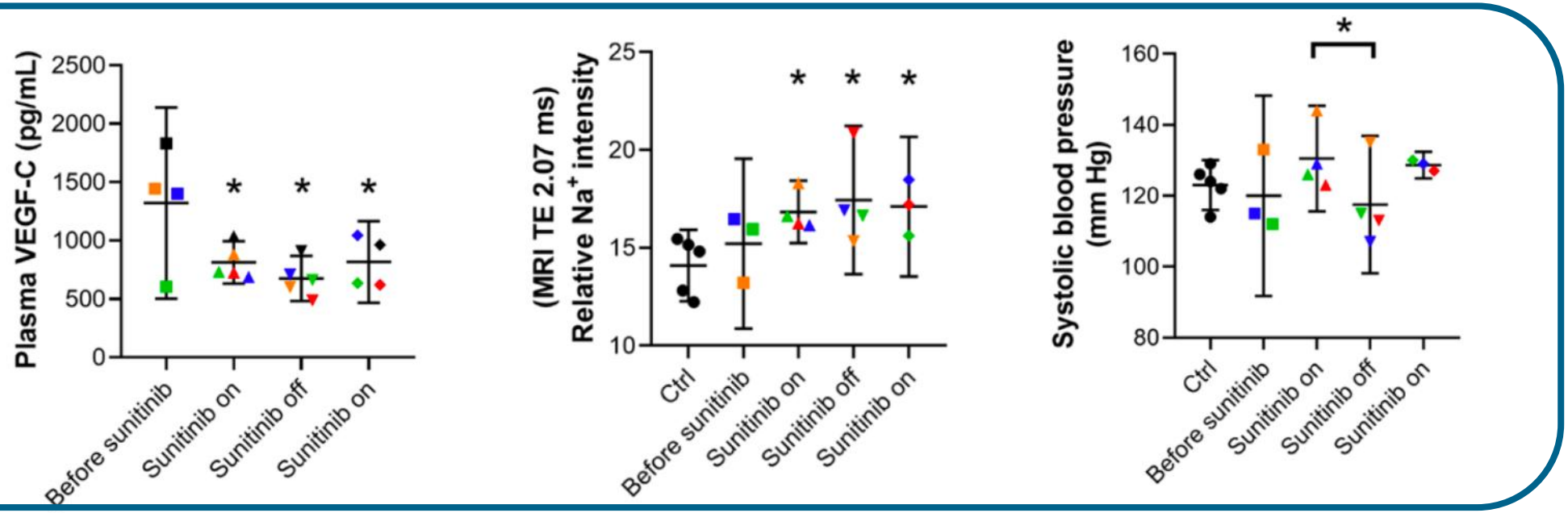
Table 2. General parameters in healthy subjects during LS and HS diet

General parameters in healthy subjects ($n = 31$)	LS	HS	P-value
Proteinuria (g/day)	<0.2	<0.2	-
Systolic blood pressure (mmHg)	123 ± 2	124 ± 1	0.138
Diastolic blood pressure (mmHg)	68 ± 1	69 ± 1	0.453
Mean arterial pressure (mmHg)	86 ± 8	87 ± 7	0.251
Creatinine clearance (mL/min)	103 ± 5	123 ± 5	0.003
NT-proBNP (pg/mL)	14 (11 – 19)	26 (20 – 35)	0.002
Body weight (kg)	79.9 ± 2.1	81.6 ± 2.1	<0.001
ECV (L)	19.8 ± 0.5	20.8 ± 0.5	0.023
Plasma VEGF-C (pg/mL)	773 (748 – 921)	881 (758 – 1023)	0.070
Toatl amount of VEGF-C (pg)	14539 (1002 – 22751)	18176 (14320 – 26405)	0.01
Plasma Na^+ (mmol/L)	138.5 ± 0.4	139.8 ± 0.4	0.00
Urinary Na^+ (mmol/day)	46 ± 11	257 ± 16	<0.00

LS = low-sodium diet, HS = high-sodium diet, Total amount of VEGF-C is calculated as plasma VEGF-C× ECV. Reference value NT-proBNP < 125 ng/L

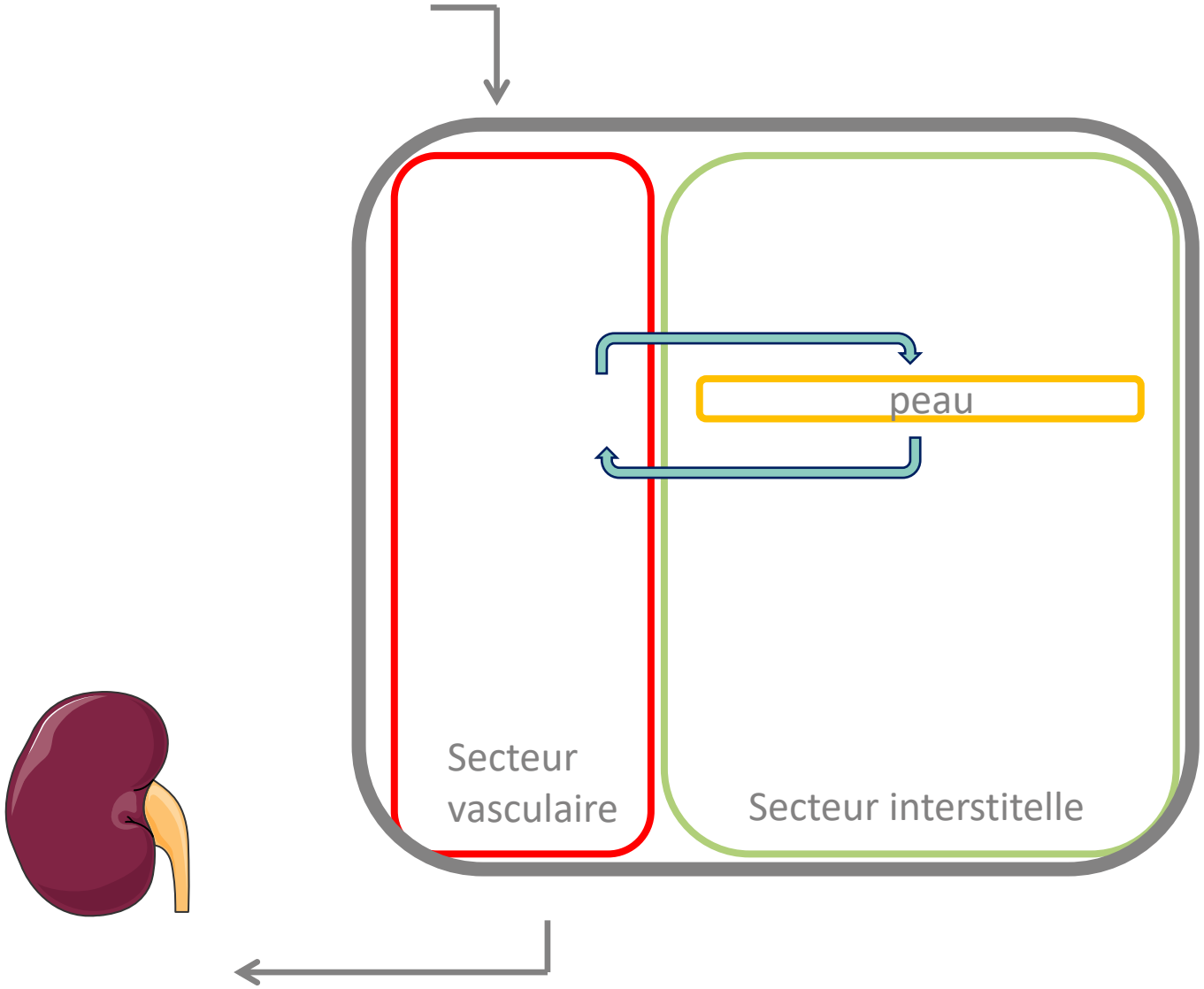
Maknick A, 2009, Nature Comun- *Slagman M, NDT, 2012*

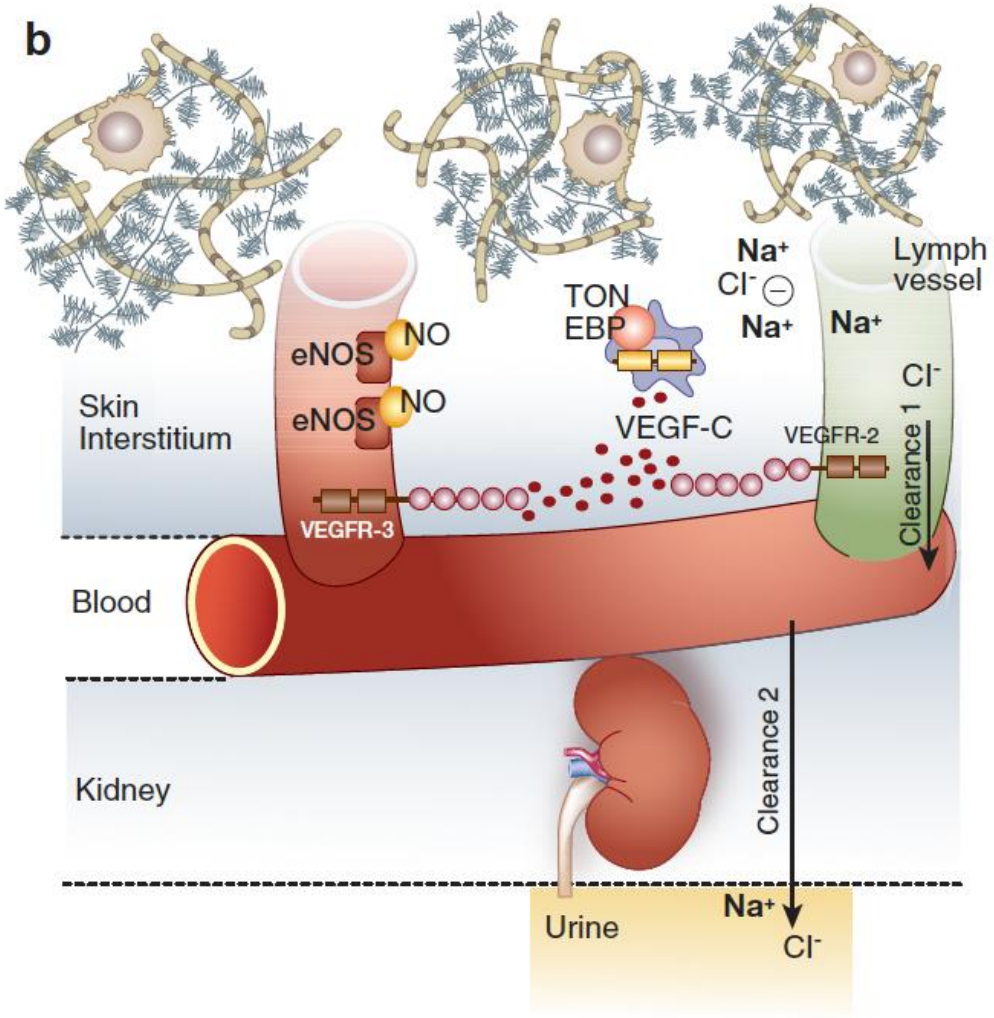
PHYSIOLOGIE DU SODIUM: EVOLUTION DU CONCEPT?



