The muscle tissue and its relationship to beef production

Isabelle Cassar-Malek

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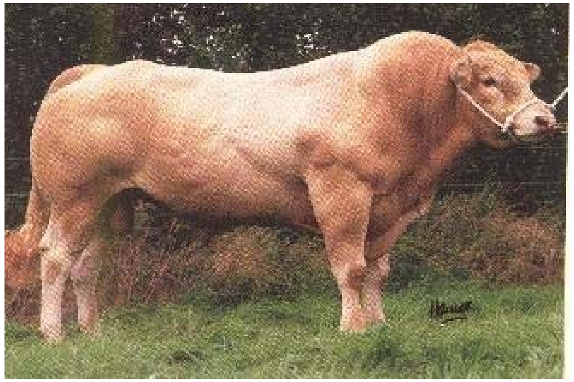
SCIENCE & IMPACT

Myogenesis of Cattle - Challenges



Beef production

"Construction" of beef quality

A model for humans

(Gibbs and Weinstock , 2002)

Etymology

The word “muscle” comes from the Latin **mus** ***/ musculus*** meaning "little mouse"

Terminology

- **Myo** = muscle

  (myofibril, myoblast, myogenesis, myotome)
- **Sarco** = flesh (sarcolemma)

Muscle tissues

Muscle

skeletal (bone attached)

- From 40 to 50% of body weight
- Precursor of meat

cardiac

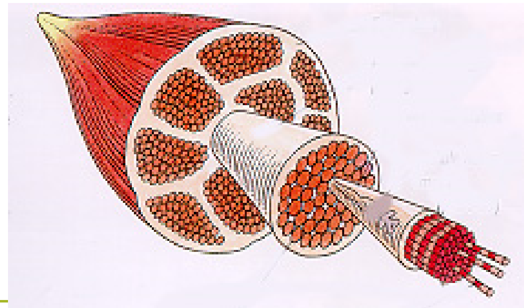
smooth (intestinal, endometrial ...)

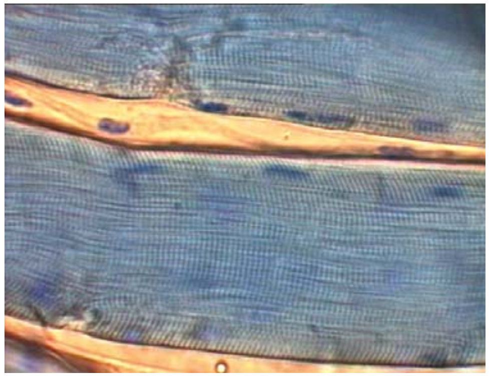
Skeletal muscle

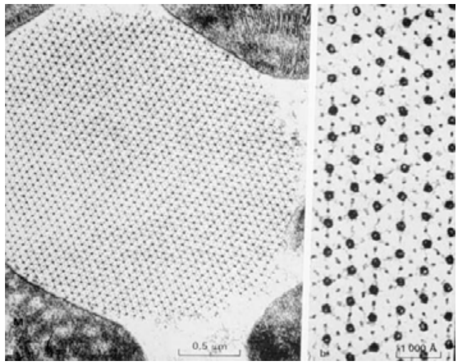
- movement (locomotion, manipulation): voluntary
- posture and body position
- stability of the joints (tendons)

- reserve of proteins
- role in the oxidation of nutrients
- maintenance of body temperature (85% body heat, chill)

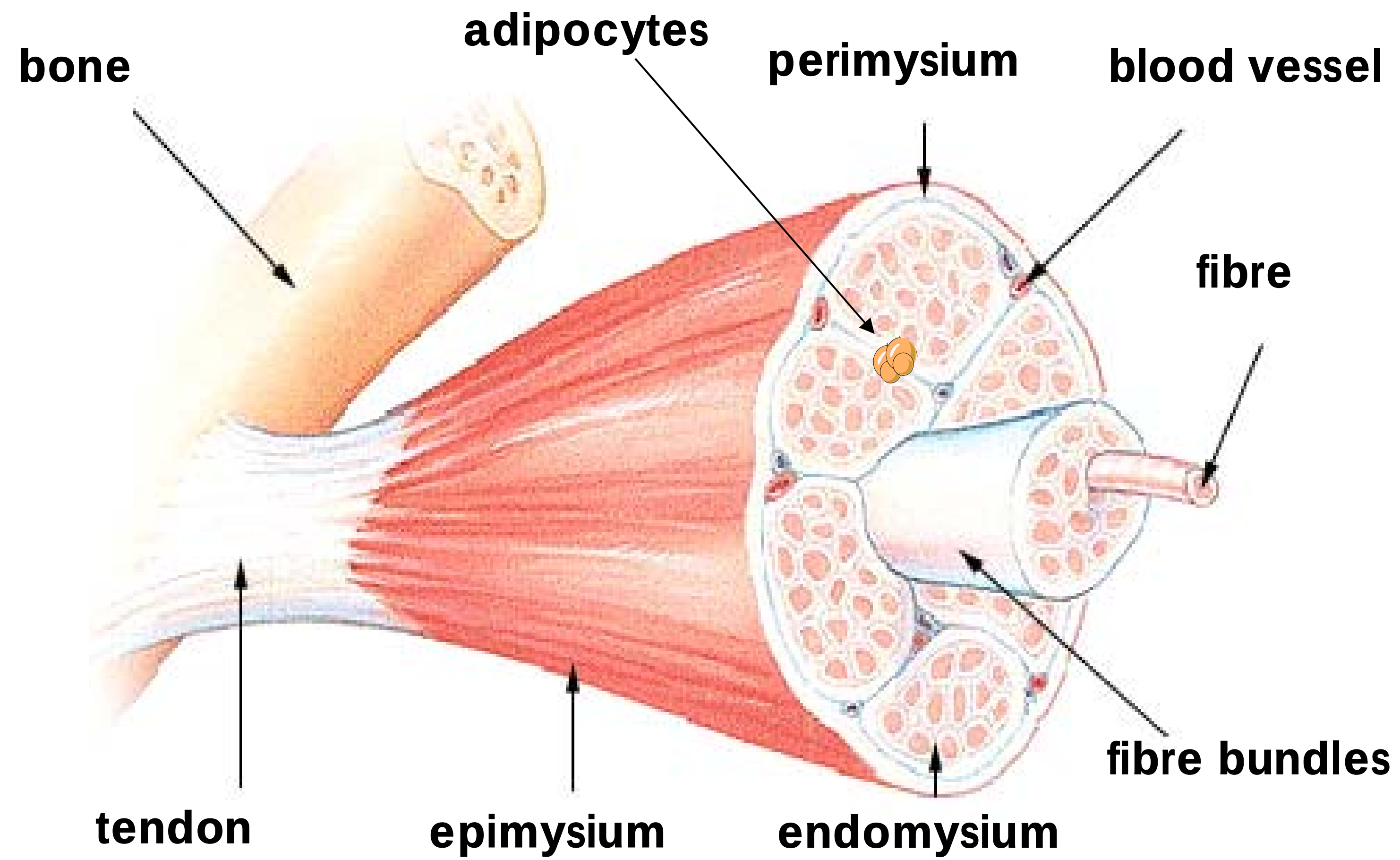
STRUCTURE OF THE SKELETAL MUSCLE



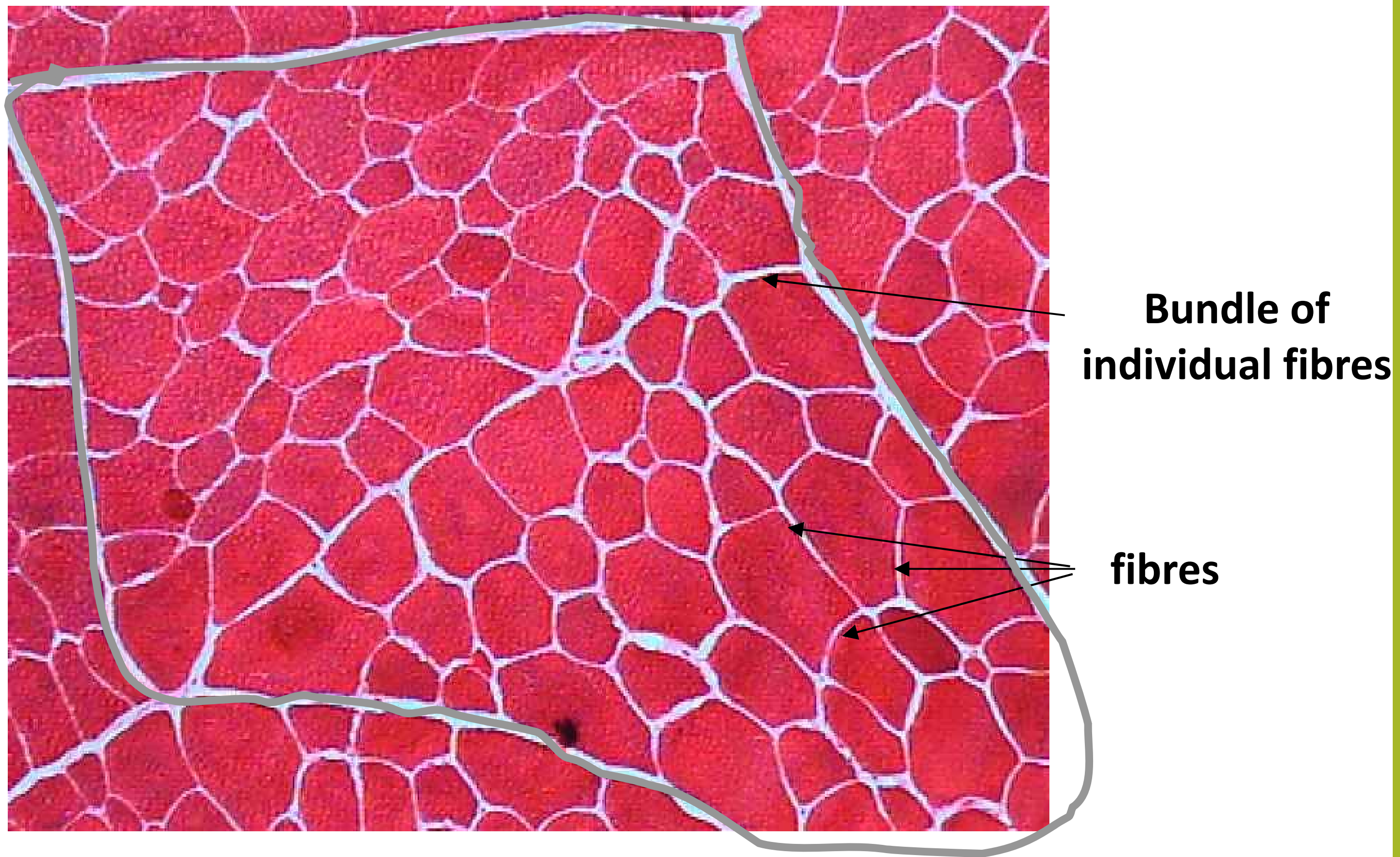




Macroscopic structure



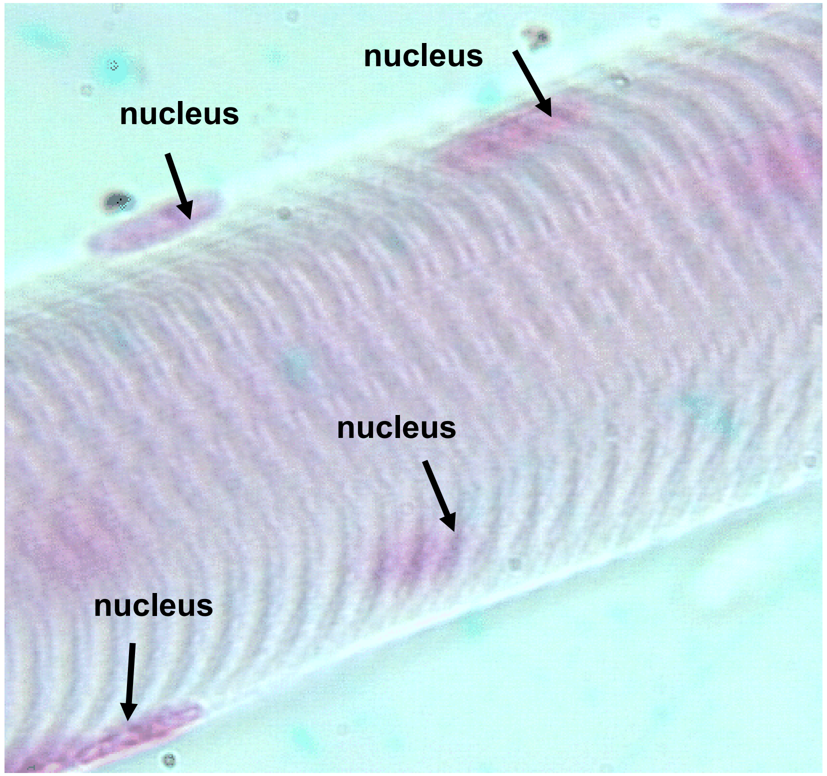
Microscopic structure



Histological section (bovine muscle)

