Université Paris Sud - M1 parcours Physique Médicale
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Physique de la Cellule & des Tissus

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Métabolisme

Energétique
Respiration, effet Warburg, glycolyse

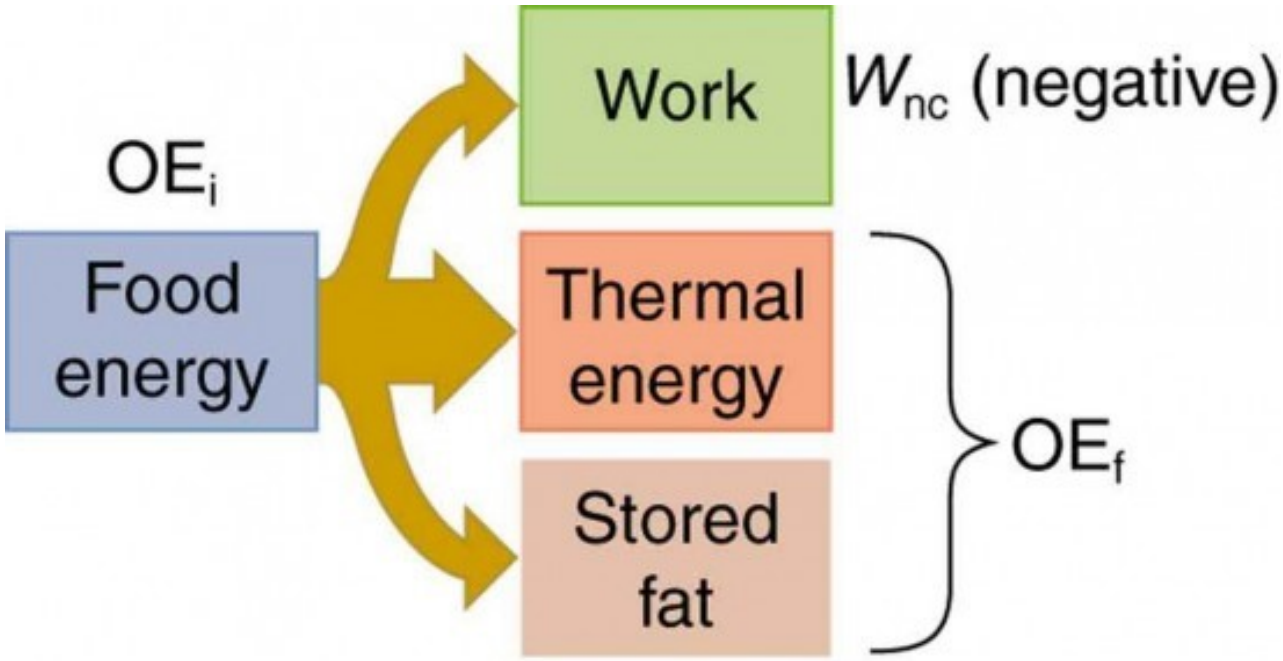
Cell respiration: glucose combustion

$$C_6H_{12}O_6\ (s) + 6\ O_2\ (g) \rightarrow 6\ CO_2\ (g) + 6\ H_2O\ (l)$$

$$\Delta G = -2880\ \text{kJ per mol of } C_6H_{12}O_6$$

Exercice: chaleur produite par la respiration

Calculer la puissance dégagée par un individu au repos



$$OE_i + W_{nc} = OE_f$$

Table 1. Basal Metabolic Rates (BMR)			
Organ	Power consumed at rest (W)	Oxygen consumption (mL/min)	Percent of BMR
Liver & spleen	23	67	27
Brain	16	47	19
Skeletal muscle	15	45	18
Kidney	9	26	10
Heart	6	17	7
Other	16	48	19
Totals	85 W	250 mL/min	100%