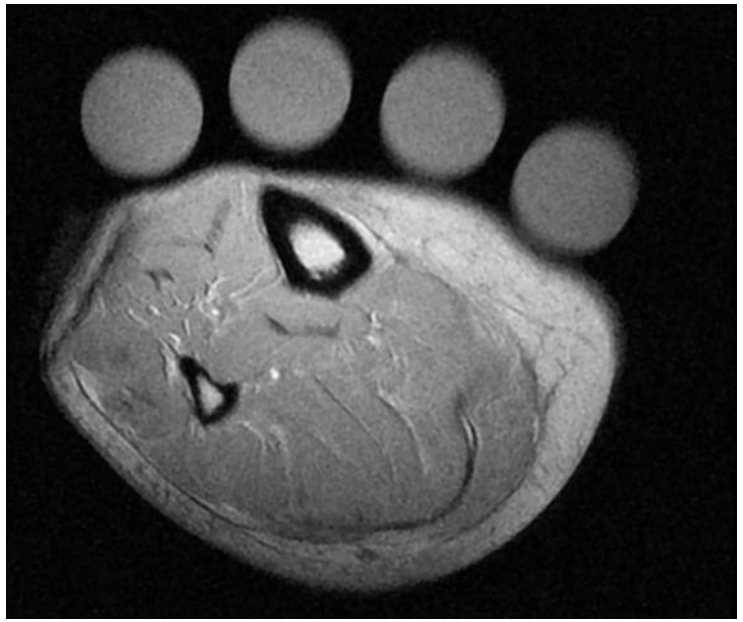
Dahlman, KI, 2015 *Marko, hypertension, 2022*

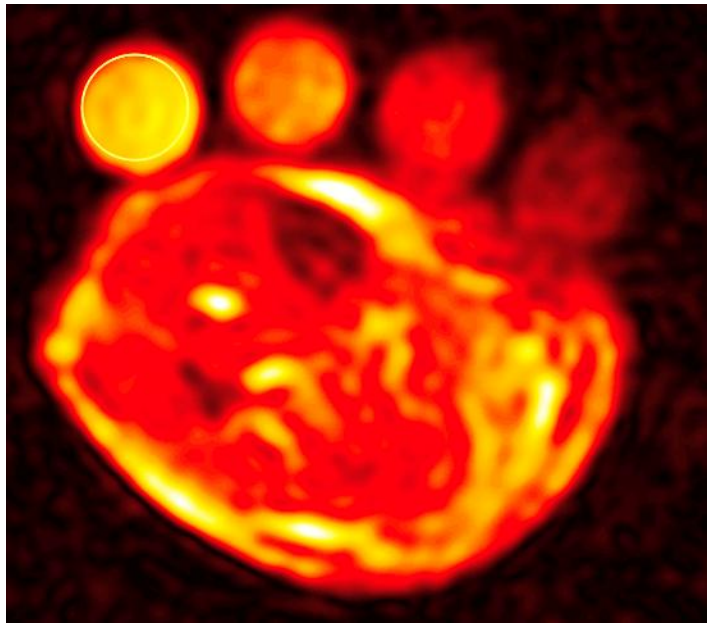
PHYSIOLOGIE DU SODIUM: EVOLUTION DU CONCEPT?





^{23}NA MRI : TECHNICALLY CHALLENGING





Mesure non invasive

Quantitative pour les organes superficiels

La sensibilité de l'IRM au sodium est d'env 10 % de celle du proton [Na^+] <<< [H^+]

Temps de scannage pour 1 image = 15 min

SPECTRO-RMN: IMPLICATIONS TECHNIQUES

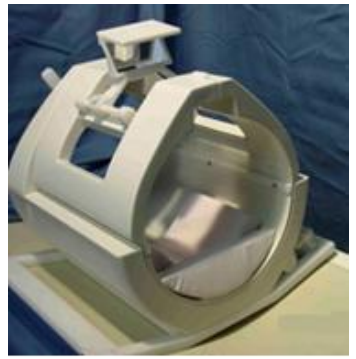
De préférence sur des IRMs 3T

Contraintes techniques couteuses car:

La spectroscopie multinoyaux nécessite une **chaine de radio-fréquence supplémentaire adaptée** en fréquence à chaque noyau étudié

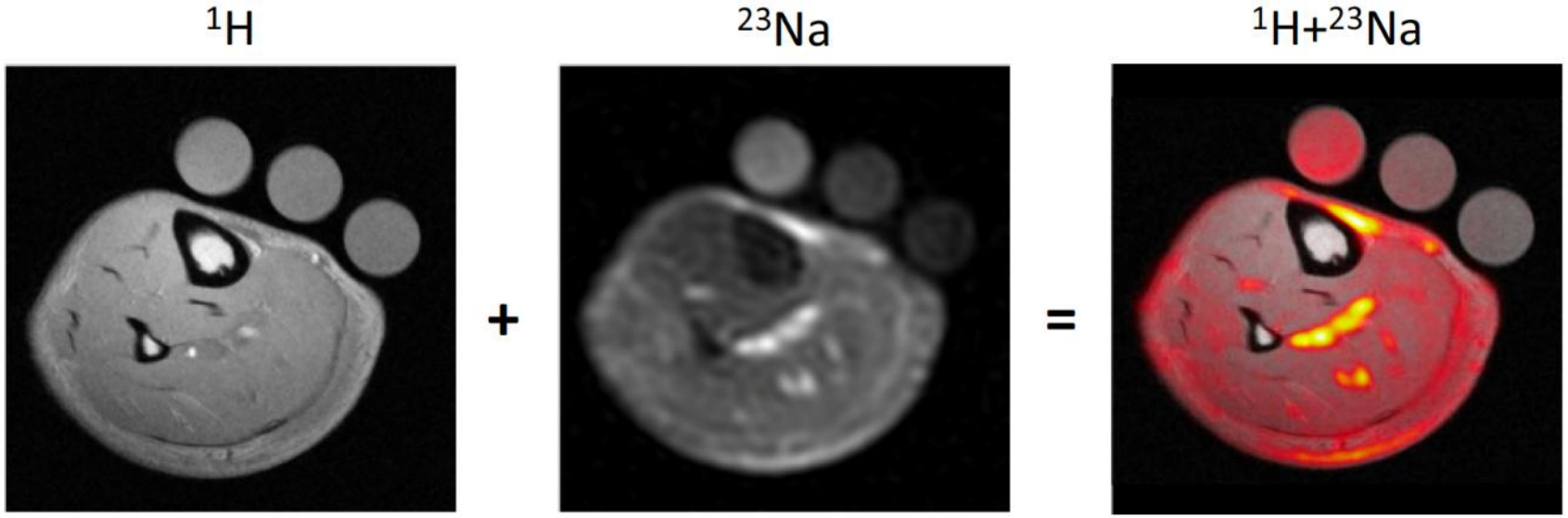
Antenne de surface ou une birdcage double accord 1H/31P

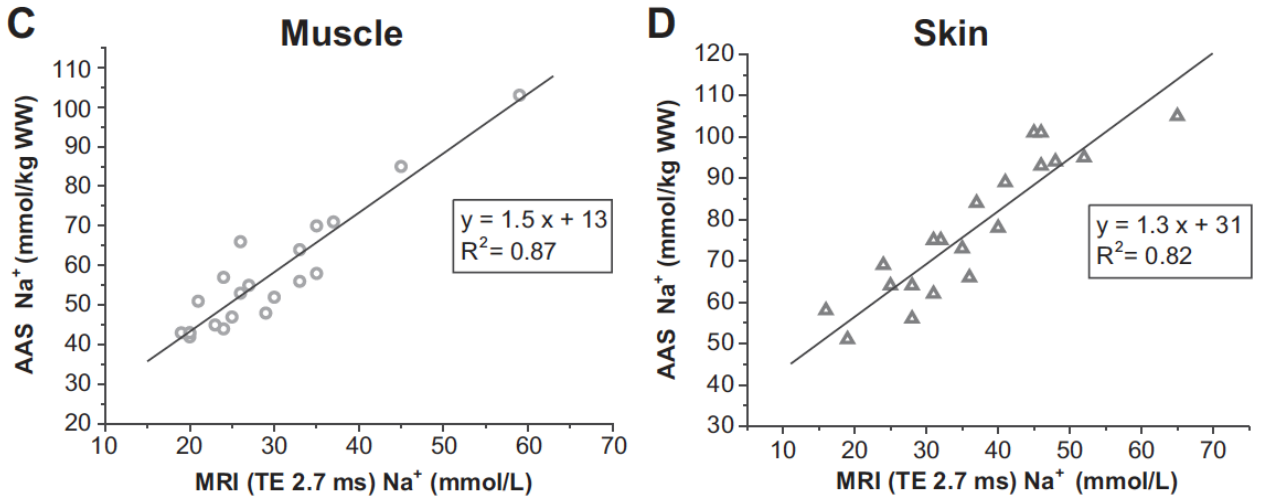
→ Nécessite un ingénieur/physicien



Couplage images morphologiques (Proton) et fonctionnelle non invasive, quantitative ou semi-quantitative

23NaMRI

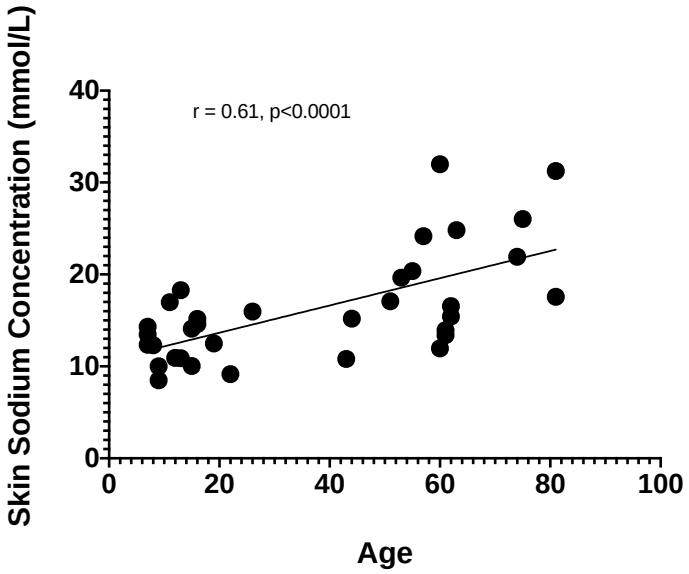

^{1}H
^{23}Na
$^{1}H+^{23}Na$
+
=

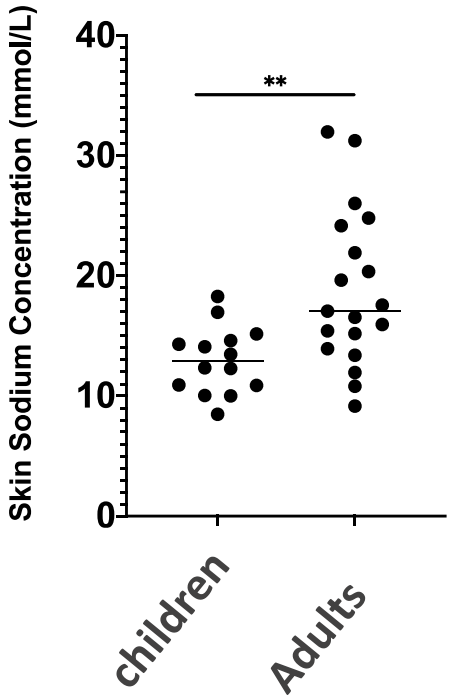

C
Muscle
AAS Na+ (mmol/kg WW)
MRI (TE 2.7 ms) Na+ (mmol/L)
y = 1.5 x + 13
R2= 0.87
D
Skin
AAS Na+ (mmol/kg WW)
MRI (TE 2.7 ms) Na+ (mmol/L)
y = 1.3 x + 31
R2= 0.82

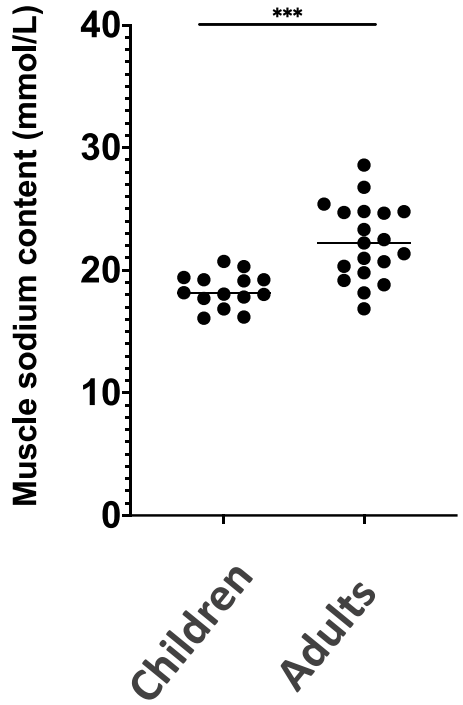
LE SODIUM TISSULAIRE

Unpublished data, S. Lemoine and C.M McIntyre.