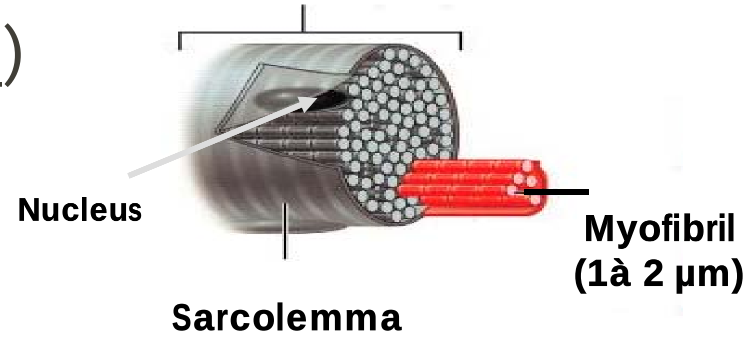
Muscle fibres

- differentiated cells
- From 75 to 90% of muscle volume
- cylindrical
- unbranched
- multinucleated
- length: up to 60 cm
- diameter: 10 to 100 microns
- striated



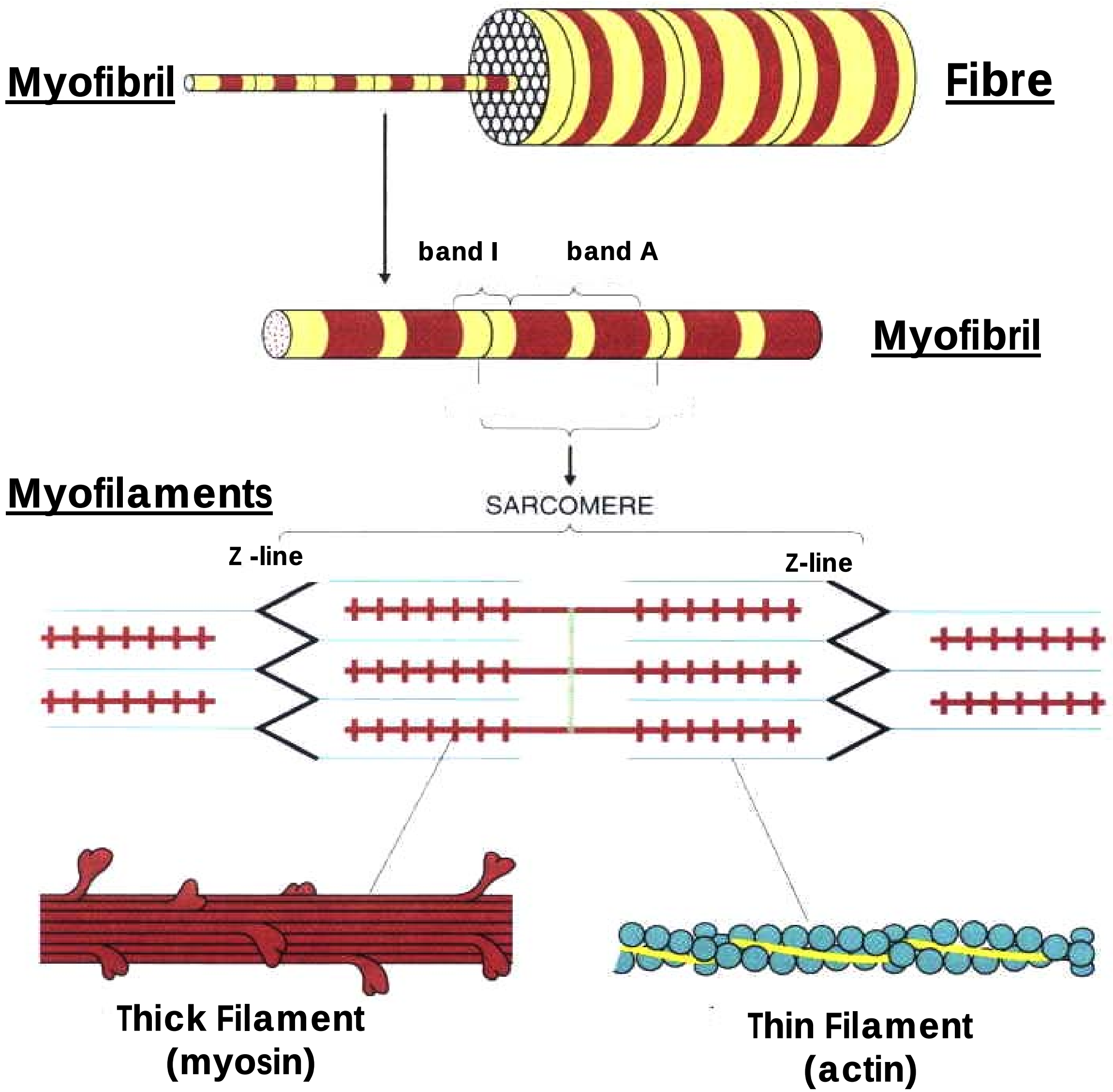
Cellular organisation

- membrane (sarcolemma)
- cytoplasm (sarcoplasm): incl. glycogen, myoglobin
- post-mitotic nuclei
- mitochondria
- endoplasmic reticulum : differentiated (sarcoplasmic)
- cytoskeleton (myofibrils)