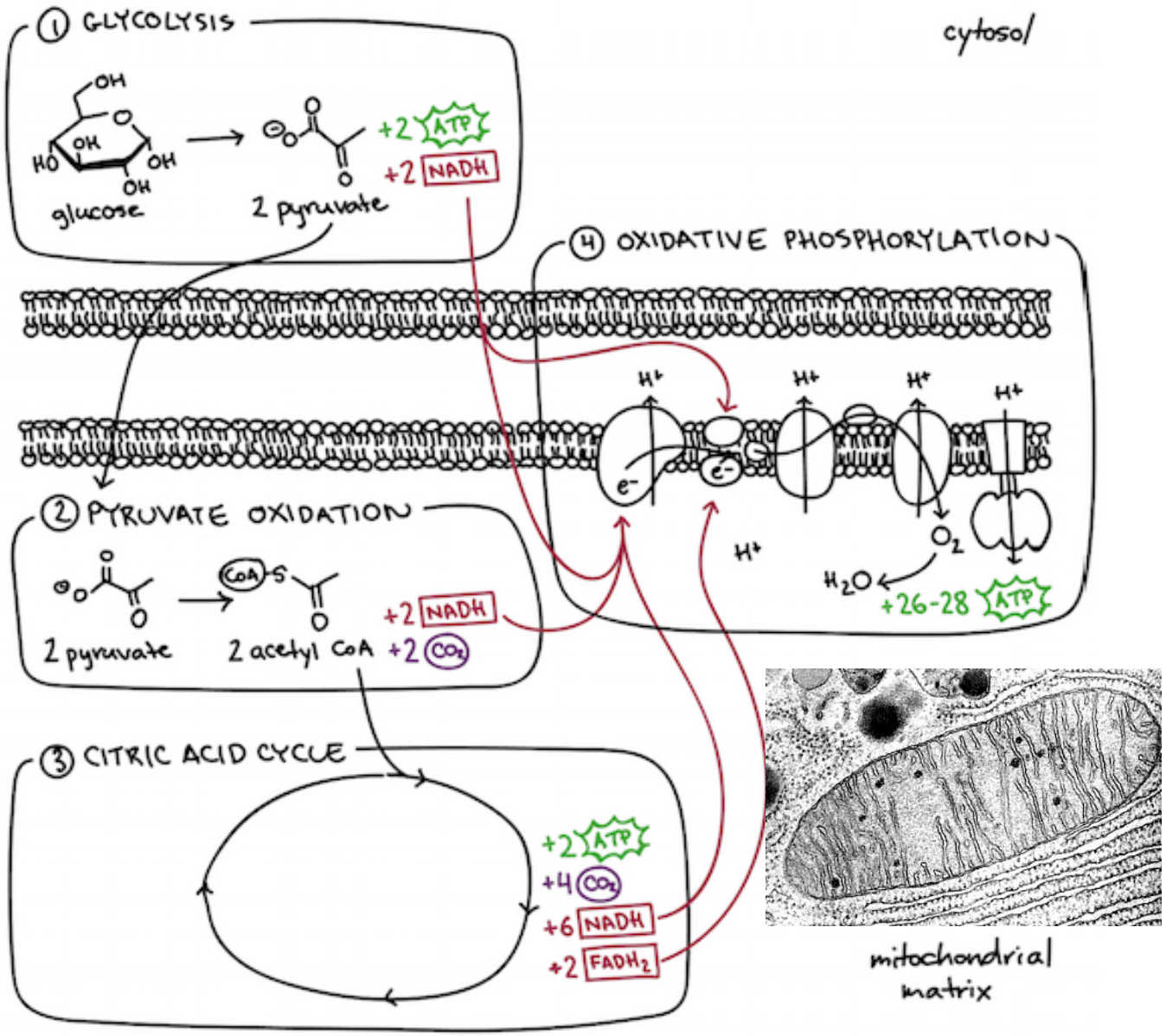
https://courses.lumenlearning.com/physics/chapter/7-8-work-energy-and-power-in-humans/

Table 2. Energy and Oxygen Consumption Rates (Power)

Activity	Energy consumption in watts	Oxygen consumption in liters O_2/min
Sleeping	83	0.24
Sitting at rest	120	0.34
Standing relaxed	125	0.36
Sitting in class	210	0.60
Walking (5 km/h)	280	0.80
Cycling (13–18 km/h)	400	1.14
Shivering	425	1.21
Playing tennis	440	1.26
Swimming breaststroke	475	1.36
Ice skating (14.5 km/h)	545	1.56
Climbing stairs (116/min)	685	1.96
Cycling (21 km/h)	700	2.00
Running cross-country	740	2.12
Playing basketball	800	2.28
Cycling, professional racer	1855	5.30
Sprinting	2415	6.90

https://courses.lumenlearning.com/physics/chapter/7-8-work-energy-and-power-in-humans/