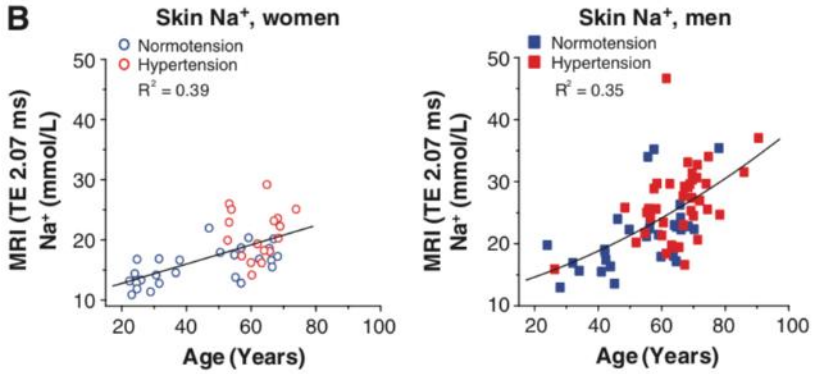
Age





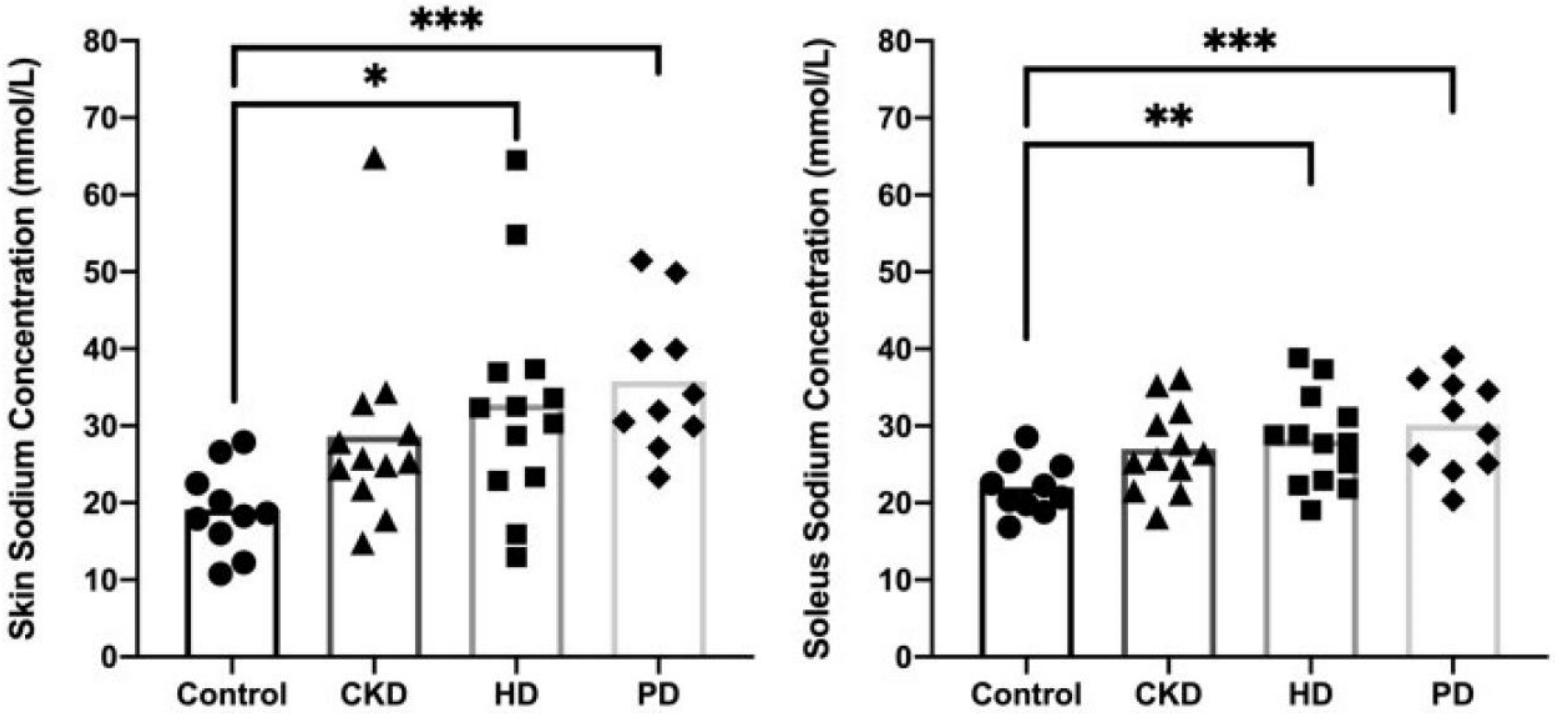


Sexe



Kopp et al, hypertension, 2013

LE SODIUM TISSULAIRE, MRC, HD ET DP



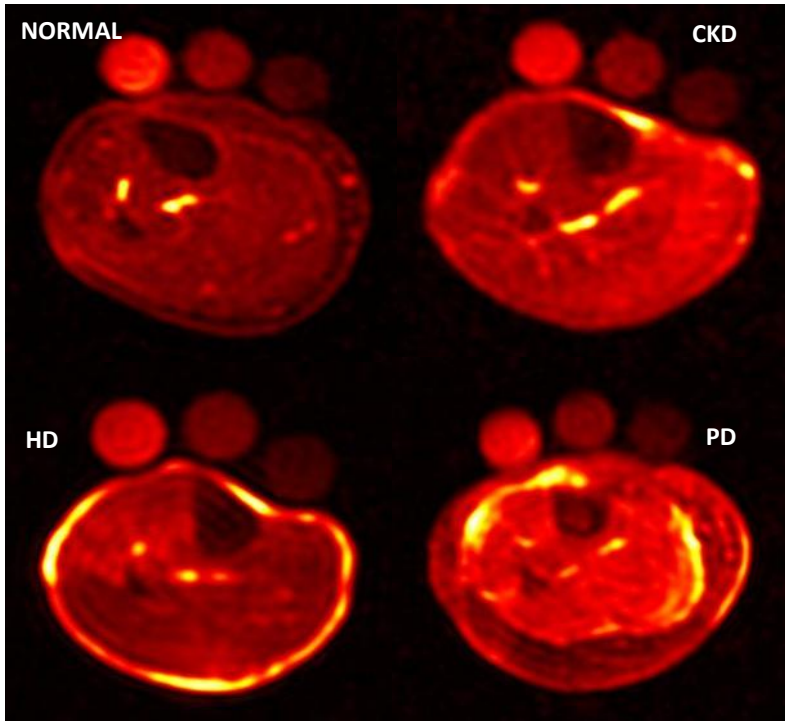


FIGURE 4: Between-group comparison in mean tissue sodium concentration [(A) skin; (B) soleus and (C) tibia]. *P < 0.01; **P < 0.001; ***P < 0.0001.

Qirjazi, McIntyre, NDT, 2020

LE SODIUM TISSULAIRE PEUT-IL ÊTRE MOBILISÉ?

With loop diuretic

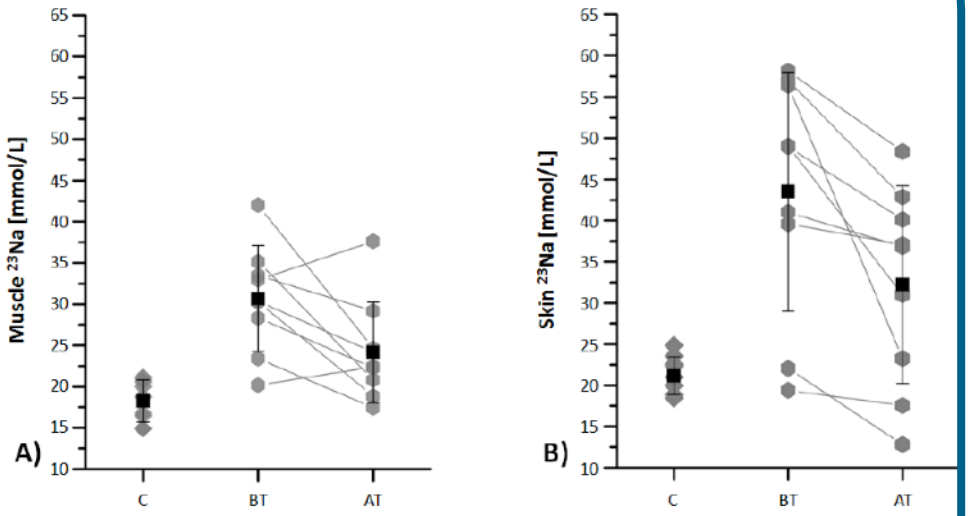
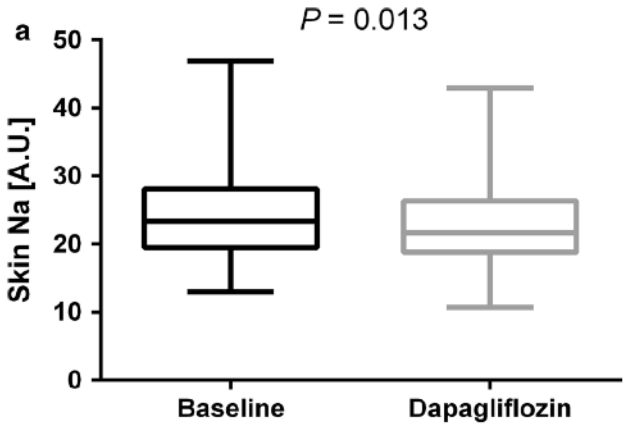


Table 2. Demographic data and results.

	Patients	
Gender	7 men/2 women	
Age [years]	78 (range: 58–87)	
	Before Therapy	**After Therapy**
Muscle Na^+ [mmol/L]	30.7 ± 6.4	24.2 ± 6.1
Skin Na^+ [mmol/L]	43.5± 14.5	32.2 ± 12.0
Whole lower leg Na^+ [mmol/L]	44.7 ± 15.3	29.9 ± 10.7

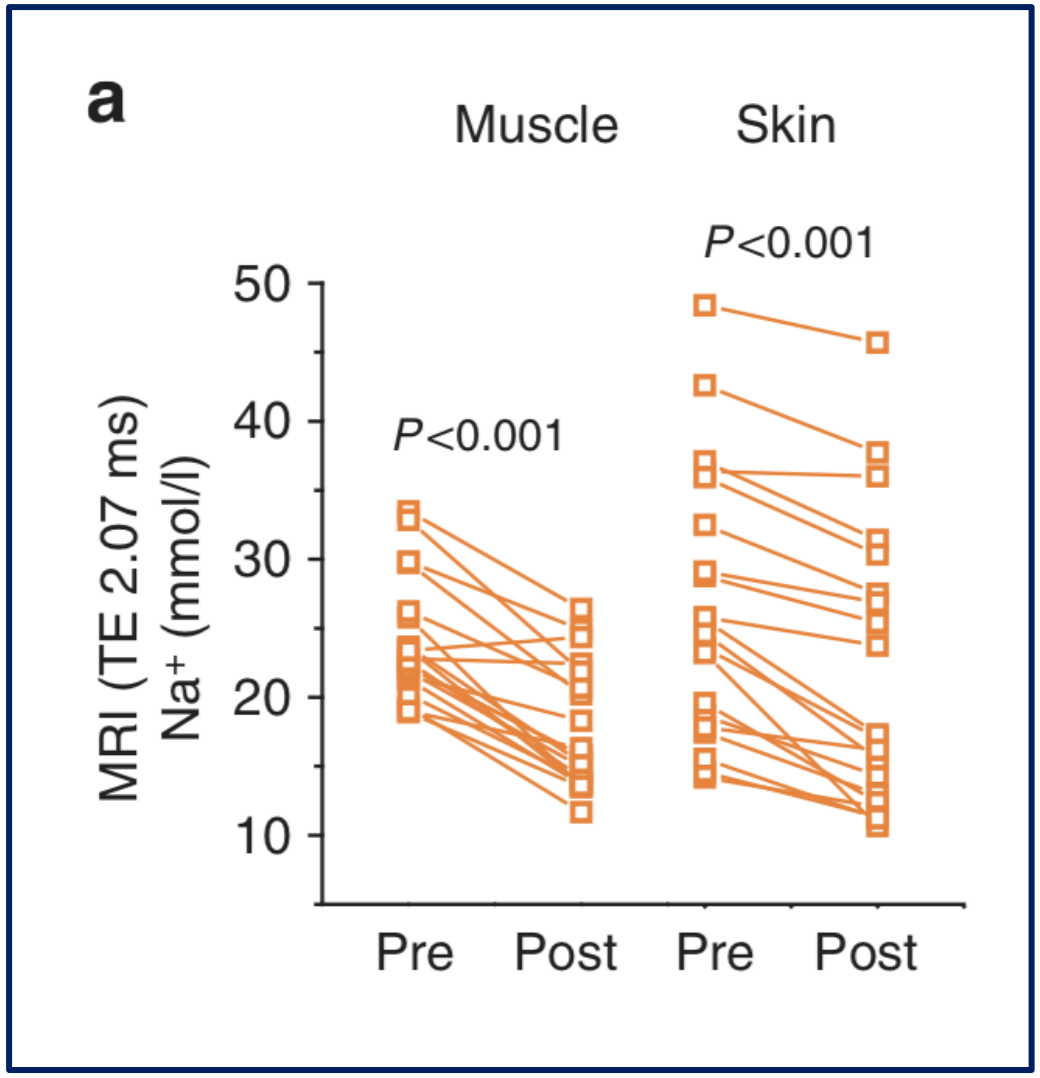
Hammon et al, Plos one, 2025

With SGLT2i



Karg et al. Cardiovasc Diabetol (2018)

LE SODIUM TISSULAIRE PEUT-IL ÊTRE MOBILISÉ EN DIALYSE ?