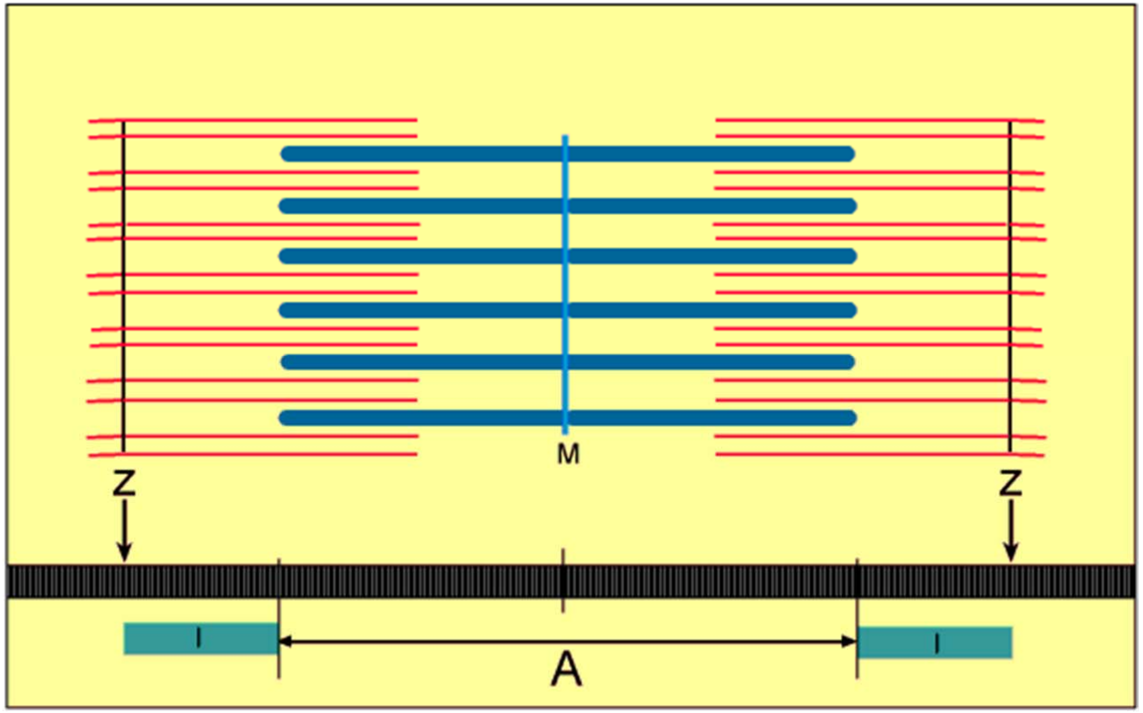


Watch https://www.youtube.com/watch?v=yJ85idDumtA

Ultra-structure



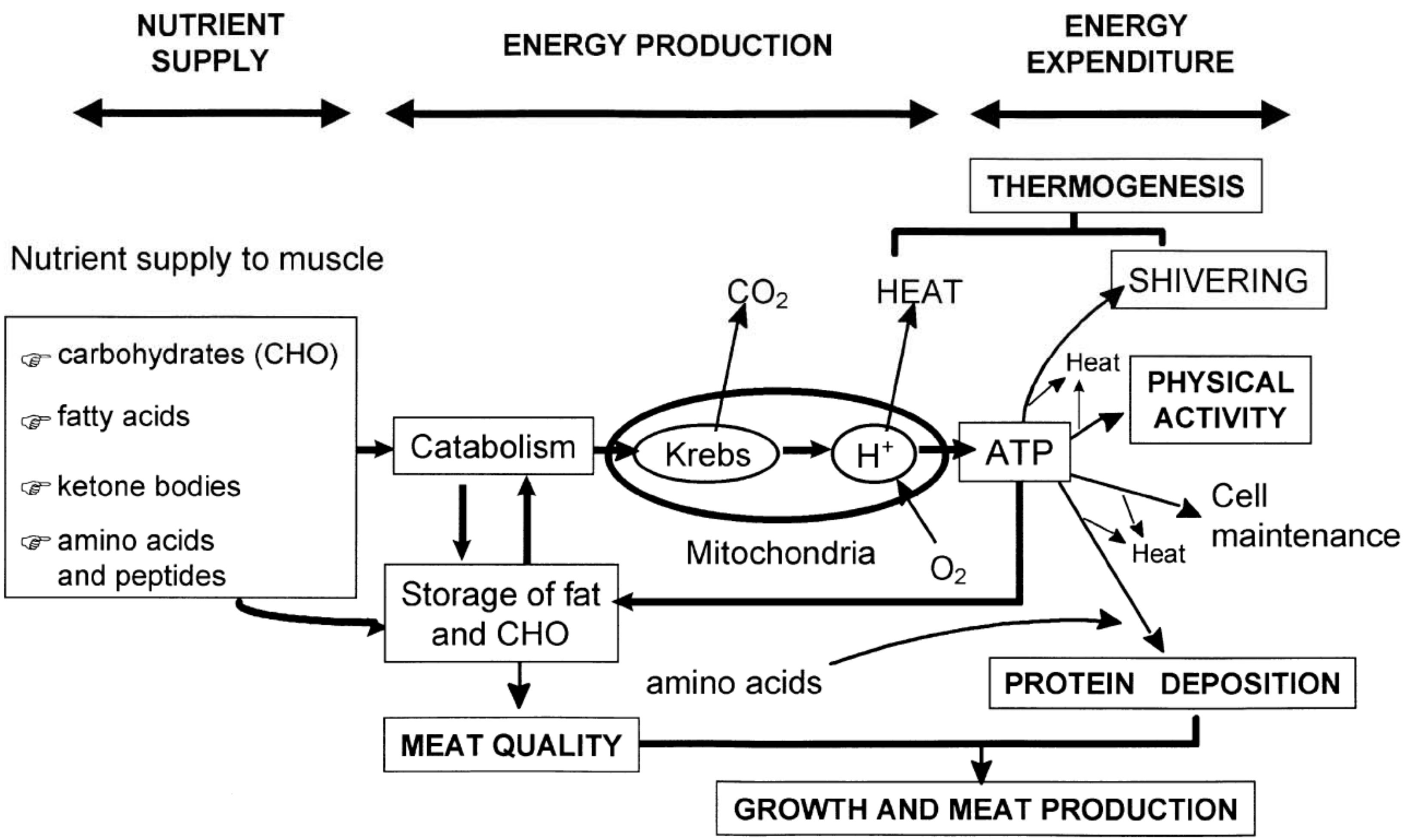
The sarcomer



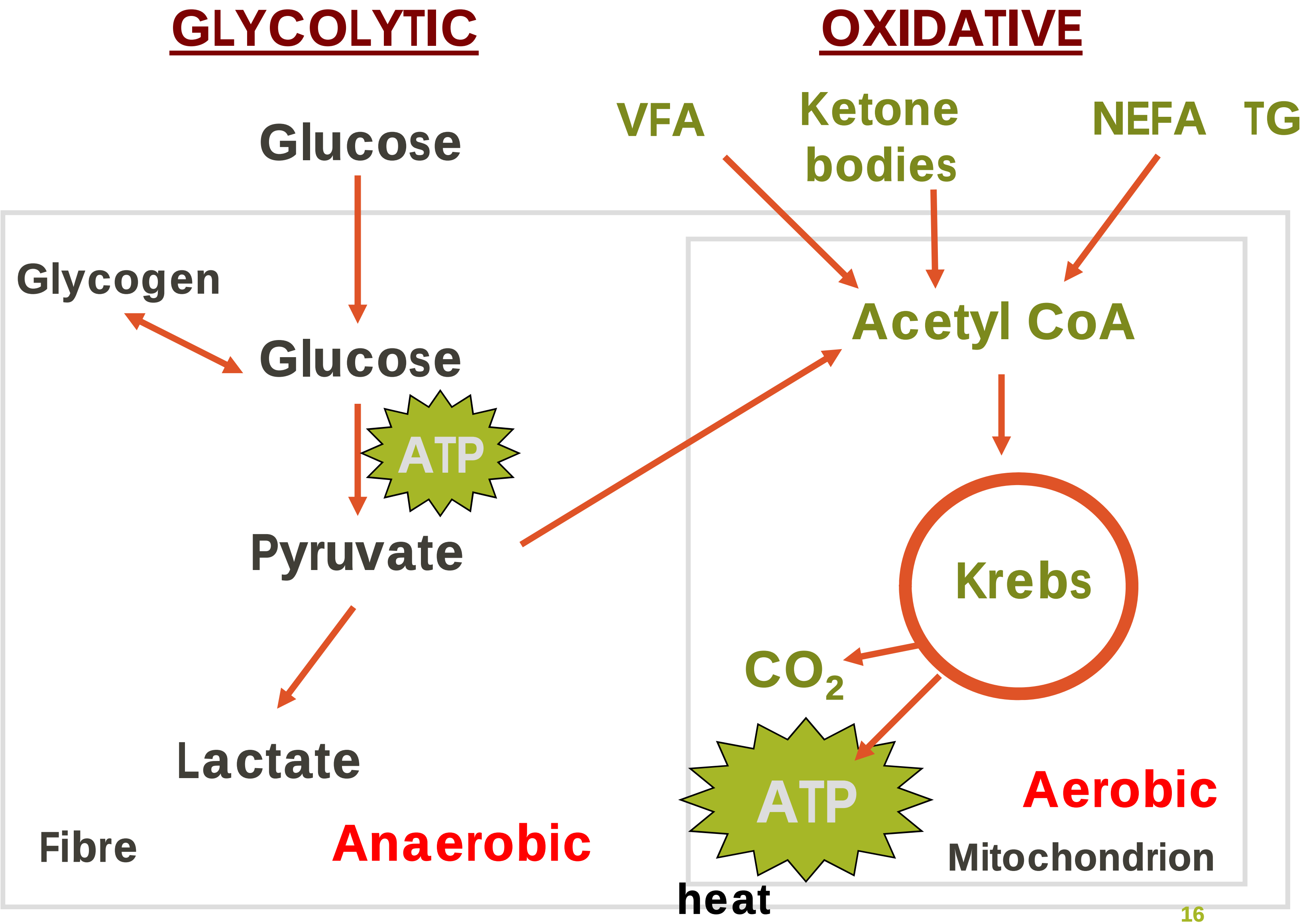
CONTRACTILE AND METABOLIC PROPERTIES

Metabolism

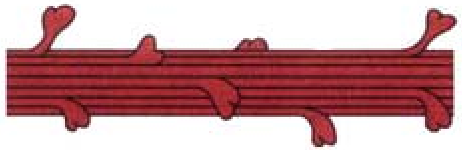
J.F. Hocquette et al. / Livestock Production Science 56 (1998) 115–143



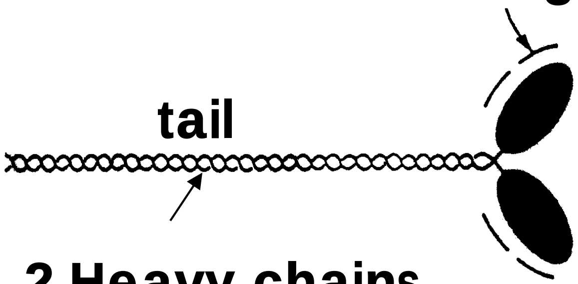
Metabolic pathways



Myosin



Contraction
Anchorage,
tension, traction



ATP-ase activity

<u>Several isoforms</u>

- Embryonic : E
- Neonatal or fetal : F
- Slow: I
- Fast: IIa, IIb, IIx

MyHC isoforms

« Adult » isoforms

I (slow)
IIA
IIX (fast)
IIB

Developmental isoforms

Embryonic
Fetal
α-cardiac
Extra occular (exoc)

Two gene clusters

Chr. 7

— α — β=I — slow

Chr. 12

— emb – IIA – IIX – IIB – Fet – exoc —

Example for pig muscle

for a review: Schiaffino and Reggiani, 2011

Fibre types

CLASSIFICATION	I	IIA	IIX
Speed of contraction	Slow	Fast	Fast
Metabolism	Oxidative	Oxido-glycolytic	Glycolytic
Fatigue resistance	High	High	Low
Glycogen Content	Low	High	High
Lipid Content	High	High	Low
Vascularization	High	High	Low

I ⇄ I/IIA ⇄ IIA ⇄ IIA/IIX ⇄ IIX

Hybrid (I/IIA)   Hybrid (IIA/IIX)

Fibre types / physical activity

Sprint ⇨
- Fast IIX fibres
- using glycogen

Jogging, ski, distance runner ⇨
- Slow type I fibres
- using lipids

Alternating sprint/endurance ⇨
- Fast oxido-glycolytic IIA fibres
- Using both carbohydrates and lipids
- Adapted to rhythm changes

Classification according to fibre type

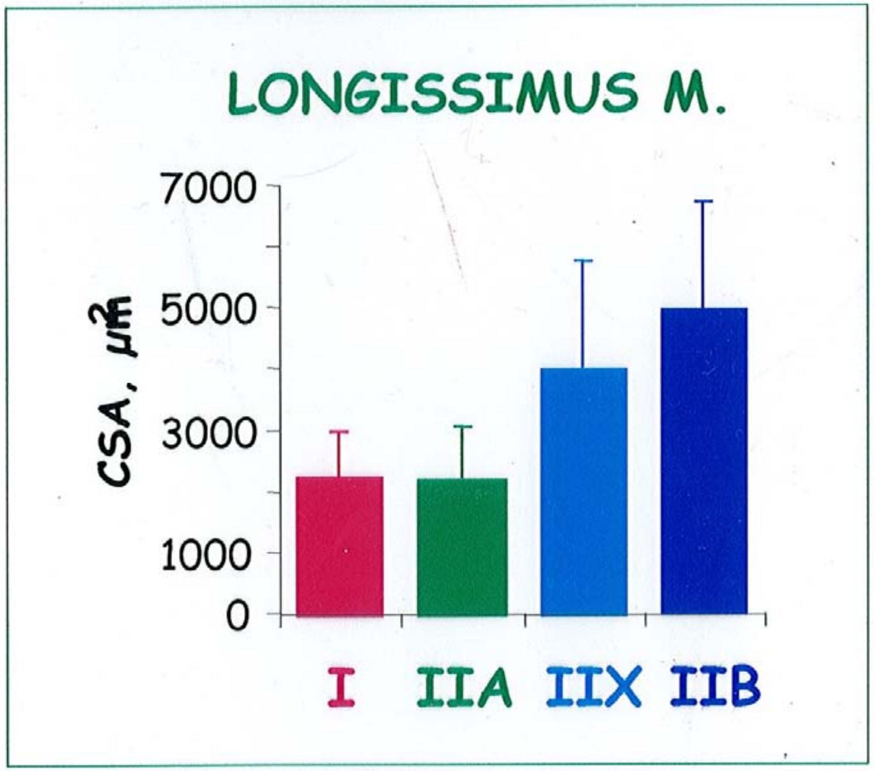
Type	I	IIA	IIX	
« Mean value »	20	25	55	
m. Diaphragma	55	45	0	(red)
m. Longissimus thoracis	25	25	50	
m. Semitendinosus	15	25	60	(white)

In cattle, according to Totland et al. (1991), Picard et al (2002)

IC1

Cross section area of the fibres

in cattle



Diapositive 22

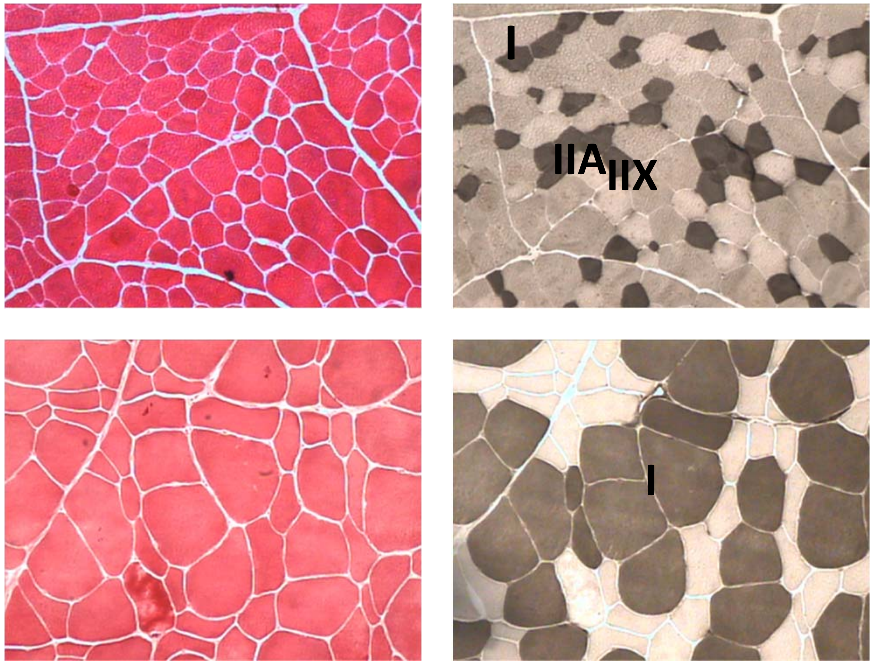
IC1 Isabelle Cassar-Malek; 30/09/2019

Mean cross section area of fibres

Azorubine | **ATPase**

TB

RA



In cattle

TB: m. *triceps femoris*

Ra: m. *rectus abdominis*

Mean area of type I fibres

TB	RA	signif.
1725	3957 µm^2	***

TB: I<IIA<IIX

RA: I>IIA>IIX

Oury et al., 2009

QTL analysis of type I and type IIA fibres

- In soleus muscle in a cross between LG/J and SM/J mouse
- LG/J and SM/J strain divergently selected for large and small body size, respectively

- 3 significant quantitative trait locus (QTL) affecting CSA for type I and type IIA fibers mapped to chromosomes (Chr) 1, 6, and 11
- 3 suggestive QTL for percentage of type I fibres mapped to Chr 2, 3, and 4
- Within each significant QTL, regions of conserved synteny were also implicated in variation of similar traits in pigs

Caroll et al, 2012. Frontiers in Genetics

CLASSIFICATION OF MUSCLE FIBRES

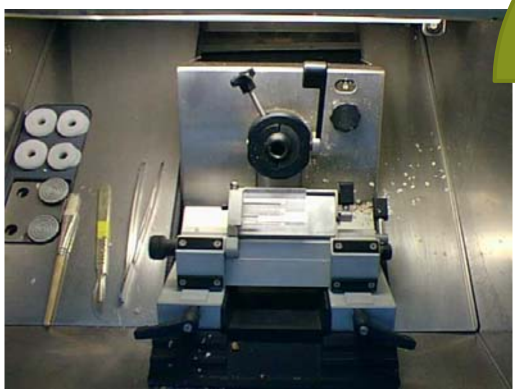
Methods

DIFFERENT METHODS BASED ON

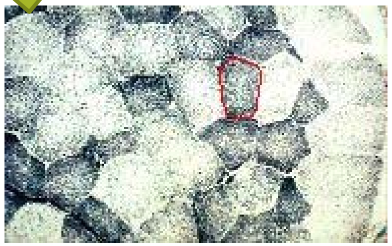
- functional tests (speed of contraction)
- metabolic criteria (the type of energy metabolism)
    - speed of energy utilization during contraction
    - main source of energy