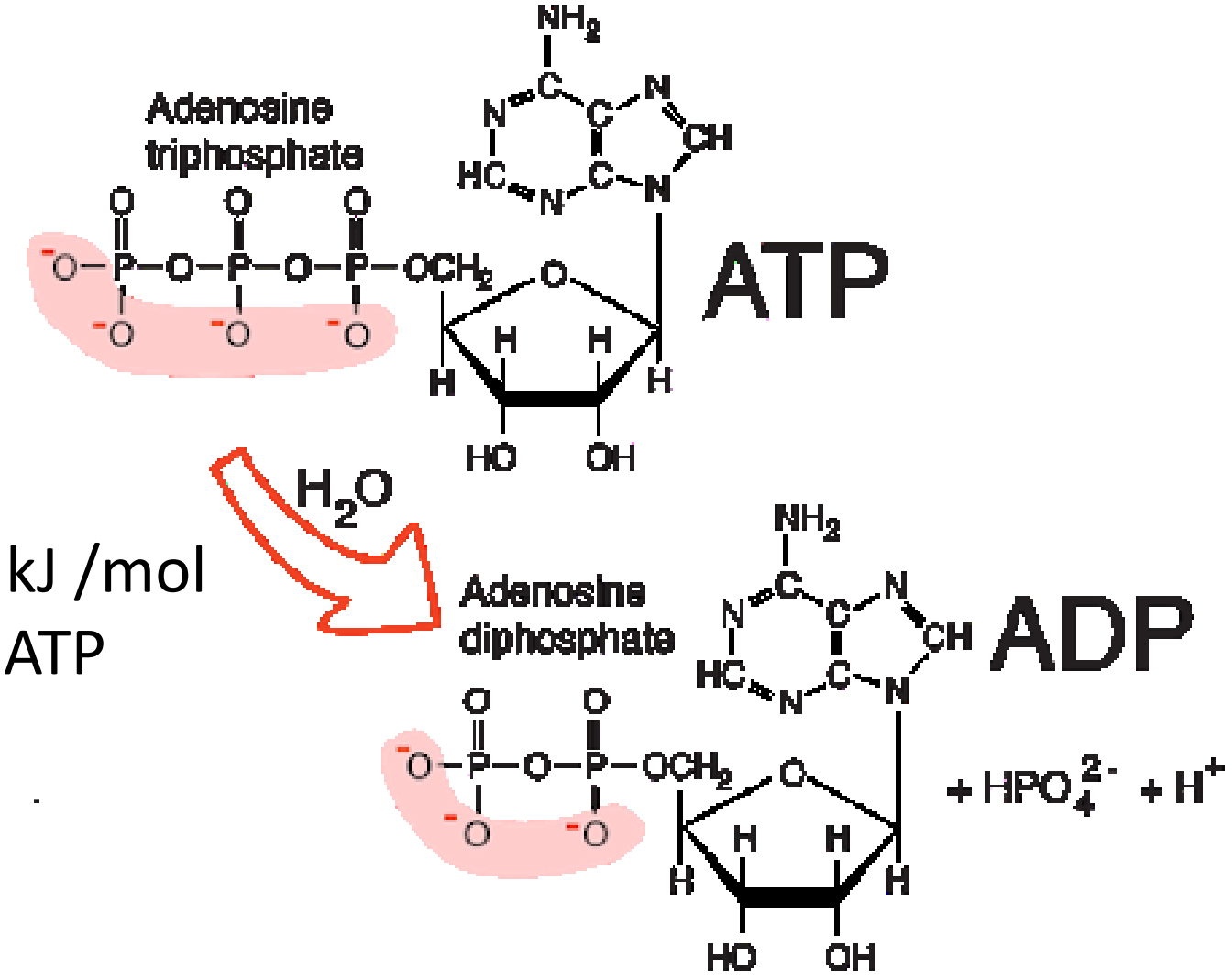
Cell respiration: details of oxydative phosphorylation