HD removes osmotic and non osmotic active sodium

Dahlmann et al, Kidney international 2015

METHOD

✓ **hypothesis**

Na dialysate prescription can modify tissular sodium content

Prospective observational study

NCT03004547

36 patients in HD > 3 mois

resolve

Randomised Evaluation of SOdium dialysate Levels on Vascular Events

18 patients [137 mmol/L]

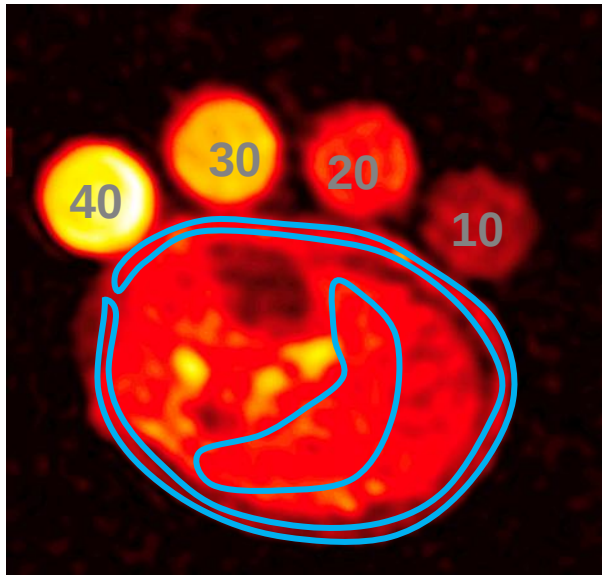
18 patients [140 mmol/L]

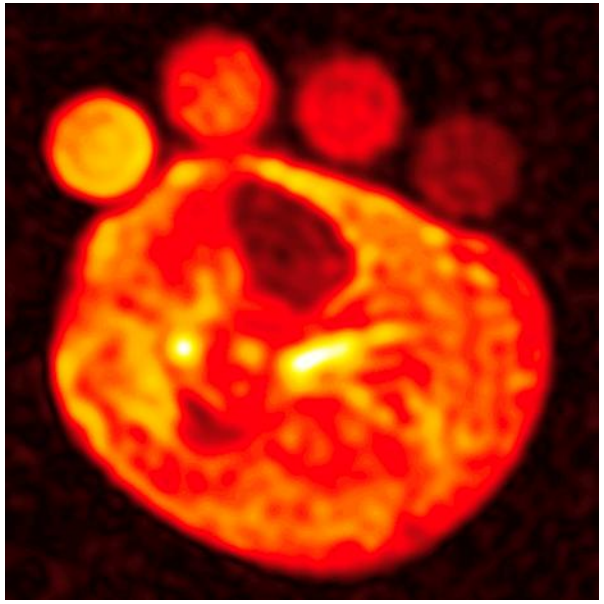
^{23}NaMRI

Mid week

Non dialysis day

Blood pressure





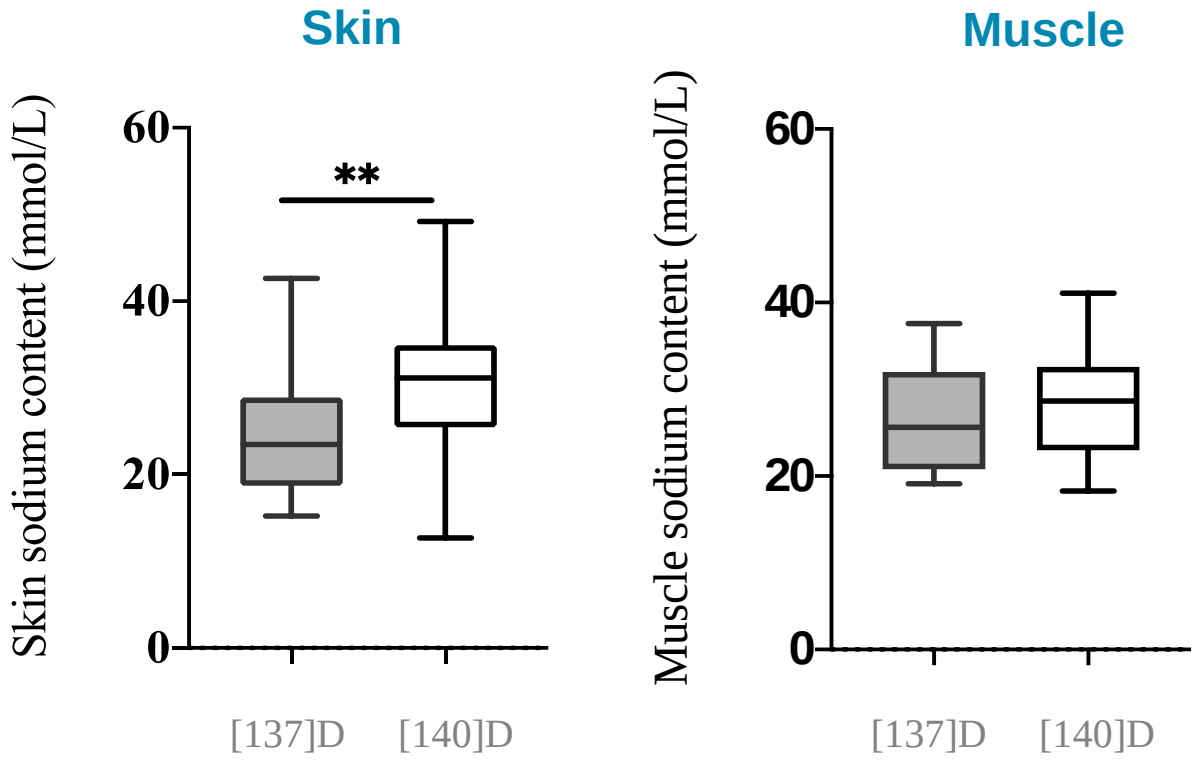
Lemoine S, *Salerno F, Akbari A McIntyre CW. AJKD Feb 2021*

PATIENTS CHARACTERISTICS

	137 mmol/L	140 mmol/L
Age	66 yo (47-79)	65 yo (40-82)
% men	55%	66%
BMI (kg/m^2)	31,5 (21.6 – 41.1)	32.4 (21.4 – 43)
PAS/PAD	128/73 mmHg	133/79 mmHG
% Hypertension	83 %	88 %
% DT2	57 %	66 %
Dialysis vintage	19 months	22 months
Interdialytic weight	1.65 kg (0 – 3.2)	2.3 kg (0.1 – 5)

Lemoine S, *Salerno F, Akbari A McIntyre CW. AJKD Feb 2021*

SODIUM 137 ET 140 MMOL/L PRESCRIPTION AND TISSULAR SODIUM CONTENT

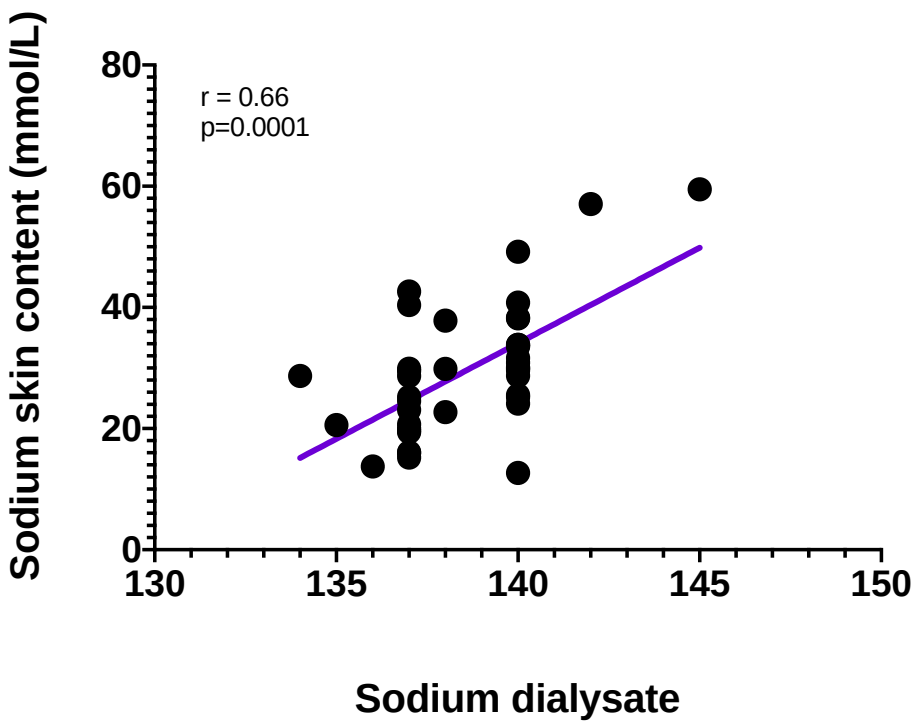


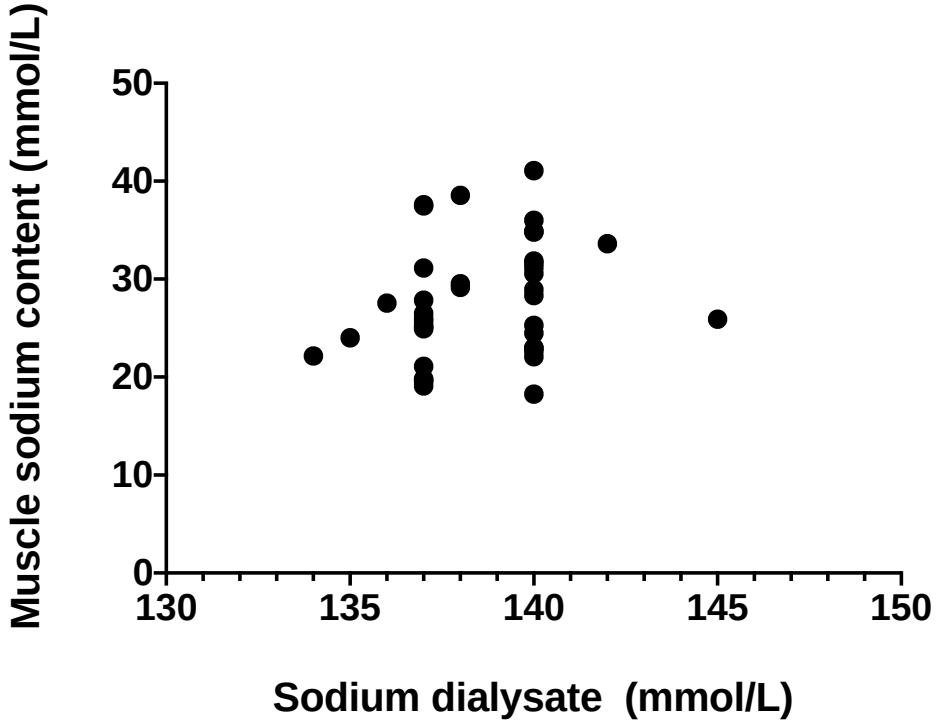
→skin sodium content is significantly lower in [137] than [140] concentration