1- *In situ* techniques

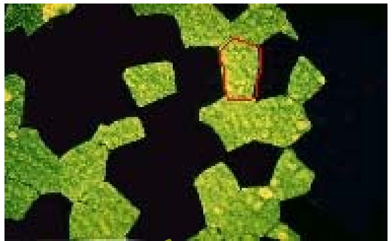
tissues → section



Detection



enzymatic
(SDH activity)



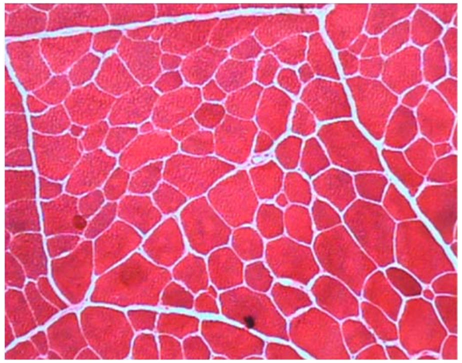
immunology
(slow MyHC)

Image analysis

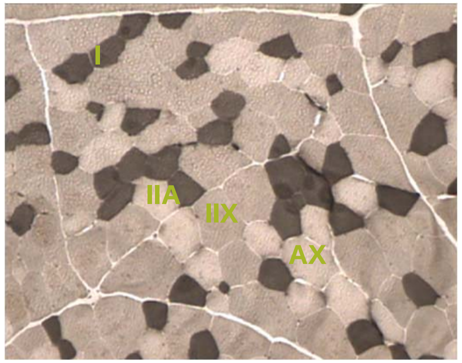
Histochemistry for fibre typing

Detection of three pure fibres and hybrid fibres in cattle muscle

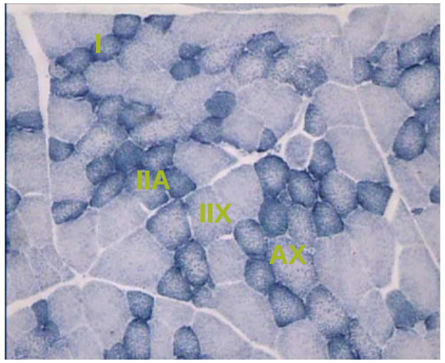
Azorubine



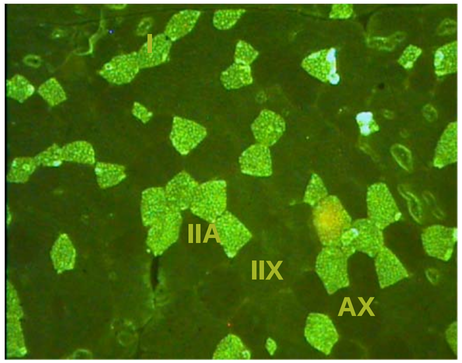
ATPase



SDH

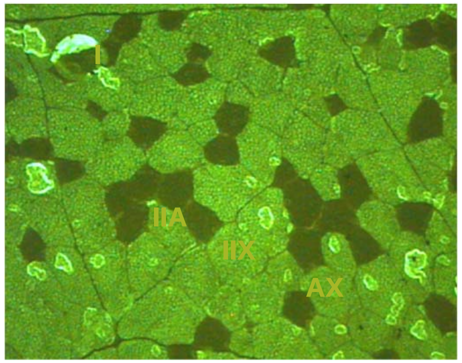


slow MyHC



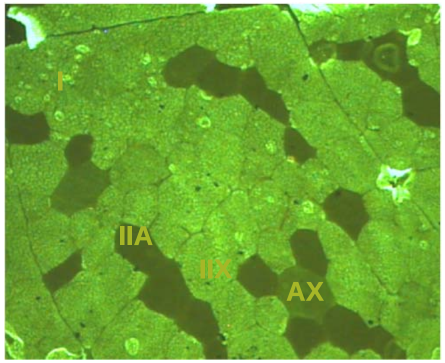
5B9 Alexis

fast MyHC



S5 15F4 (Agrobio)

MyCH I + IIx

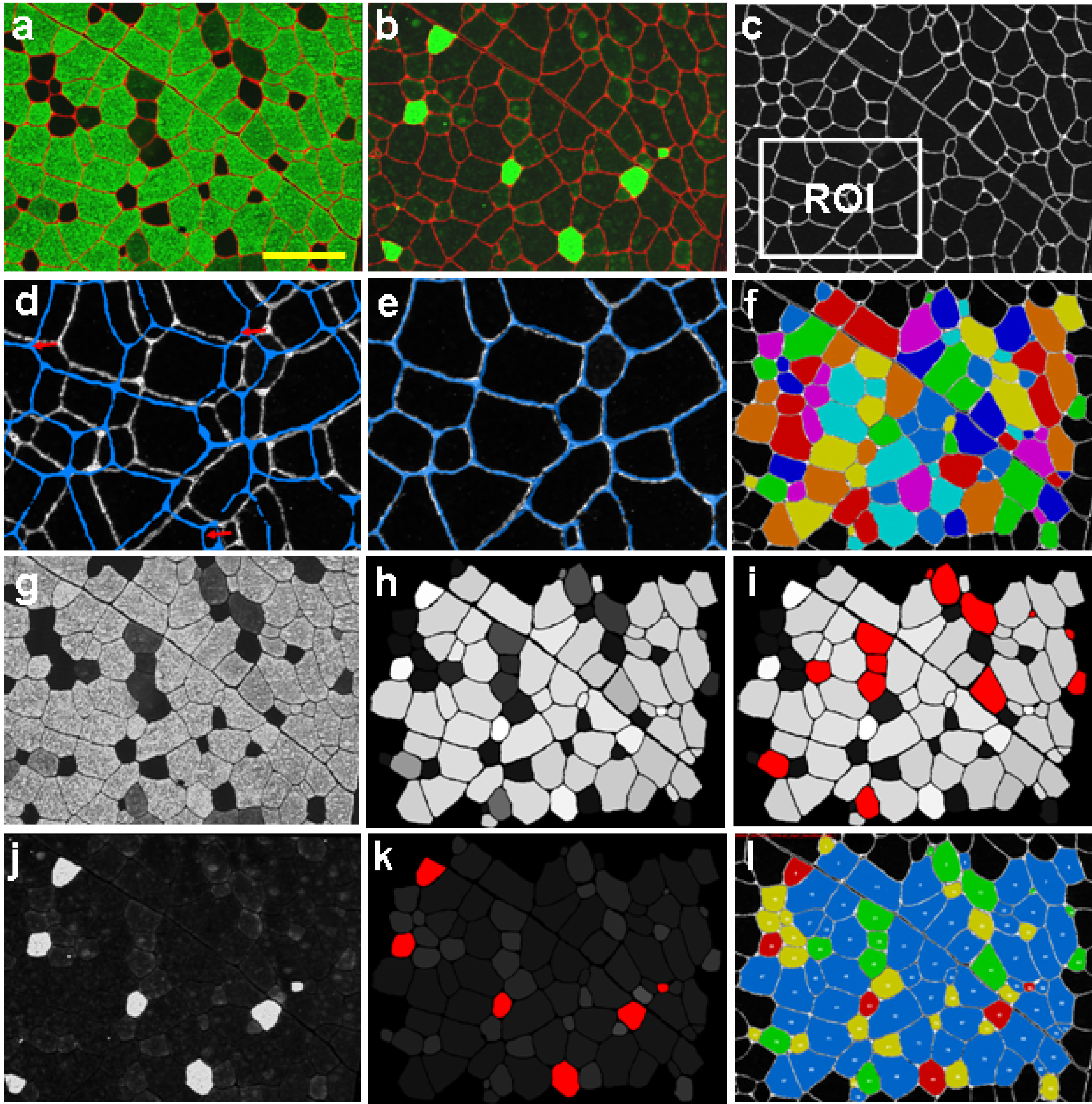


S5 8H2 (Agrobio)

Image analysis

on high number of fibres

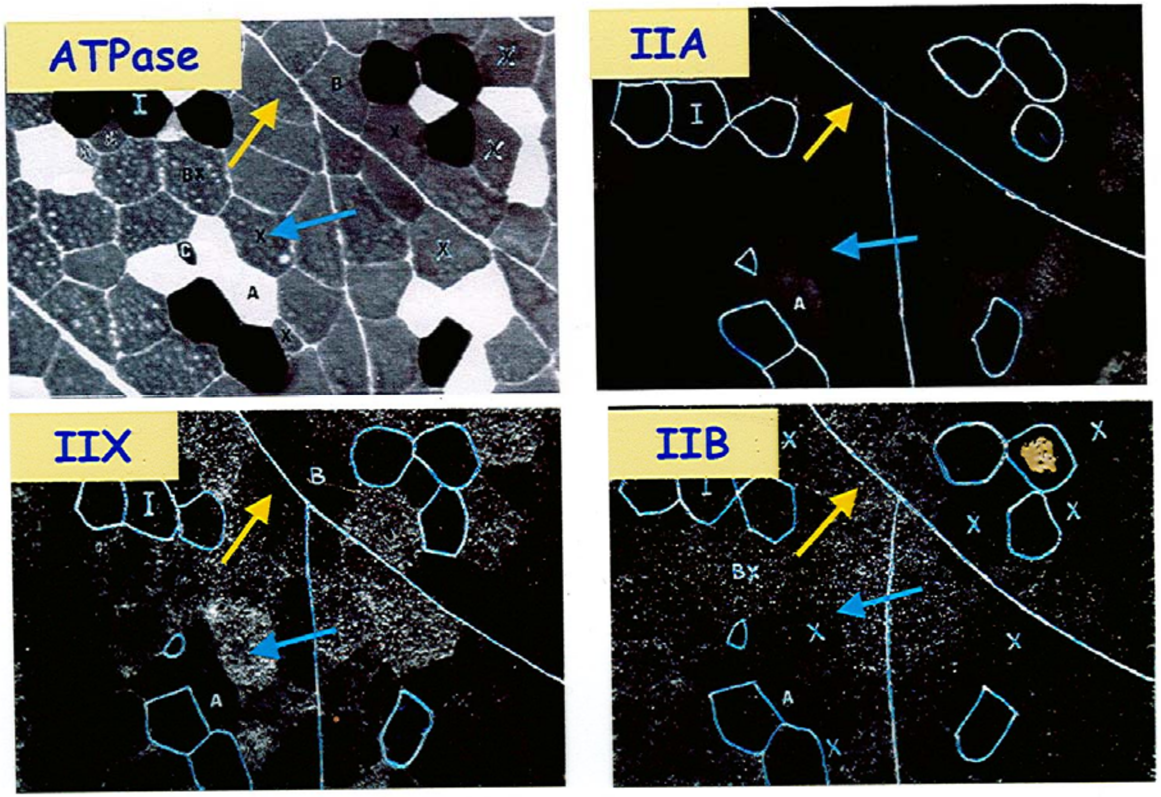
- % of each fibre type
- area
- % of area



Meunier et al. 2010, Histochem Cell Biol

MyHC *in situ* hybridisation

in pig *longissimus* muscle (100 kg BW)

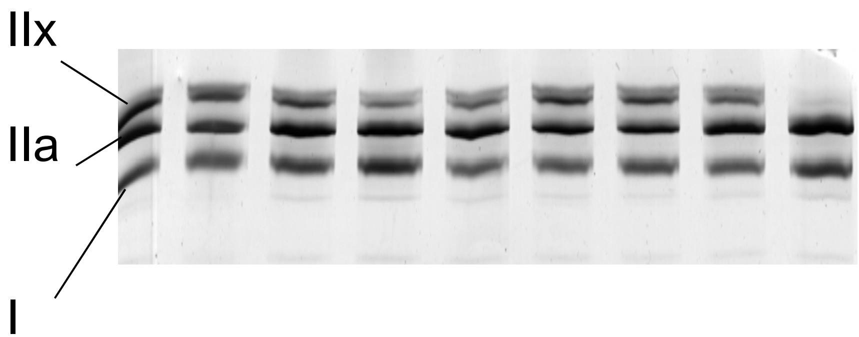


Lefaucheur et al. (1998)