Stage	Direct products (net)	Ultimate ATP yield (net)
Glycolysis	2 ATP	2 ATP
	2 NADH	3-5 ATP
Pyruvate oxidation	2 NADH	5 ATP
Citric acid cycle	2 ATP/GTP	2 ATP
	6 NADH	15 ATP
	2 FADH_22start subscript, 2, end subscript	3 ATP
Total		**30-32 ATP**

https://www.khanacademy.org/science/biology/cellular-respiration-and-fermentation/oxidative-phosphorylation/a/oxidative-phosphorylation-etc

Hydrolysis of ATP to ADP



- 50-70 kJ /mol per ATP

Rendement de la respiration

30-32 ATP / mol glucose
-50 à -70 kJ/mol pour ATP → ADP
1500 kJ/mol à 2240 kJ/mol sur les 2880 kJ/mol de la combustion du glucose

→ Soit de 50-80% de “rendement”

Comparaison rendement moteur thermique (puissance mecanique / puissance combustible):

36 % pour un moteur à essence à allumage commandé et 42 % pour un moteur Diesel à rampe commune haute pression

(attention: quasi 100% transformé *in-fine* en thermique dans le corps humain)

What if all this energy used for ?

tissue	protein synthesis	Na^+/K^+ ATPase	Ca^{+2} ATPase	other
liver	20%	5-10%	5%	gluconeogenesis (15-40%), substrate recycling (20%), proton leak (20%), urea synthesis (12%)
kidney	6%	40-70%	-	gluconeogenesis (5%)
heart	3%	1-5%	15-30%	actinomyosin ATPase (40-50%), proton leak (15% max)
brain	5%	50-60%	significant	a single cortical action potential was estimated to require 10^8-10^9 ATP, BNID 111183)
skeletal muscle	17%	5-10%	5%	proton leak (50%), nonmitochondrial (14%)

25% of all energy consumed by the body is used to maintain electrical potentials in all living cells.

This bioelectrical energy ultimately becomes mostly thermal energy, but some is utilized to power chemical processes such as in the kidneys and liver, and in fat production.