Lemoine S, *Salerno F, Akbari A McIntyre CW. AJKD Feb 2021*

RELATIONSHIP BETWEEN SODIUM DIALYSAT AND TISSULAR SODIUM

On the whole Cohorts, n=50

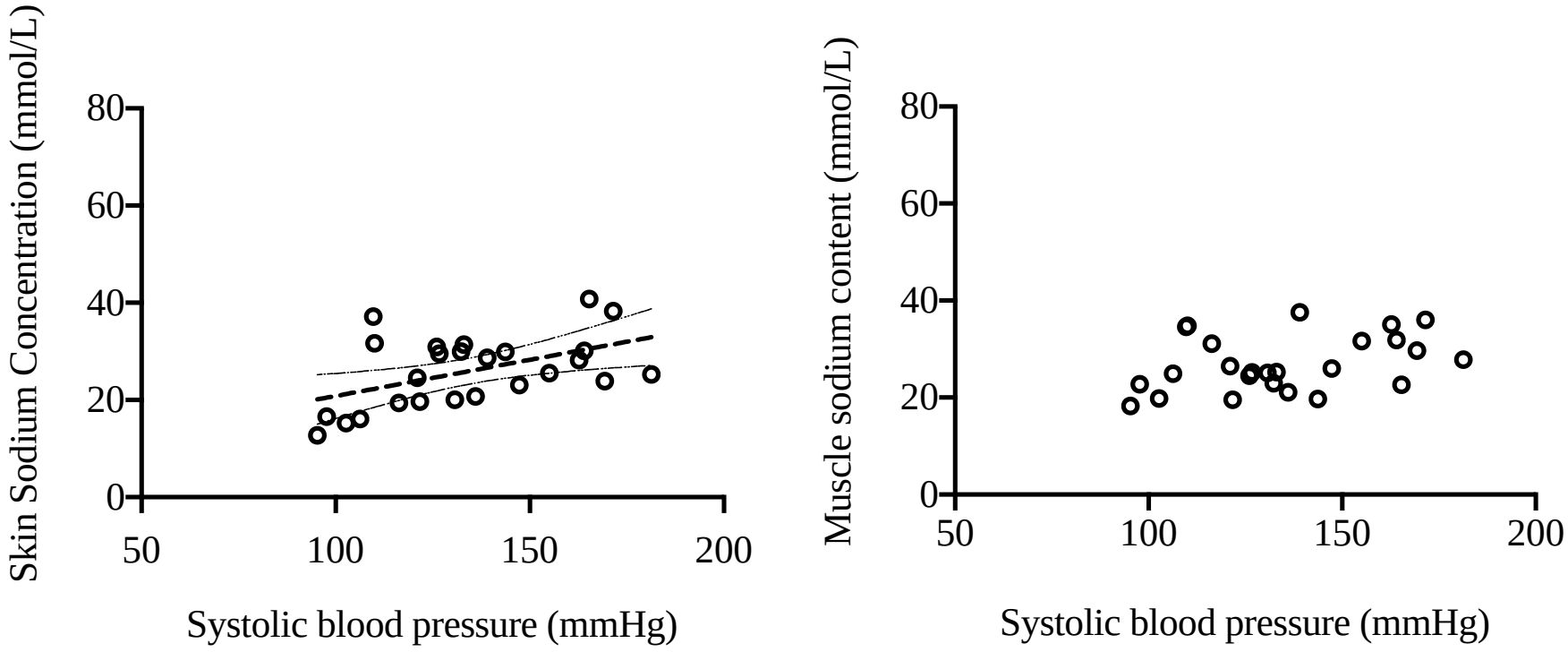




P=0.06

S. Lemoine and CW McIntyre's data

BLOOD PRESSURE AND SODIUM CONTENT



→ **Positive correlation netween BP and skin sodium concentration**

Lemoine S, *Salerno F, Akbari A McIntyre CW. AJKD Feb 2021*

DO WE HAVE OTHERS PARAMETERS IN HD THAT COULD IMPACT TISSULAR SODIUM CONTENT ?

→ **No impact of residual kidney function, dialysis vintage and vascular access.**

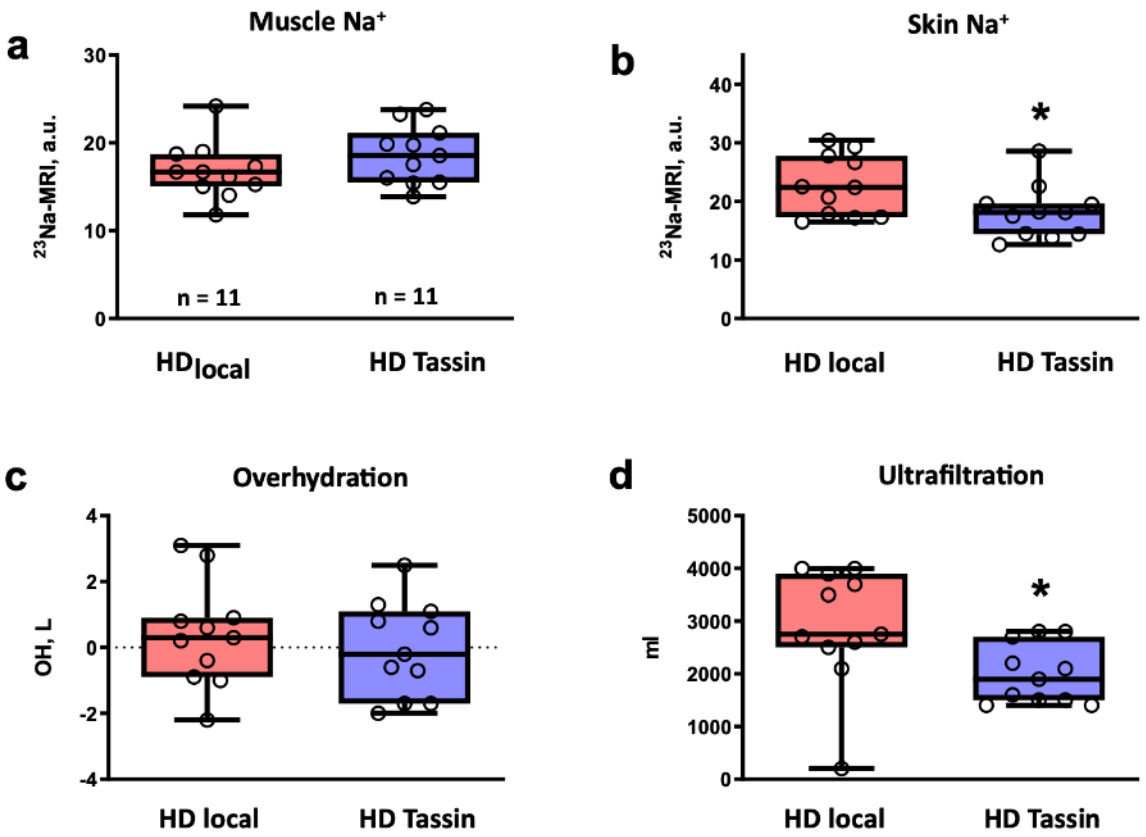
S. Lemoine and CW McIntyre's data

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

1) Durée longue d'HD associée à un régime strict en sodium (Tassin, France)

11 patients de Tassin vs 11 patients matchées en âge et sexe d'Allemagne

La concentration cutanée de sodium est-elle du UF?
Sodium du dialysat?
Longueur du traitement?



Kopp et al, kidney international reports, 2024

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

2) Cohorte d'HD en Allemagne (n=75 patients)

→ Part A: UF : 37 patients en HD UF <2.4 l vs 38 patients on HD > 2.4 l

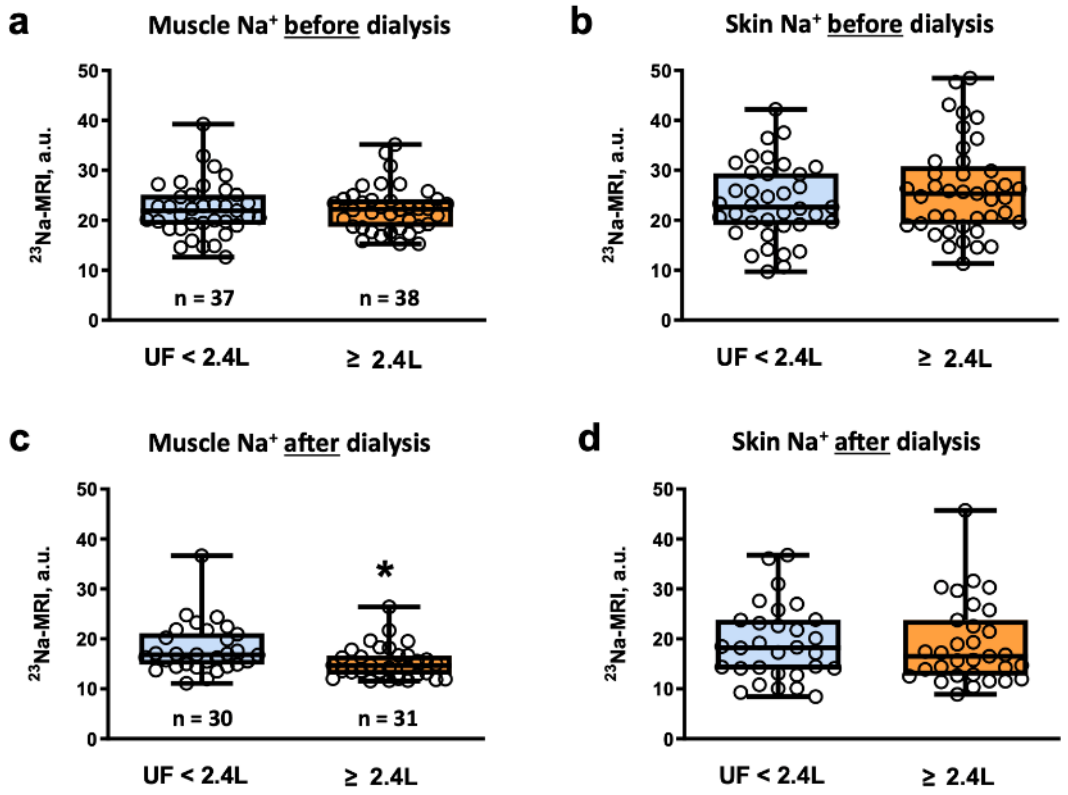
→ Part B: 41 patients HD < 4.5 hrs vs 34 patients HD >4.5 hours.

→ Part C: 17 patients HD [Na]dialysat = 138 mmol/l vs 58 patients [Na]dialysat < 138 mmol/l.

Kopp et al, kidney international reports, 2024

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

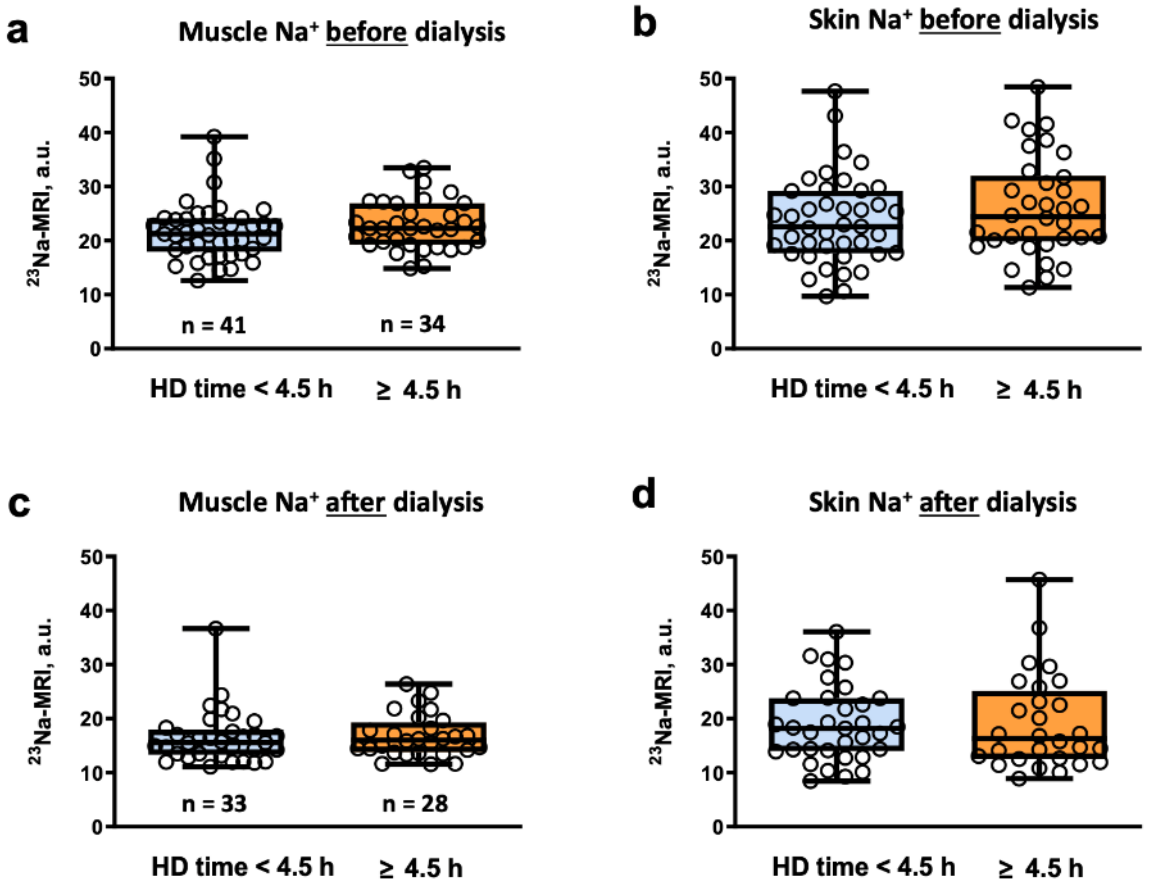
→ **Part A: UF : 37 patients en HD UF <2.4 l vs 38 patients on HD > 2.4 l**