2- From muscle homogenates

Electrophoretic separation of MyHC isoforms

SDS PAGE

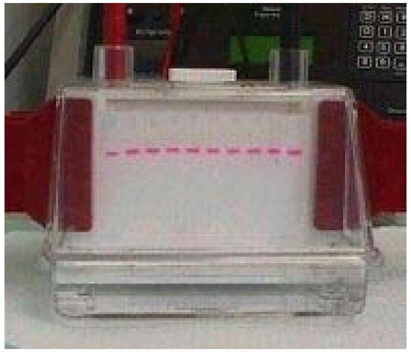


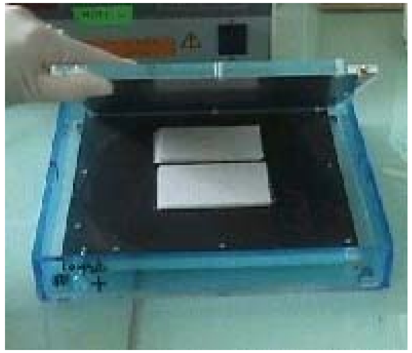
Talmadge and Roy (1995) modified by Picard et al. (2011)

Western-blot

Electrophoresis | **Transfert**

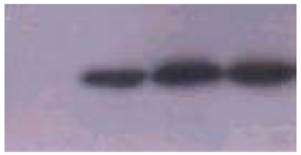
proteins →





Immuno-detection

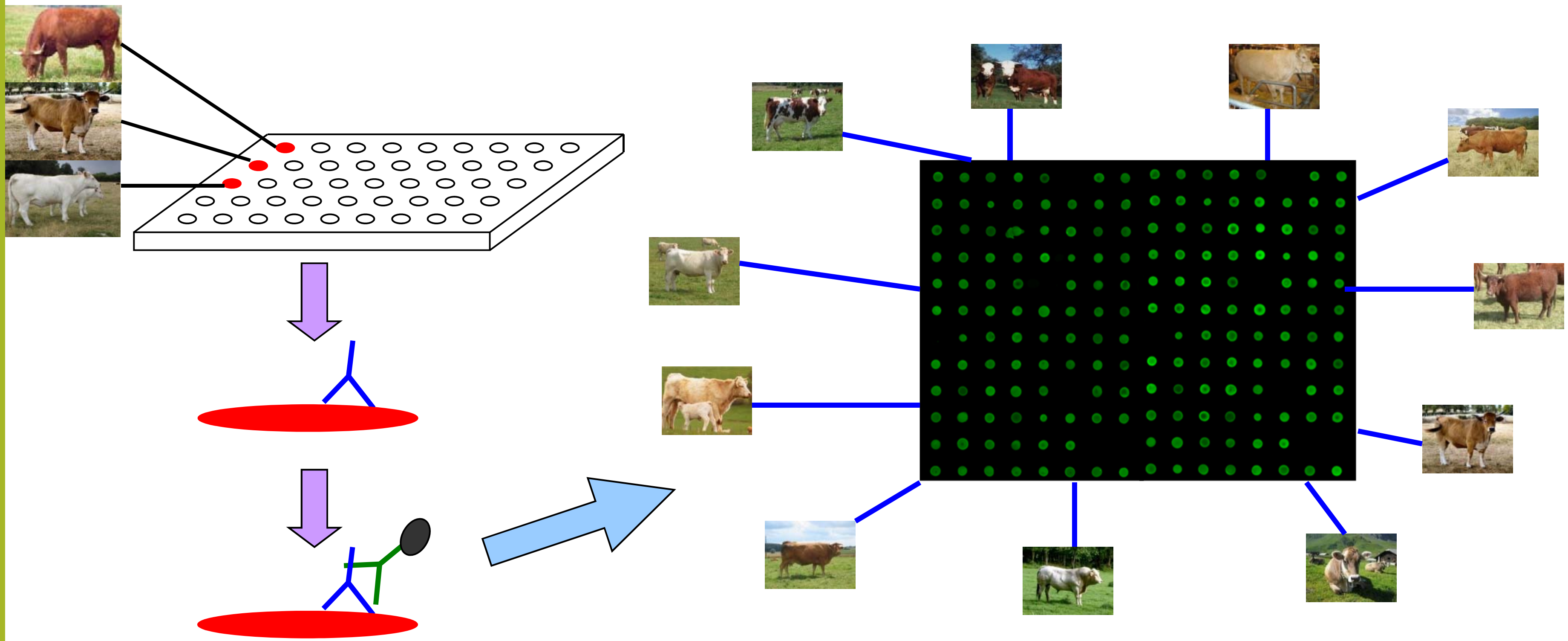
Bovine myoblast culture



desmin

D4 D6 D8 D10

High-throughput protein analysis

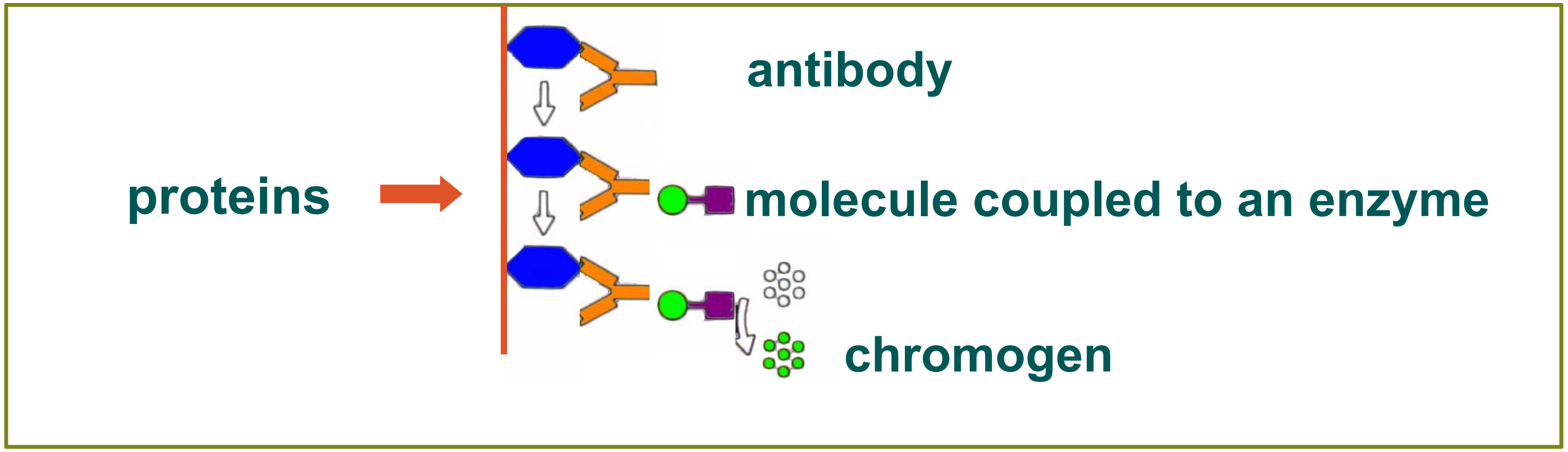


Dot-blot technology: analyse up to 96 samples simultaneously

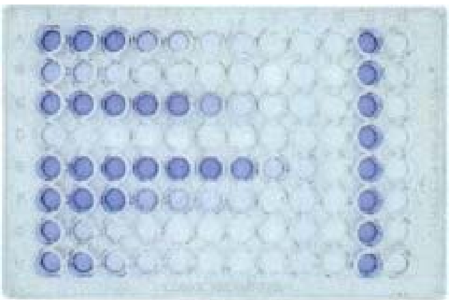
simplification of the western blot method

Guillemin et al. 2009.