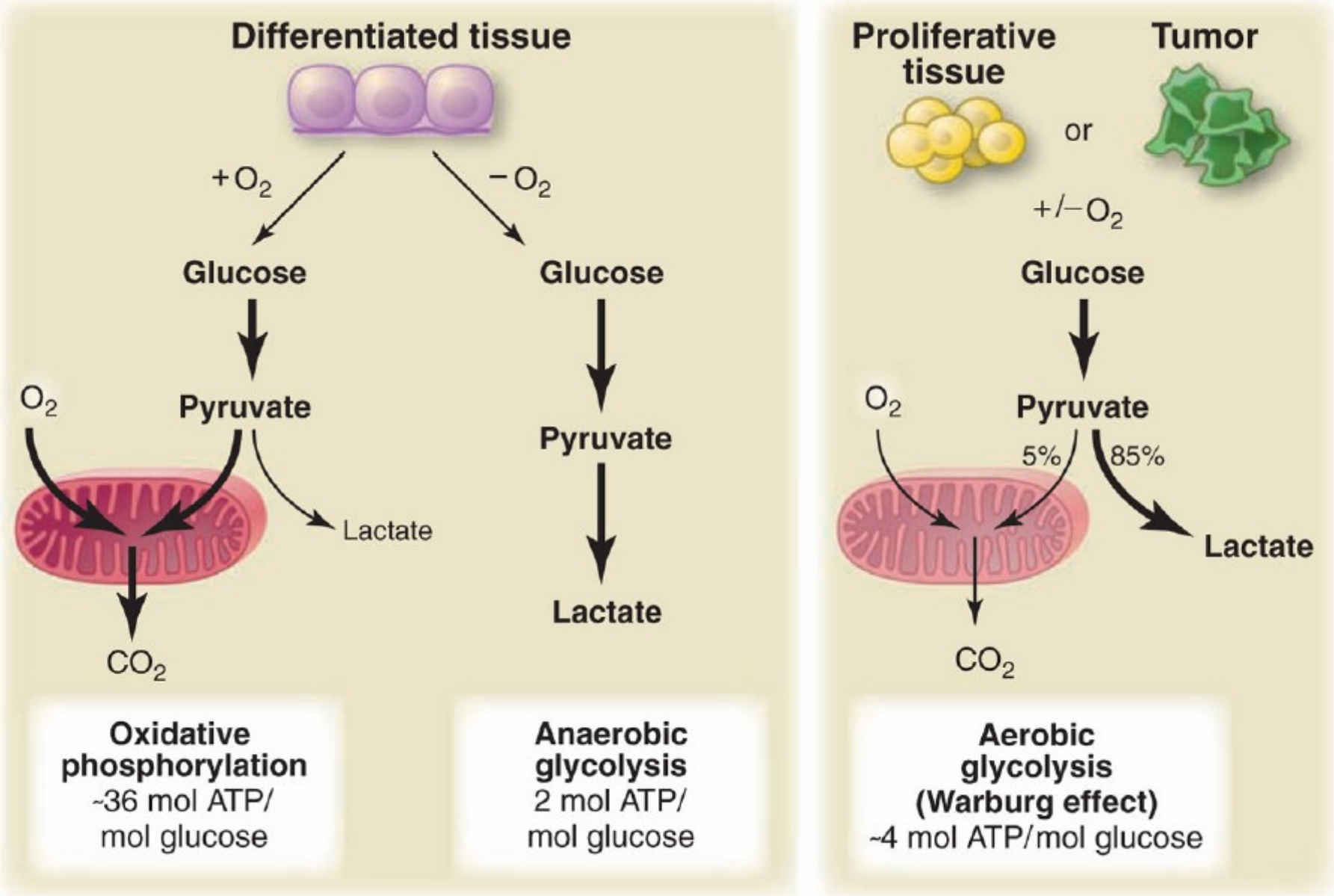
Another metabolic route: glycolysis

$$\text{Glucose} + 2\ NAD^+ + 2\ P_i + 2\ ADP \rightarrow 2\ \underline{\text{pyruvate}} + 2\ NADH + 2\ ATP + 2\ H^+ + 2\ H_2O + \text{heat}$$

$$\text{Pyruvate}^- + NADH + H^+ \leftrightarrow \text{Lactate}^- + NAD^+$$

Pas besoin d'oxygène; seules 2 ATP / mol glucose ; produit de l'acide lactique (pH baisse, cf papier exposé)

Differentiated tissue and cancer tumors / embryonic proliferative tissue have different metabolisms



Metabolic differentiation in the embryonic retina

Michalis Agathocleous[1,2,4], Nicola K. Love[1], Owen Randlett[1,4], Julia J. Harris[3], Jinyue Liu[1], Andrew J. Mu
and William A. Harris[1,5]

Unlike healthy adult tissues, cancers produce energy mainly by aerobic glycolysis instead of oxidative phosphorylation[1]. This adaptation, called the Warburg effect, may be a feature of all dividing cells, both normal and cancerous[2], or it may be specific to cancers[3]. It is not known whether, in a normally growing tissue during development, proliferating and postmitotic cells produce energy in fundamentally different ways. Here we show in the embryonic *Xenopus* retina *in vivo*, that dividing progenitor cells depend less on oxidative phosphorylation for ATP production than non-dividing differentiated cells, and instead use glycogen to fuel aerobic glycolysis. The transition from glycolysis to oxidative phosphorylation is connected to the cell differentiation process. Glycolysis is indispensable for progenitor proliferation and biosynthesis, even when it is not used for ATP production. These results suggest that the Warburg effect can be a feature of normal proliferation *in vivo*, and that the regulation of glycolysis and oxidative phosphorylation is critical for normal development.

Barth's solution (MBS), a salt buffer without nutrients.
proliferating explants fell by significantly less than in
explants after NaN_3 treatment (Fig. 1b and Supplemen
Similar results followed inhibition of Complex III wi
A or of ATP synthase with oligomycin (Supplementa
Differentiated cells might seem more oxidative because t
on external nutrients; however, in galactose-containing L
glucose-containing DMEM, ATP in differentiated but no
explants was still severely depleted after NaN_3 treatn
Therefore, proliferating cells rely less on oxidative phosp
ATP than differentiated cells *in vivo* or *ex vivo*, irrespectiv
nutrients. Proliferating cells from freshly explanted retir
less O_2 in oxidative phosphorylation than differentiated
intracellular lactate (Fig. 1e) and lactate dehydrogenase (
(Fig. 1f) *in vivo* were elevated in proliferating when cc
differentiated cells, suggesting increased glycolysis.