Kopp et al, kidney international reports, 2024

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

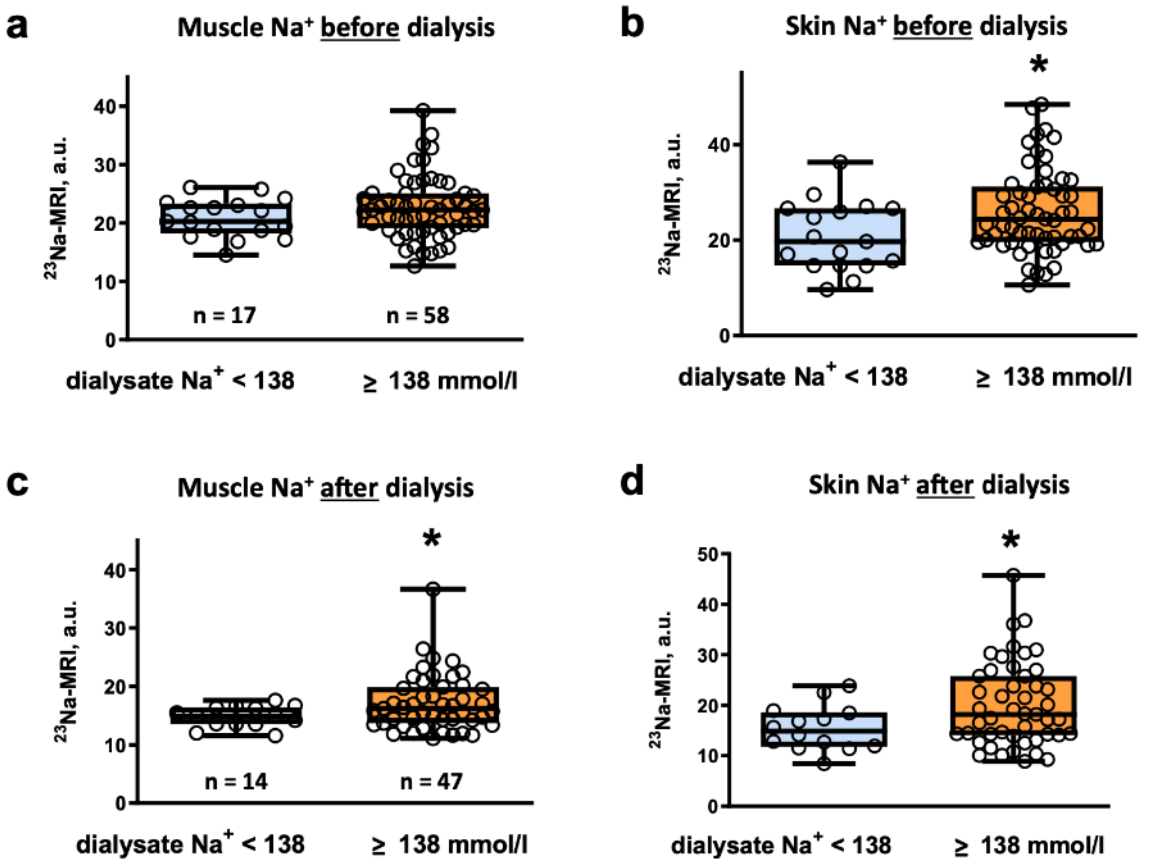
Part B: 41 patients HD < 4.5 hrs vs 34 patients HD >4.5 hours.



Kopp et al, kidney international reports, 2024

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

Part C: 17 patients HD [Na]dialysat = 138 mmol/l vs 58 patients [Na]dialysat < 138 mmol/l.



Kopp et al, kidney international reports, 2024

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

Table 2. Clinical characteristics on substudies of local HD patient cohort

Characteristics	UF <2.4 l	UF ≥2.4 l	*P*-value	HD time <4.5 h	HD time ≥ 4.5 h	*P*-value	Dialysate Na^+ <138 mmol/l	Dialysate Na^+ ≥138 mmol/l	*P*-value
Demographics									
Individuals, *n*	37	38		41	34		17	58	
Age, yr	55.4 ± 14.9	57.1 ± 14.6	0.62	58.4 ± 13.3	53.7 ± 16.0	0.17	56.5 ± 16.1	56.2 ± 14.4	0.93
BMI, kg/m^2	26.7 ± 4.7	28.5 ± 5.0	0.12	27.3 ± 4.2	27.9 ± 5.7	0.62	28.9 ± 5.3	27.2 ± 4.8	0.22
SBP, mmHg	132 ± 17	140 ± 20	0.05	136 ± 19	137 ± 18	0.85	135 ± 22	136 ± 18	0.75
DBP, mmHg	72 ± 10	75 ± 12	0.39	72 ± 10	75 ± 12	0.35	70 ± 13	74 ± 11	0.16
HD-related parameters									
HD vintage, yr	2 (3.1)	4 (5.7)	<0.05	1.75 (3.5)	3 (5.5)	0.15	4 (6.4)	2.1 (4.5)	0.20
Treatment time, h	4.5 (1.25)	4.75 (1.0)	0.1	4.25 (0.5)	5.5 (2.5)	-	4.5 (0.75)	4.5 (1.3)	0.81
Residual diuresis, ml/d	500 (1500)	100 (500)	<0.01	500 (1000)	0 (500)	<0.05	200 (1000)	300 (1000)	0.86
IDWG, kg	0.8 ± 0.9	2.7±1.1	<0.01	1.4 ± 1.2	2.1 ± 1.4	<0.05	1.8 ± 1.5	1.7 ± 1.3	0.84
Ultrafiltration, l	1.3 ± 0.7	3.2±0.7	-	2.0 ± 1.0	2.7 ± 1.3	0.01	2.5 ± 1.5	2.2 ± 1.1	0.45
Dialysate Na^+, mmol/L	138 (0)	138 (2)	0.95	138 (2)	138 (0)	0.55	135 (0)	138 (0)	-
Laboratory data									
Plasma Na^+, mmol/l	138.6 ± 2.5	137.4 ± 2.6	<0.05	138.4 ± 2.5	137.5 ± 2.6	0.16	136.4 ± 3.0	138.4 ± 2.3	<0.01
Plasma K^+, mmol/l	5.2 ± 0.7	5.7 ± 0.8	<0.05	5.4 ± 0.8	5.5 ± 0.7	0.54	5.5 ± 0.9	5.4 ± 0.7	0.85
BIS data	32	35		35	32		13	54	
Total body water, l	40.8 ± 7.9	39.3 ± 6.8	0.40	38.7 ± 7.6	41.5 ± 6.9	0.11	37.7 ± 6.7	40.6 ± 7.5	0.20
Extracellular water, l	19.4 ± 3.9	19.2 ± 3.3	0.83	18.7 ± 3.7	20.0 ± 3.0	0.15	18.7 ± 3.3	19.5 ± 3.6	0.46
Intracellular water, l	21.4 ± 4.5	20.1 ± 4.0	0.21	19.9 ± 4.3	21.5 ± 4.2	0.13	19.0 ± 3.9	21.1 ± 4.3	0.11
ratio ECW/ICW	0.92 ± 0.12	0.97 ± 0.14	0.08	0.95 ± 0.13	0.94 ± 0.14	0.51	0.99 ± 0.13	0.94 ± 0.13	0.15
Overhydration, l	2.1 ± 2.1	1.9 ± 1.5	0.73	1.8 ± 1.9	2.1 ± 1.7	0.76	1.7 ± 1.4	2.0 ± 1.9	0.51

Kopp et al, kidney international reports, 2024

QUELS IMPACTS SUR LE SODIUM TISSULAIRE DES PARAMÈTRES D'HD?

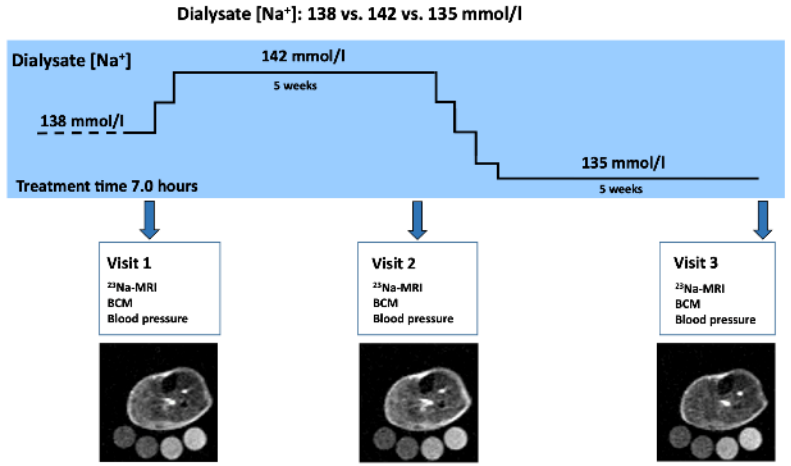
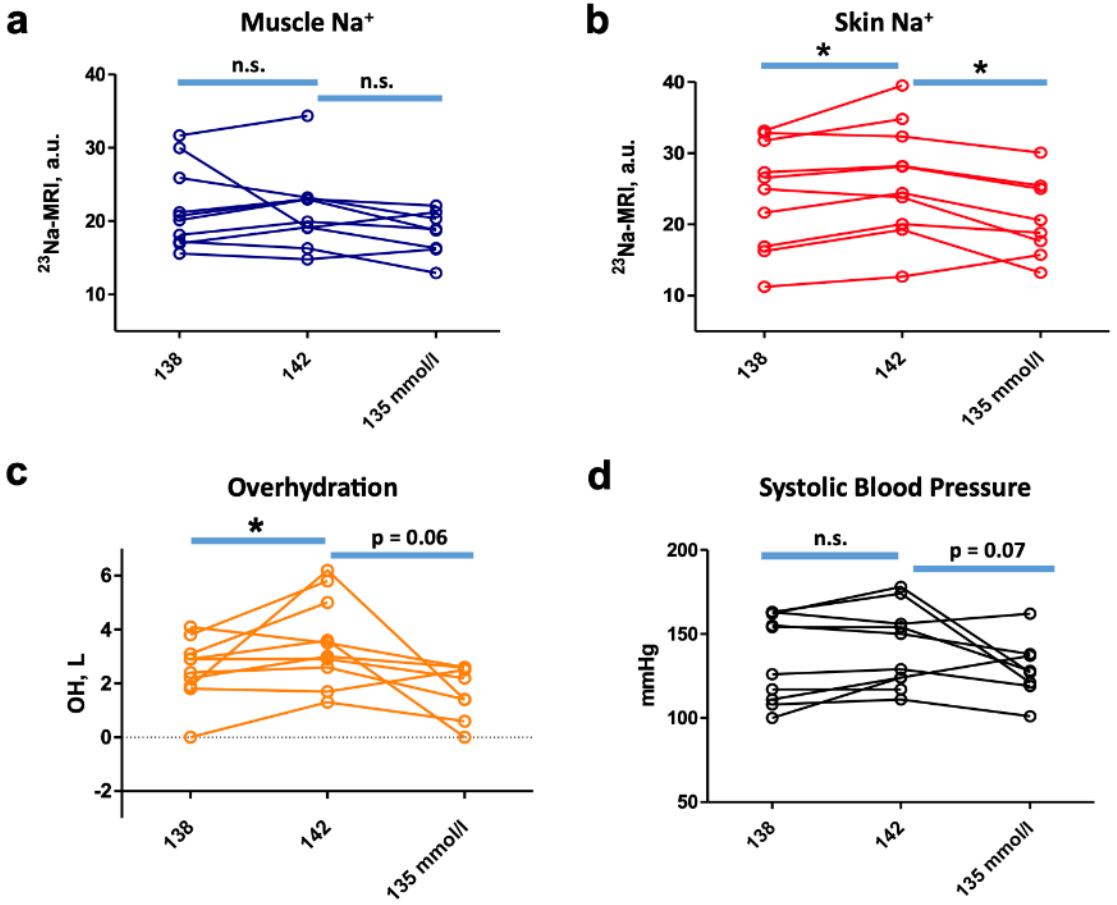


Figure 6. Study synopsis of interventional cross-over adaptation of dialysate [Na^+]. Upper panel: timeline of stepwise changes in dialysate [Na^+] from 138 to 142 to 135 mmol/l with according visits 1 to 3. Lower panel: Representative ^{23}Na-MR images of the left calf during visits 1 to 3. Calibration tubes with 10, 20, 30, and 40 mmol/l NaCl are situated below the leg; the brightness of the resonance signal reflects the Na^+ amount. ^{23}Na-MRI, ^{23}Na magnetic resonance imaging; a.u., arbitrary unit; BCM, body composition monitor.