ELISA assay

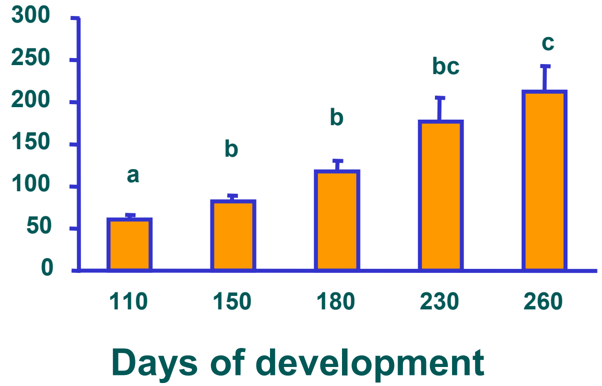


Detection



Optical density

FABP content



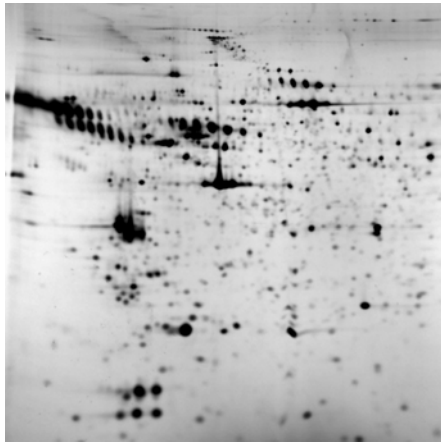
Proteomics

Gel-based proteomics: 2DE

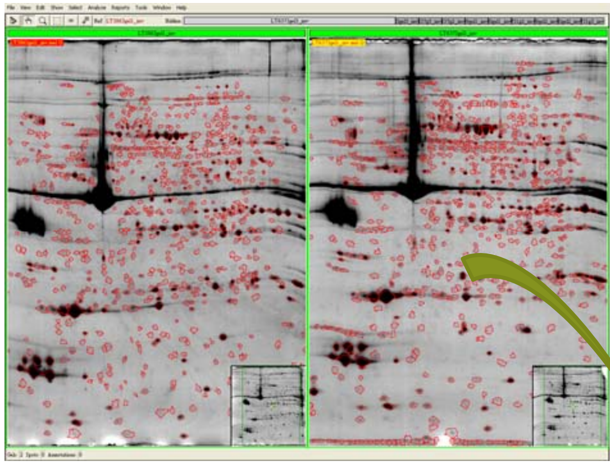
1st D: pI

2nd D : PM

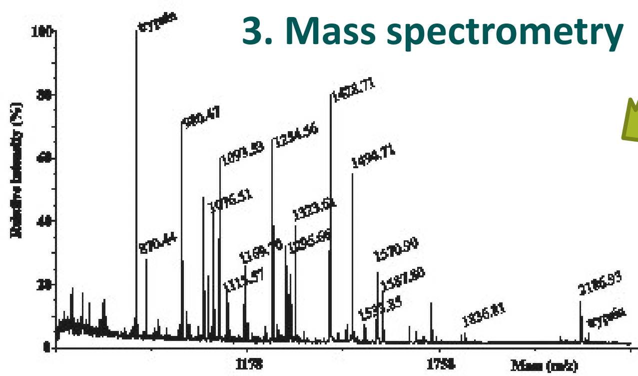
1. Separation



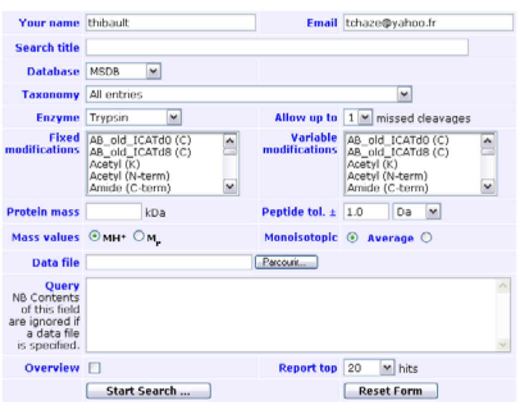
2. Image analysis



3. Mass spectrometry



4. Protein identification (databases)



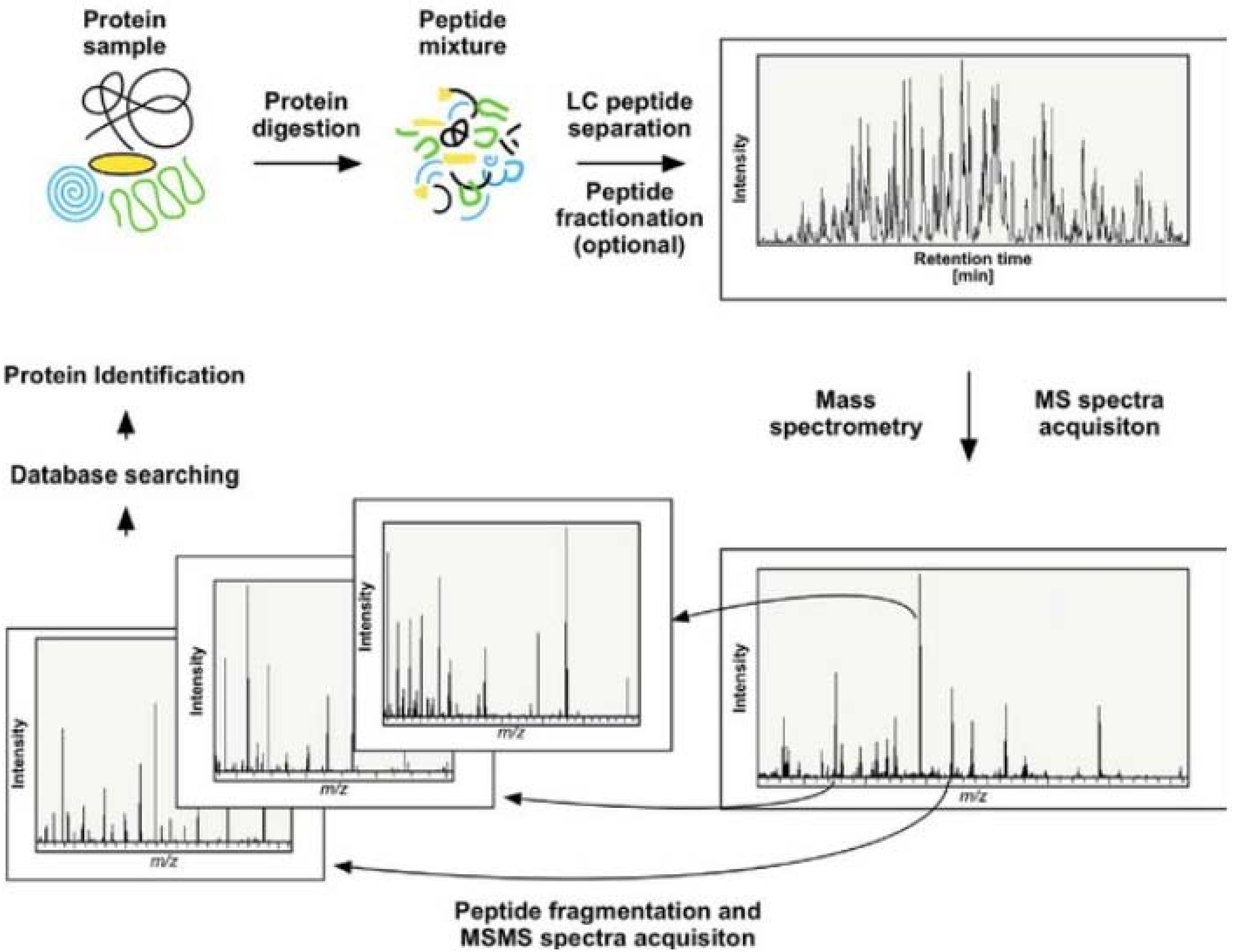
MASCOT Peptide Mass Fingerprint

Your name	thibault	Email	tchaze@yahoo.fr
Search title			
Database	MSDB		
Taxonomy	All entries		
Enzyme	Trypsin	Allow up to	1 missed cleavages
Fixed modifications	AB_old_ICATd0 (C) AB_old_ICATd8 (C) Acetyl (K) Acetyl (N-term) Amide (C-term)	Variable modifications	AB_old_ICATd0 (C) AB_old_ICATd8 (C) Acetyl (K) Acetyl (N-term) Amide (C-term)
Protein mass	kDa	Peptide tol. ±	1.0 Da
Mass values	MH+ Mr	Monoisotopic	Average
Data file	Parcourir...		
Query NB Contents of this field are ignored if a data file is specified.			
Overview		Report top	20 hits
	Start Search ...		Reset Form

Bouley et al. (2003)

Proteomics

Shotgun: nano LC MS/MS



From Vojtech Tambor

Gene expression

Northern-blotting to detect specific RNA molecules among a mixture of RNA

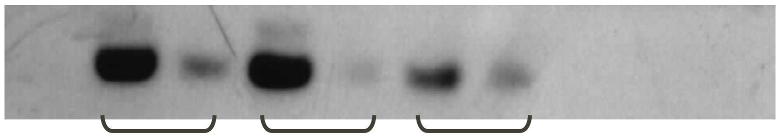
Electrophoresis

RNA →

Transfert

Hybridization

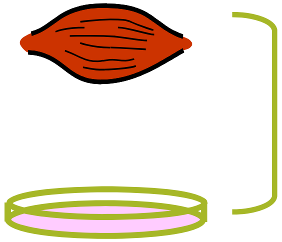
GLUT-4



Heart Ma TAd liver kidney

37

qRT-PCR



RNA → cDNA

Reverse Transcriptase
RT

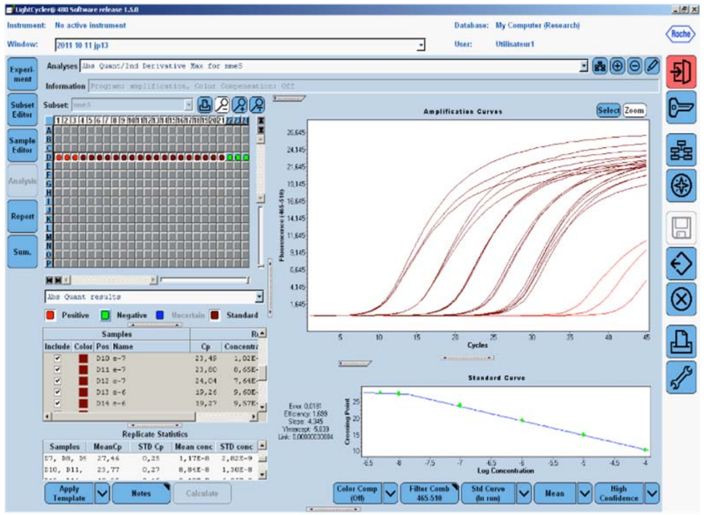
PCR

Foetus age (days)

110 180 230 260 15d

myostatin

cyclophilin



Transcriptomics

SAMPLE 1

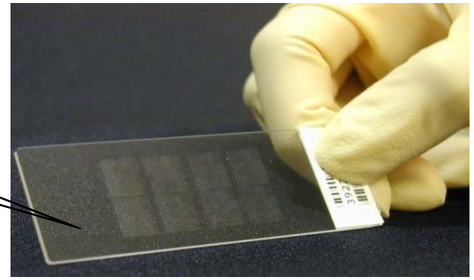
SAMPLE 2

Contractile and metabolic type

RNA extraction
Labelling

targets*

DNA chip



probes

Hybridization

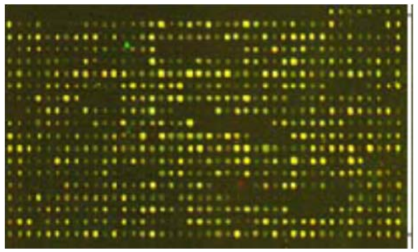


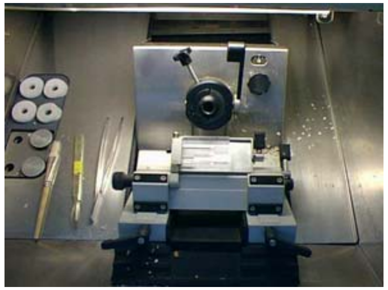
Image analysis

Biostatistics

Molecular signatures
Differential expression

Choosing the most accurate technique

- Reveal the contractile type by immuno-histochemistry using anti-MyHC antibodies and the SDH activity on serial sections (Picard and al., 1998): distinguish the hybrid fibres, and get information on the cross section area of each fibre type
- Not relevant for high throughput phenotyping (large numbers of animals)
- Detect contractile type using electrophoresis of MyHC and metabolic type by assaying metabolic enzymes



IIB OR NOT IIB?

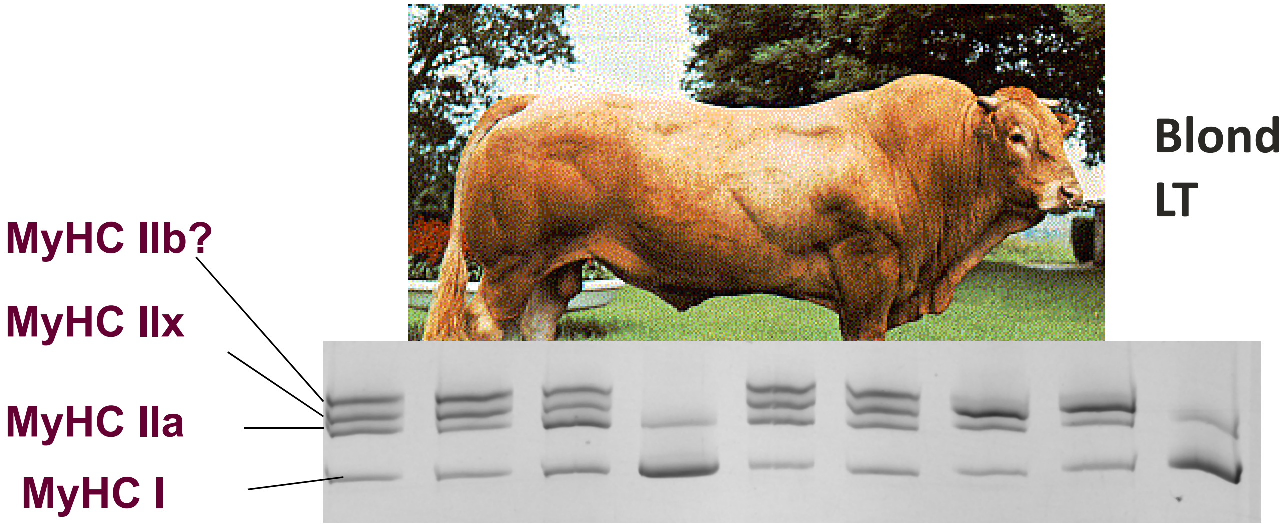
Myosin IIB

MyHC-IIb is the predominant motor protein in most skeletal muscles of rats and mice

The mRNA for this isoform is only expressed in a very small subset of specialized muscles in adult large mammals, including humans.

Is IIb MyHC expressed in cattle?

- **For many authors, IIb MyHC (MYH4, BTA 19) would not be expressed in cattle muscles, but extraoccular muscle:**



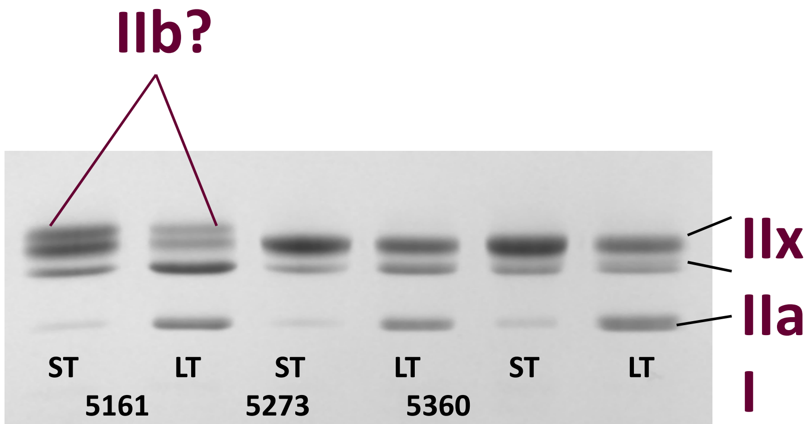
Blonde d'Aquitaine bull
LT

Picard and Cassar-Malek, 2009

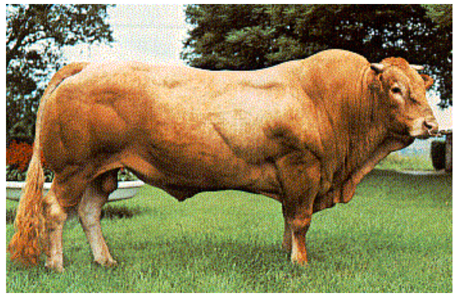
A fourth MyHC isoform in cattle

- A particular MyHC in Blonde d'Aquitaine bulls with common ancestor

SDS-PAGE
5-8% gradient

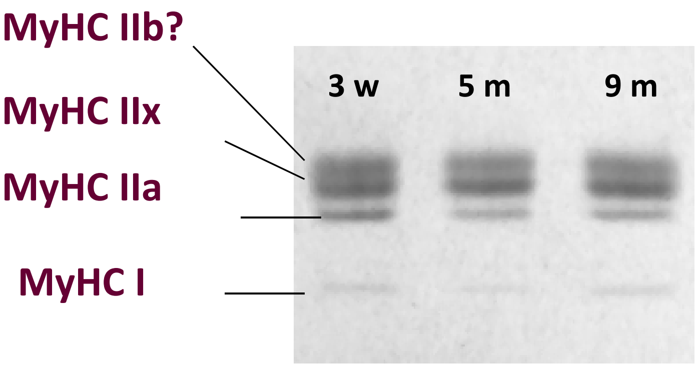


IIb?	35%	18%
IIx	41%	23%
IIa	20%	37%
I	4%	22%

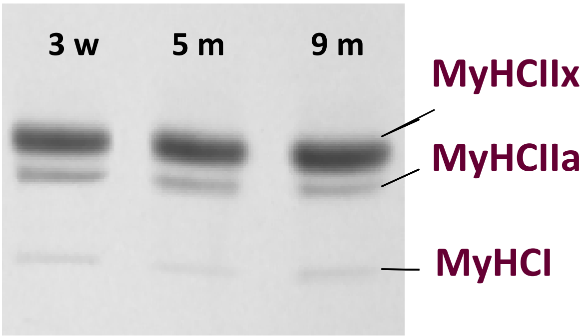


A MyHC expressed in post-natal muscle

- This MyHC is detected at all studied ages
- Onset as soon as fœtal life?