A reduced dependence on oxidative phosphorylati
peculiar to the embryonic *Xenopus* retina with its store c
nutrients. To address this question, we looked at th
zebrafish retina, where nutrients are delivered by th

Conséquence: les tumeurs consomment énormément de glucose pour alimenter leur métabolisme inefficace

Phénomène mis à profit pour l'imagerie PET (positron emission tomography)

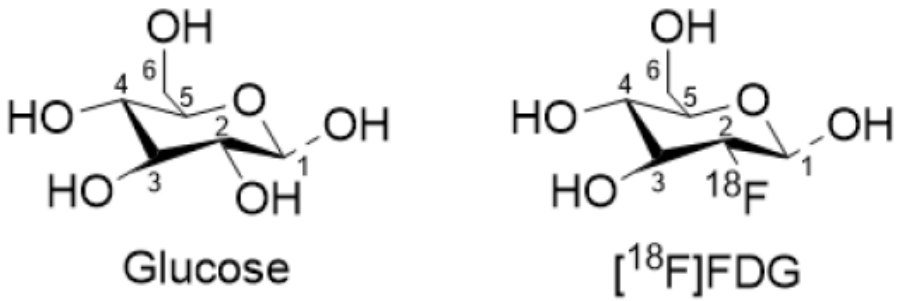
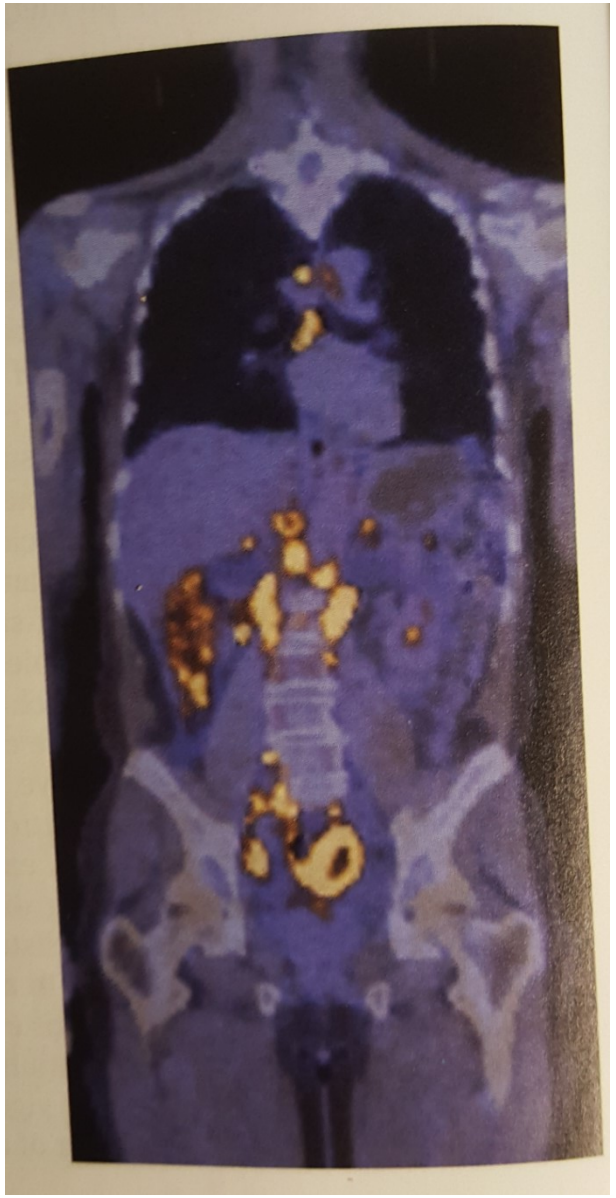


Figure 7 – Différences de structure entre le glucose (gauche) et [^{18}F]FDG (fluorodésoxyglucose) (droite)

$$^{18}F \xrightarrow{\text{Désintégration } \beta^+} {}^{18}O + \nu + \beta^+$$

Schéma 1 – Désintégration radioactive du fluor-18



Yellow: high glucose uptake, characteristic of tumor

Conclusion

tissue	protein synthesis	Na^+/K^+ ATPase	Ca^{+2} ATPase	other
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La source même de l'énergie nécessaire aux fonctionnements de ces organes est autre dans le cancer → implication sur la contractilité, la bioélectricité ?