Characteristics	Dialysate Na^+ 138 mmol/l $n = 10$	Dialysate Na^+ 142 mmol/l $n = 10$	Dialysate Na^+ 135 mmol/l $n = 8$	*P* value 138 vs. 142/ 142 vs. 135
Demographics				
Age, yr	50.5 ± 13.2	-	-	-
Body weight, kg	89.8 ± 14.5	89.9 ± 15.3	89.8 ± 14.6	0.80/0.74
HD-related parameter				
HD vintage, yr	5.6 (IQR 7.1)	-	-	-
Treatment time, h	7.0 (IQR 1.6)	7.4 (IQR 1.7)	7.4 (IQR 2.3)	0.34/0.67
Ultrafiltration volume, l	2.1 ± 1.6	1.9 ± 1.3	1.7 ± 0.9	0.62/0.83
Laboratory data				
Serum Na^+, mmol/l	138.6 ± 4.4	138.8 ± 2.2	140.6 ± 3.0	0.78/0.12
Serum K^+, mmol/l	5.5 ± 0.7	5.5 ± 0.7	5.7 ± 0.9	0.60/0.12
BIS data				
Total body water, l	46.7 ± 6.1	47.3 ± 6.1	44.9 ± 4.3	0.16/0.34
Extracellular water, l	22.0 ± 3.1	22.9 ± 3.8	20.9 ± 2.7	<0.05/0.11
Intracellular water, l	24.1 ± 2.9	24.4 ± 2.5	24.0 ± 2.2	0.60/0.09
Ratio ECW/ ICW	0.90 ± 0.08	0.94 ± 0.09	0.87 ± 0.10	0.09/0.05



Kopp et al, kidney international reports, 2024

LE SODIUM TISSULAIRE A-T-IL UN IMPACT CLINIQUE ?

Relationship between skin sodium content and LVM (Schneider et al, JASN, 2017)

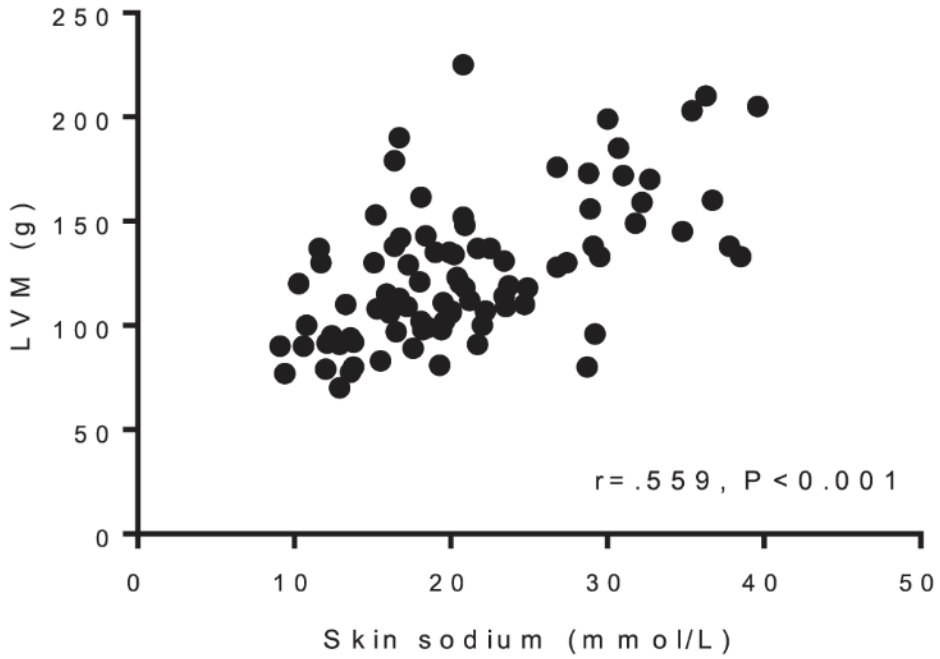


Figure 4. Relationship between skin sodium content and LVM.

Schneider et al, JASN, 2017

SODIUM TISSULAIRE ET RISQUE CV EN HD

Methods

Observational study

Cohort: Chronic HD/PD patients

Imaging: Skin [Na^+] with ^{23}Na MRI (Leg)

Follow-up: Clinical outcomes (death and MACE) by skin [Na^+] quartile

Results

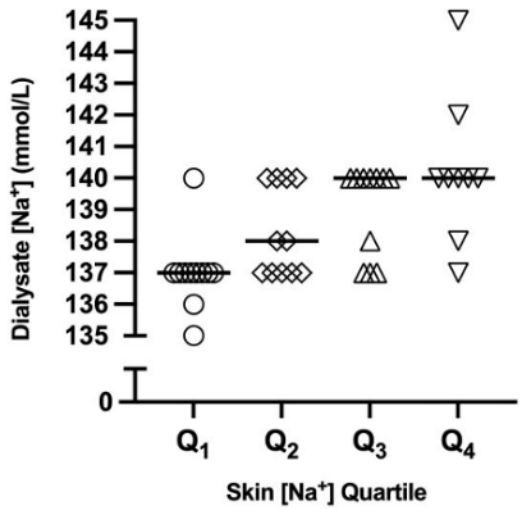
n=52 patients

	Q_1 (n=11)	Q_2 (n=13)	Q_3 (n=15)	Q_4 (n=13)
Mean skin [Na^+] (mmol/L)	17.4	25.7	31.7	46.1
Median follow-up (days)	546	505	588	544
Deaths (n)	1	3	4	7
MACE (n)	1	1	2	3

Cox regression for skin [Na^+] (per 10 mmol/L)

Death: HR = 1.83, $HR_{adjusted}$ = 4.01

Death and MACE: HR = 1.72, $HR_{adjusted}$ = 2.32



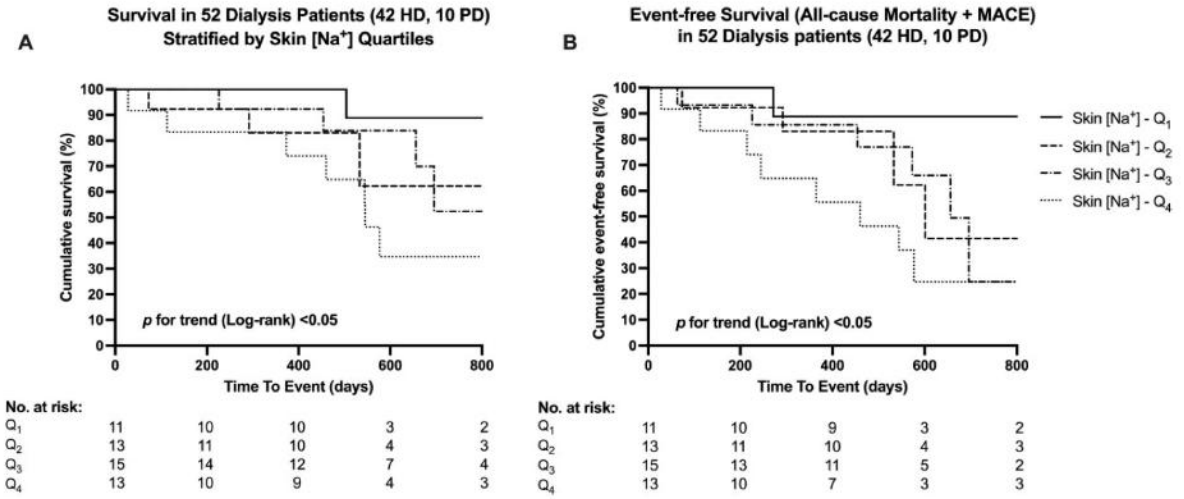
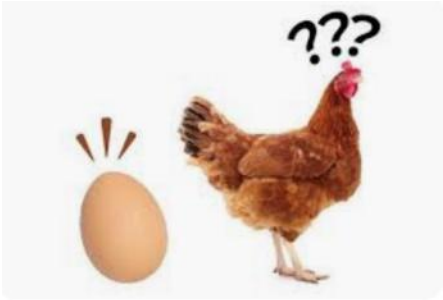


FIGURE 2: Kaplan–Meier curves for overall survival (A) and event-free survival as a composite of all-cause mortality and MACE (B) after skin [Na^+] quartile stratification.

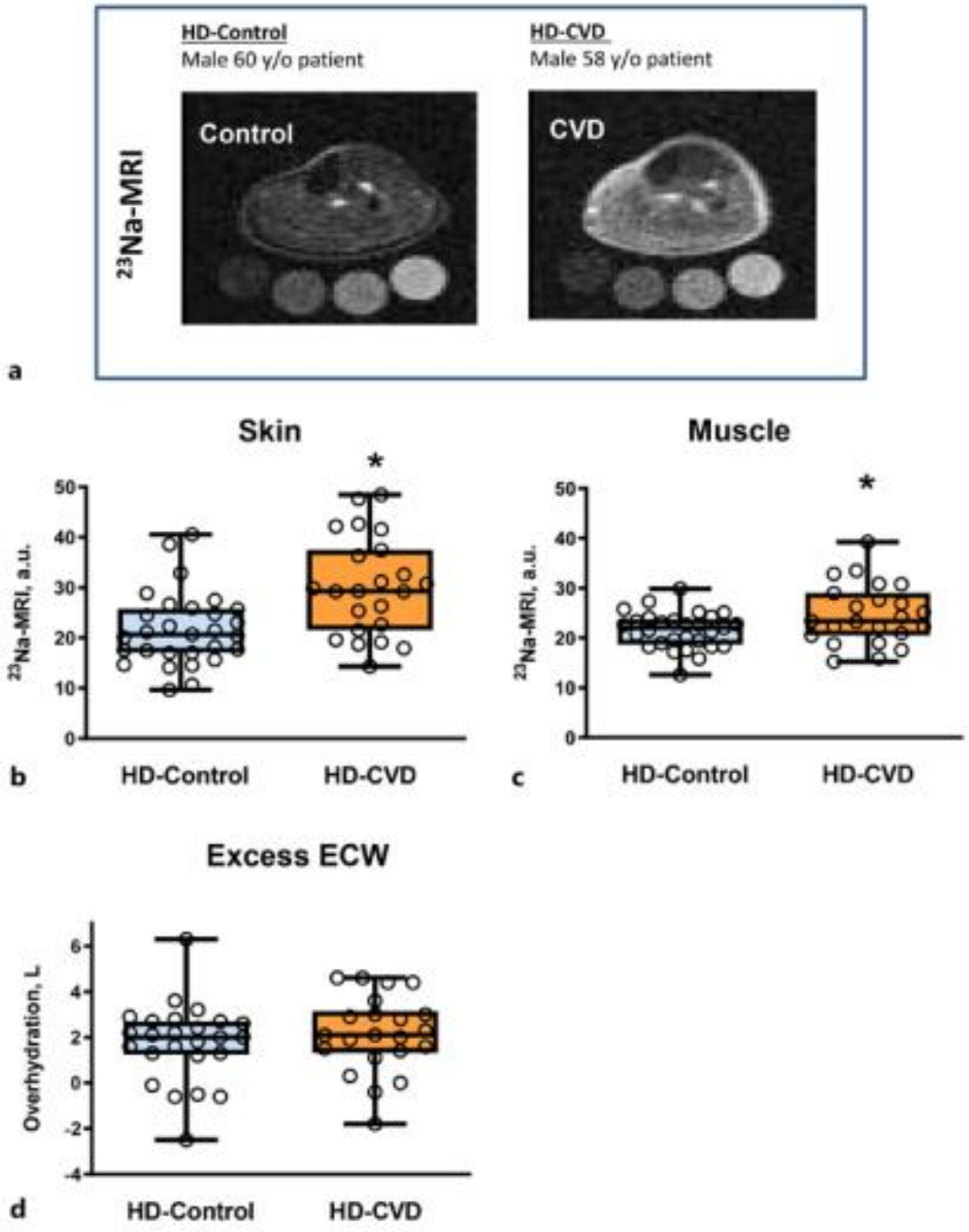
Salerno F**, Lemoine S**, McIntyre CW. Clin Kidney J 2022