Bull with this MyHC

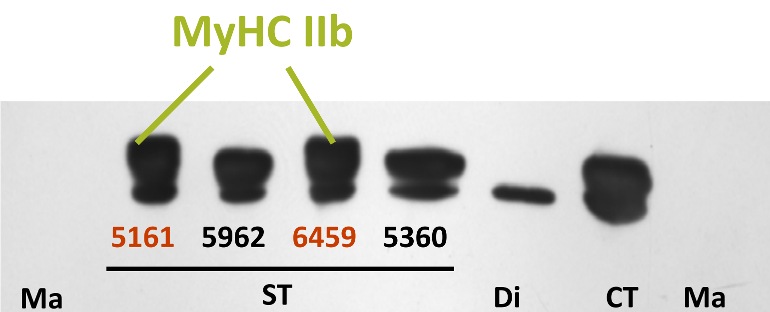


Control

Identification

Immuno-detection

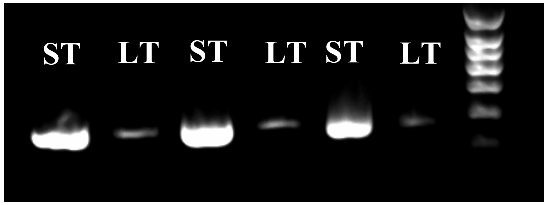
with an antibody specific of the fast MyHC (IIa, IIx, IIb)



Ma : *masseter*, slow (I),
Di: *diaphragma* (I +IIa),
CT: *cutaneus trunci* (IIa+ IIx)

RT-PCR

Primers designed in the 5'-UTR of the MyHC IIb transcript



Amplification of a cDNA fragment and sequencing

This isoform is the IIb MyHC (encoded by MYH4)

Picard and Cassar-Malek, 2009

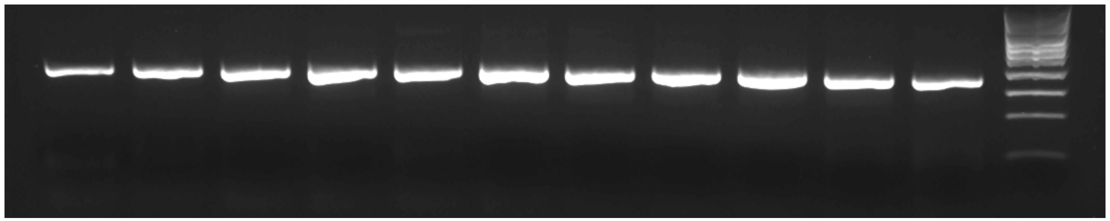
Abundance of the transcript

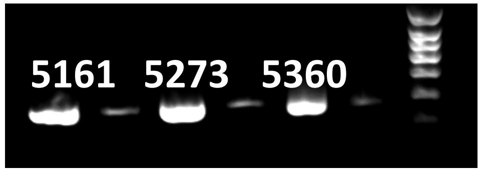
- Specific regulation of MYH4 expression in cattle?

RT-PCR using primers for 5'-UTR MyHC IIb (Chikuni et al, 2004)

Charolais

AMPLIFICATION
~300 pb in ST





ST LT ST LT ST LT

B. Aquitaine

Transcripts observed in all 11 young bulls but the protein was present in 2 only (ST BA)

What's next?

Kim (2014) by using electrophoresis and nano LC-MS/MS of MyHCs did not observed unique peptides of MyHC IIb in Hanwoo Steer LT muscle

MyHC1-IIx (n=14)
MyHC- IIa (n=8)
MyHC-I (n=21)
MyHC- IIb (n=0)

However this has to be tested on our samples!

Conclusion

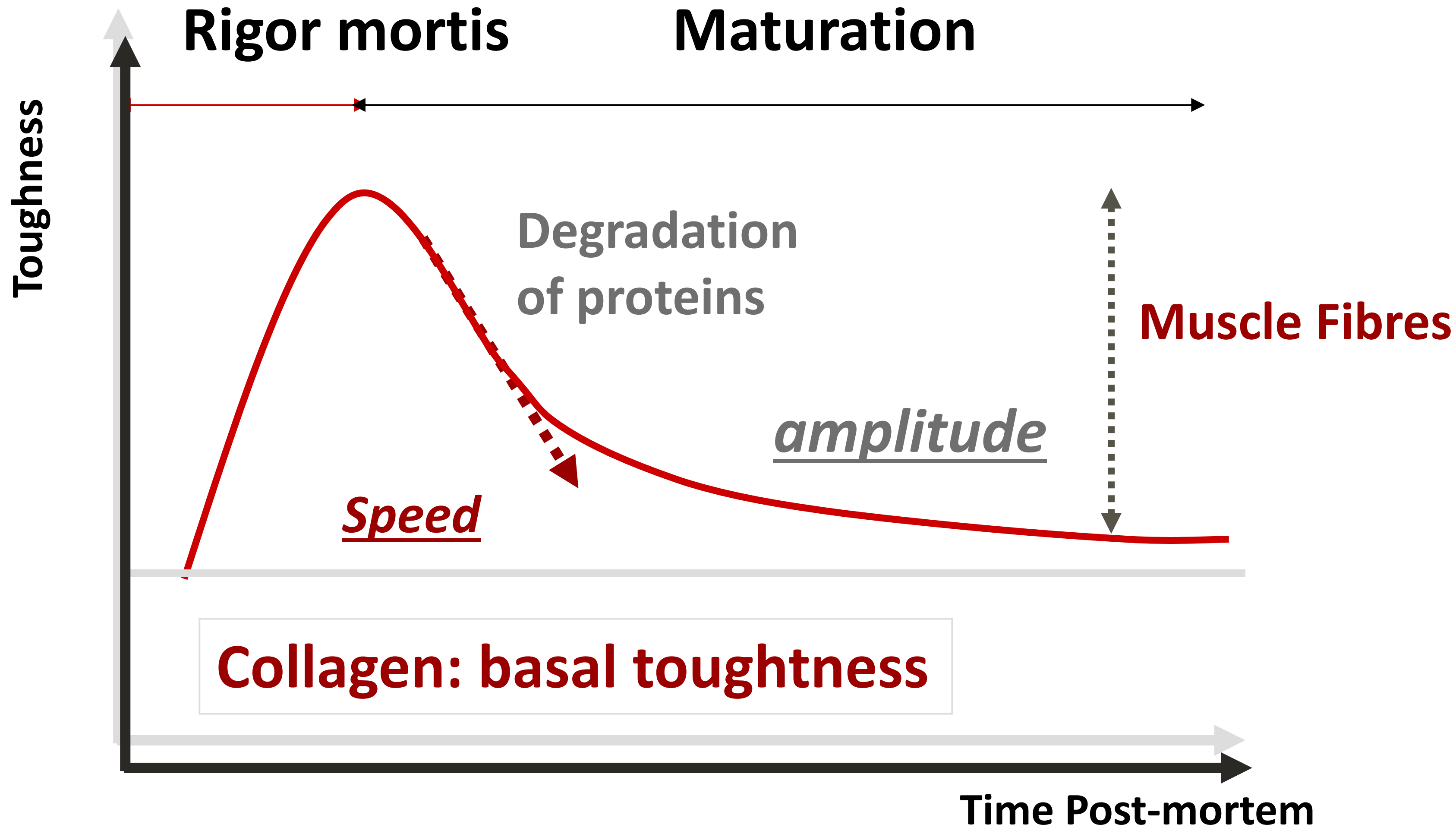
IN CATTLE

- **Three types of fibres I, IIA, IIX**
- **and a fourth one IIB in some french bovines**
- **with a variable frequency between breeds**
- **6% in Charolais, 35% in Blonde d'Aquitaine, 45% in Limousin**