RESULTATS CONFIRMÉS PAR UNE AUTRE ÉQUIPE

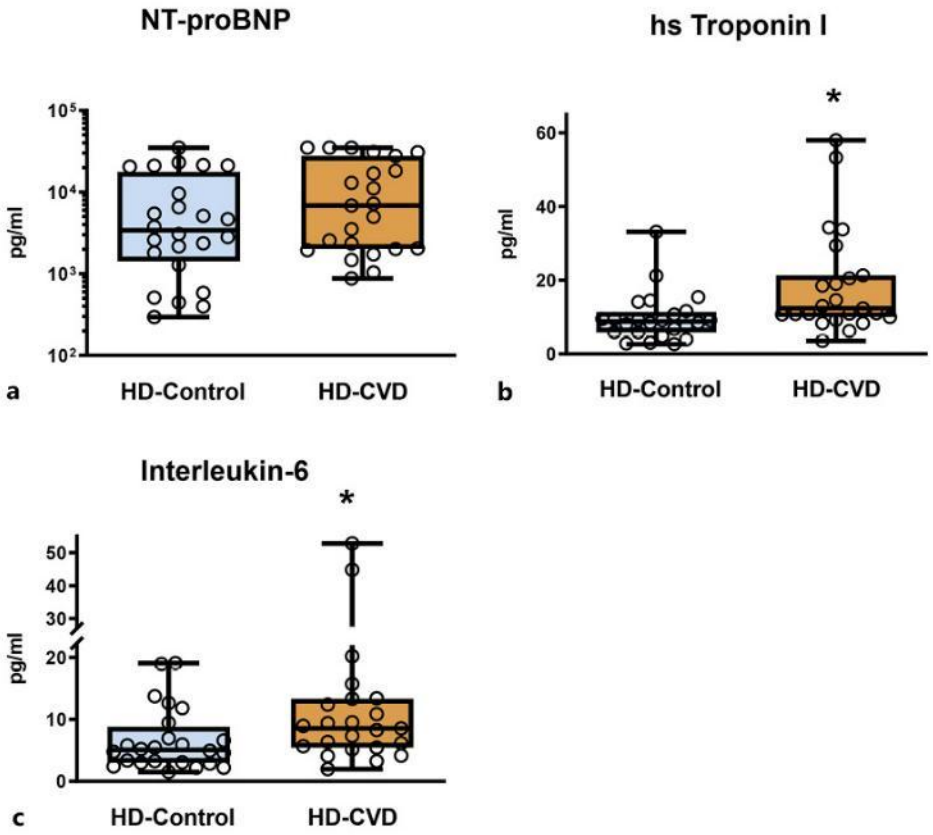
HD-related parameter			
HD vintage, years	1.6 (IQR 3.4)	2.5 (IQR 4.8)	0.22
HD technique	24 BHD/5 HDF	20 BHD/3 HDF	
Treatment time, h	4.5 (IQR 0.75)	4.75 (IQR 0.75)	0.39
Residual diuresis, mL/d	500 (IQR 950)	300 (IQR 500)	0.30
IDWG, kg	1.8±1.1	1.8±1.5	0.94
Ultrafiltration, L	2.2±1.1	2.3±1.2	0.71
Dialysate Na^+, mmol/L	138 (IQR 3)	138 (IQR 0)	0.39
Dialysate bicarbonate, mmol/L	32 (IQR 3)	32 (IQR 3)	0.95
Laboratory data			
Plasma Na^+, mmol/L	138±2	139±3	0.19
BIS data			
Total body water, L	38.2±5.9	40.6±7.7	0.25
ECW, L	18.7±3.2	20.0±3.4	0.18
ICW, L	19.5±3.2	20.6±4.6	0.37
Ratio ECW/ICW	0.96±0.12	0.99±0.11	0.43



“Chicken or egg”?: Is tissue Na+ overload involved in the development of CVD or does CVD itself lead to tissue Na+ retention?



SODIUM ET INFLAMMATION ?



Friedrich et al, Kidney Blood Press Res 2022

LE SODIUM TISSULAIRE AUGMENTE DANS LES PATHOLOGIES INFLAMMATOIRES

Polyarthite rhumatoide

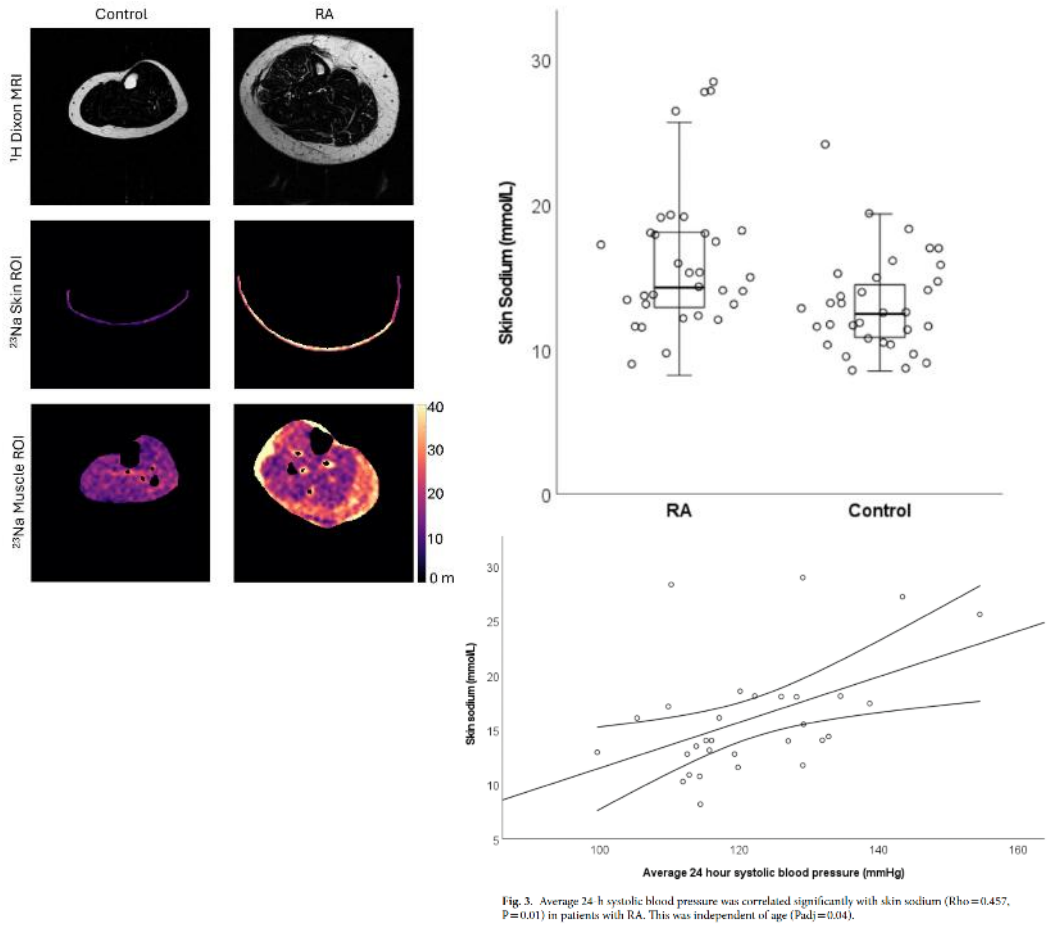
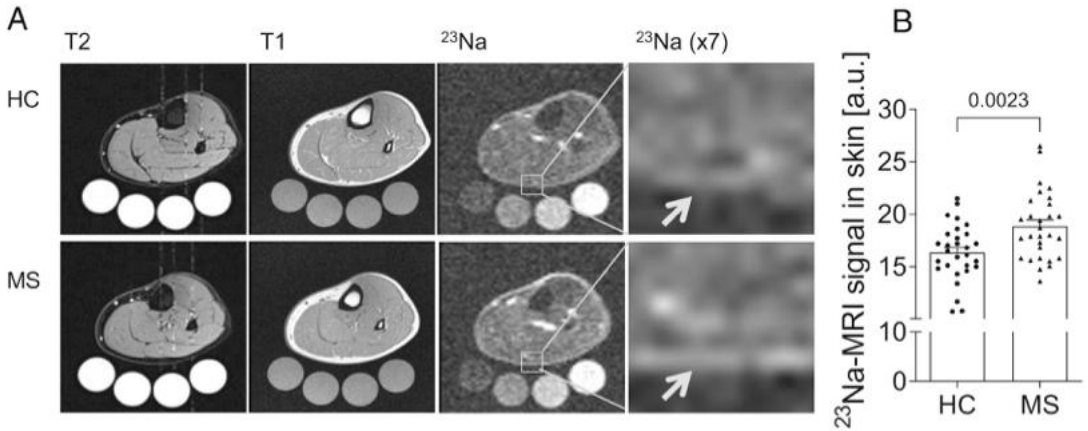
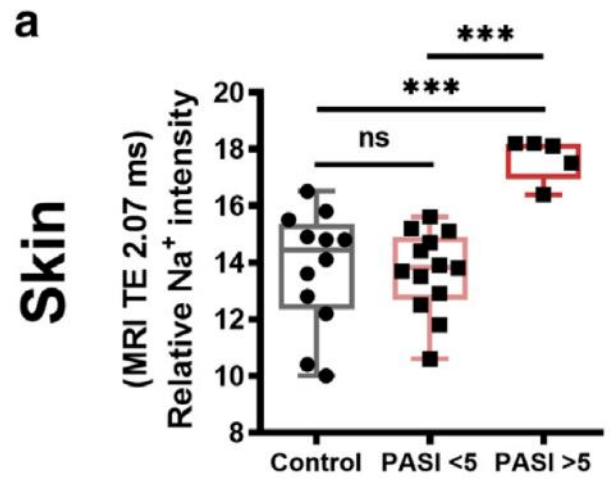


Fig. 3. Average 24 h systolic blood pressure was correlated significantly with skin sodium (Rho = 0.457, P = 0.01) in patients with RA. This was independent of age (Padj = 0.04).

Sclérose en plaques



Psoriasis



Ramirez-Becerra , scientific report, 2024 - Kopp C, Rheumatology, 2017 - Maifeld, A. J. Invest. Dermatol. 2022

EN CONCLUSION

→Le sodium peut être mesuré en HD

→Le sodium cutané peut être mobilisable

→Le sodium cutané semble être prédicteur indépendant des évènements cardiovasculaires

→Le sodium tissulaire est sensible aux interventions thérapeutiques

→Sodium cutanée: cible pour amélioration de la survie ?

→Etude sur plus grosse cohorte nécessaire mais problème d'accessibilité de l'IRM

PERSPECTIVES

Mesure des variations de sodium tissulaire au cours de la séance

Module sodium

Mesure des variations de sodium tissulaire au cours de la séance

MERCI

www.chu-lyon.fr

HCL
HOSPICES CIVILS
DE LYON