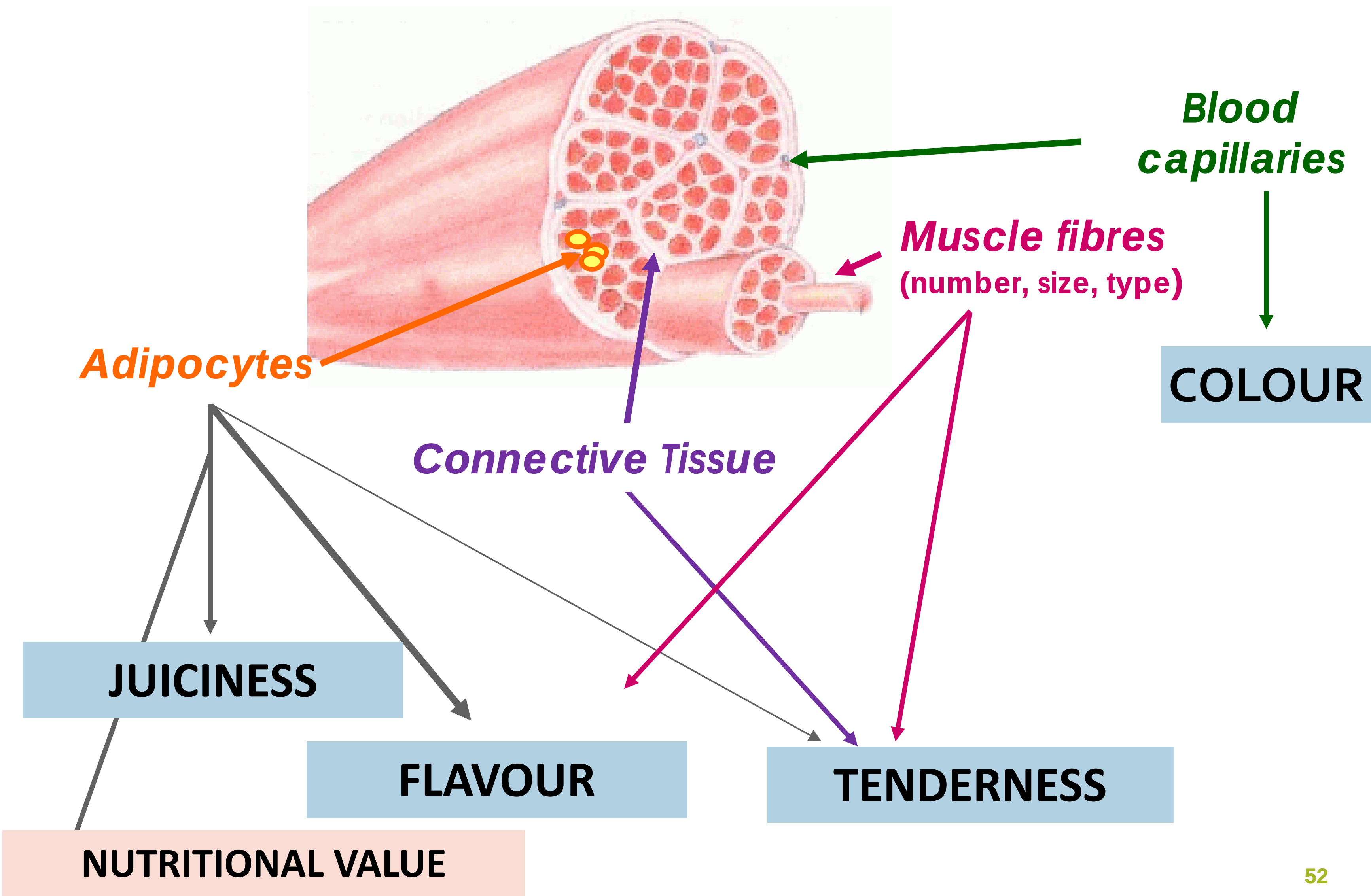
Picard et al., 2010

FROM MUSCLE TO MEAT

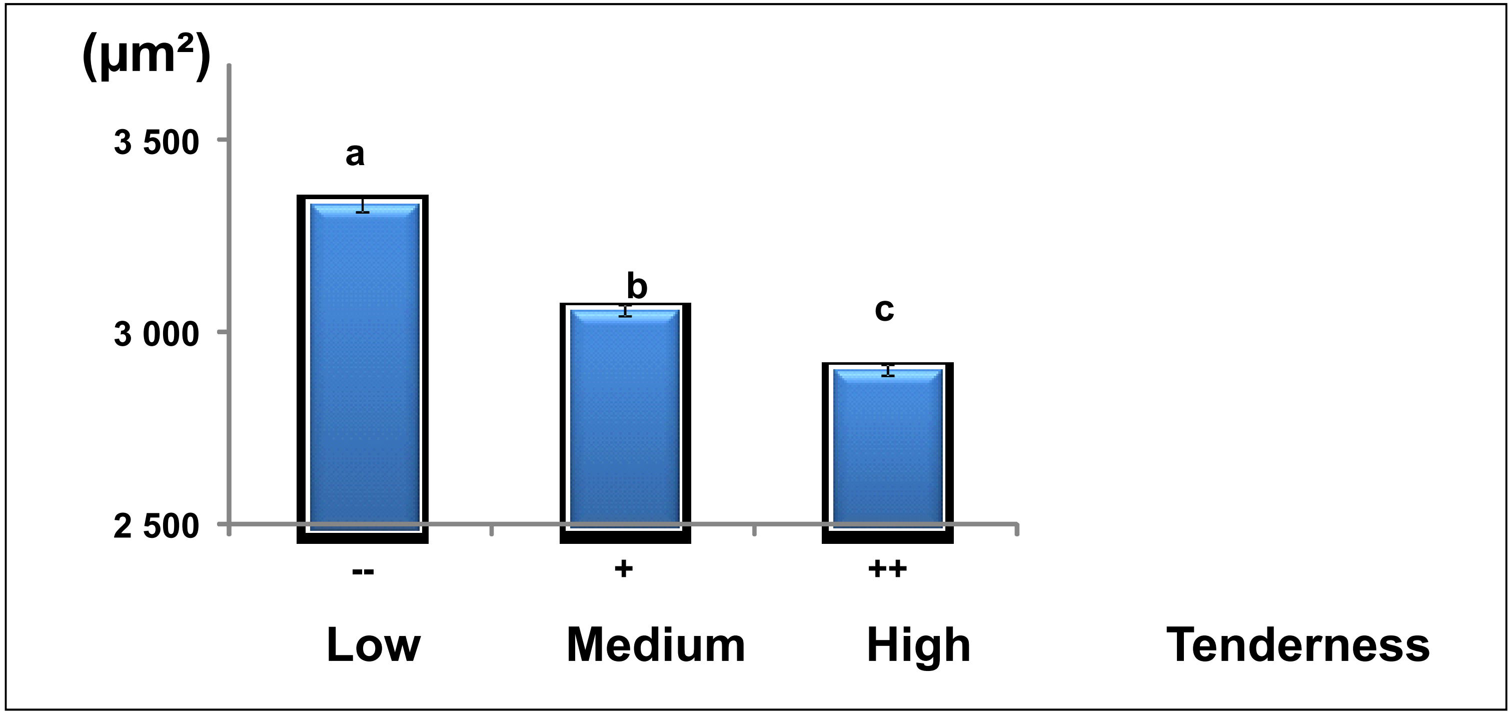
Conversion of muscle into meat



How muscle biochemistry affects Beef quality



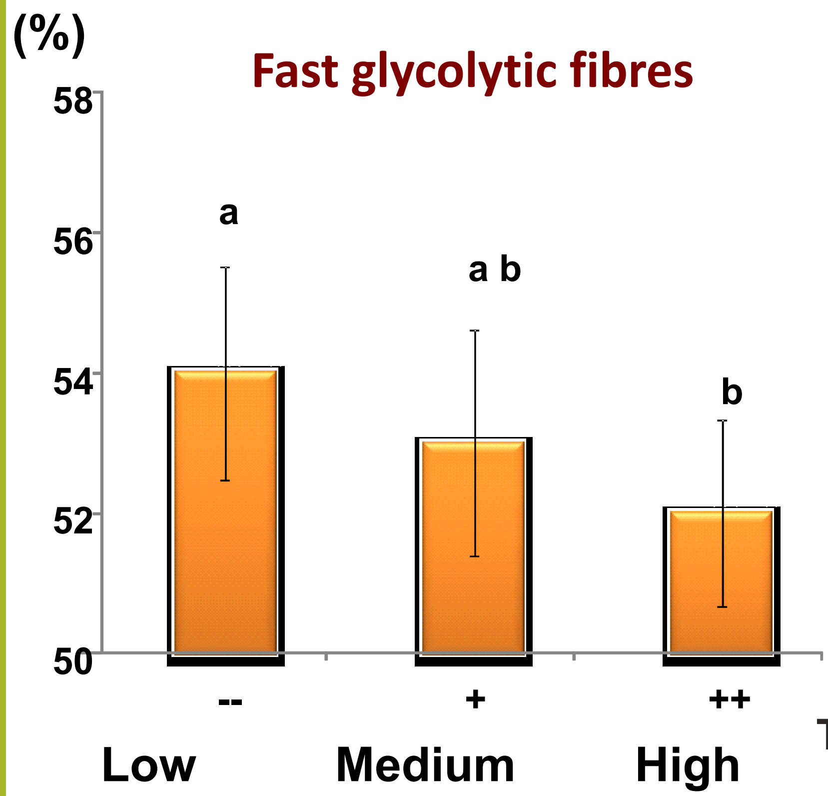
Cross sectional area of fibres/quality



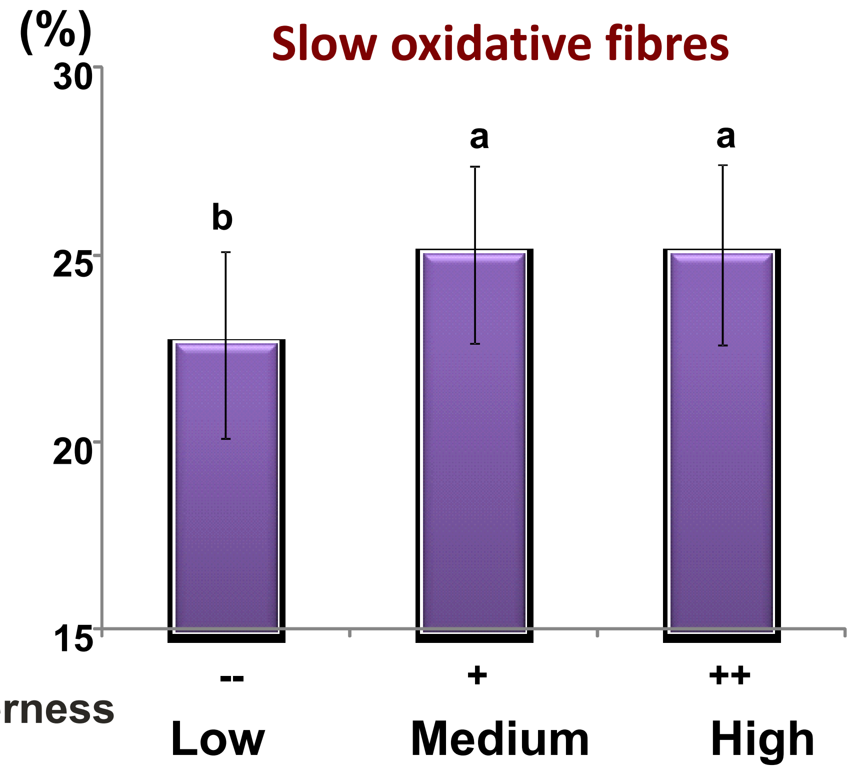
For *Longissimus thoracis* muscle (LT), the tenderest muscles have the lowerest cross sectional area of fibres

Chriki et al., ICoMST 2011

Fibre type/quality



Tenderness



For *LT,* the muscles the less tender have the higher % of IIX fibres and the lower % of slow I fibres

Chriki et al., ICoMST 2011

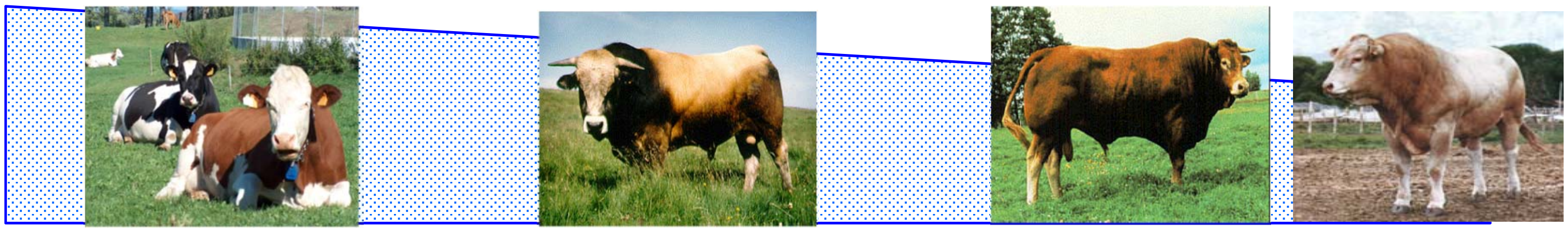
Muscle properties according to the breed

- Muscle mass
+ collagen
+ intra-muscular fat

+ Muscle mass
- collagen
- intra-muscular fat

+ red
slow
oxydative

+ white
fast
glycolytic



Dairy breeds

Hardy breeds

Beef breeds

Research for the meat sector

- For beef cattle research, a main objective is to control both the development of muscles and qualities of the meat, with specific attention towards tenderness (the top priority quality attribute).
- Variability in beef tenderness originates from genetic polymorphisms and modulation of gene expression according to rearing conditions.
- Beef tenderness is a complex phenotype (post-mortem expression). Identification of relevant markers at the DNA or protein level is ongoing.
- The next challenge is to integrate the knowledge and develop detection tests for desirable animals to ensure proper breeding programmes or management systems.

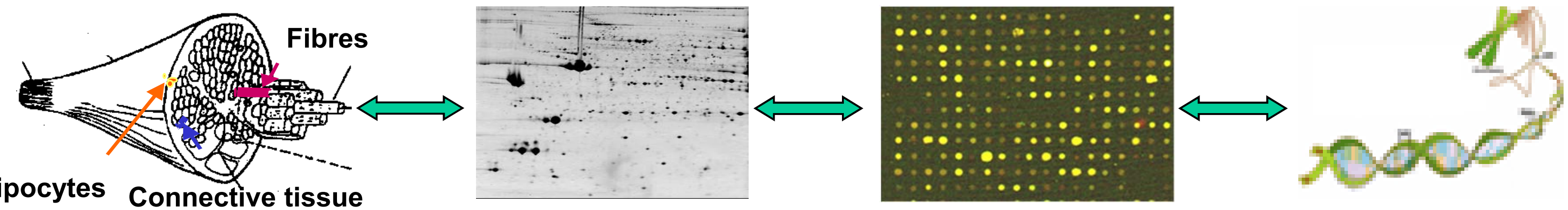
Biomarkers of tenderness

- The relationships between fibres' properties and tenderness is different according to the muscle

Difficult to establish general law

- Muscle characteristics (collagen, fibres, lipids) explain around 30% of tenderness variability

Need to identify other muscle characteristics involved in tenderness by Genomics



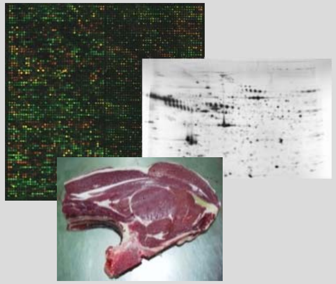
Biochemistry/Histochemistry Proteomics Transcriptomics Genetics

From omics to prediction tools for the Beef sector

Omics signatures

Transcriptome

Tenderness

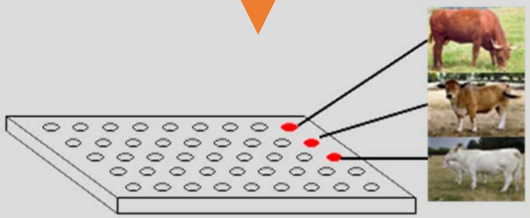


Proteome

List of candidate markers

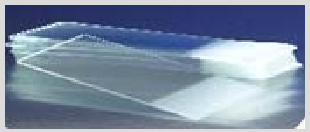
from 2005 to 2012…

Large-scale VALIDATION



from 2008 to 2012…

Development of TOOLS
(DNA chip, protein array)



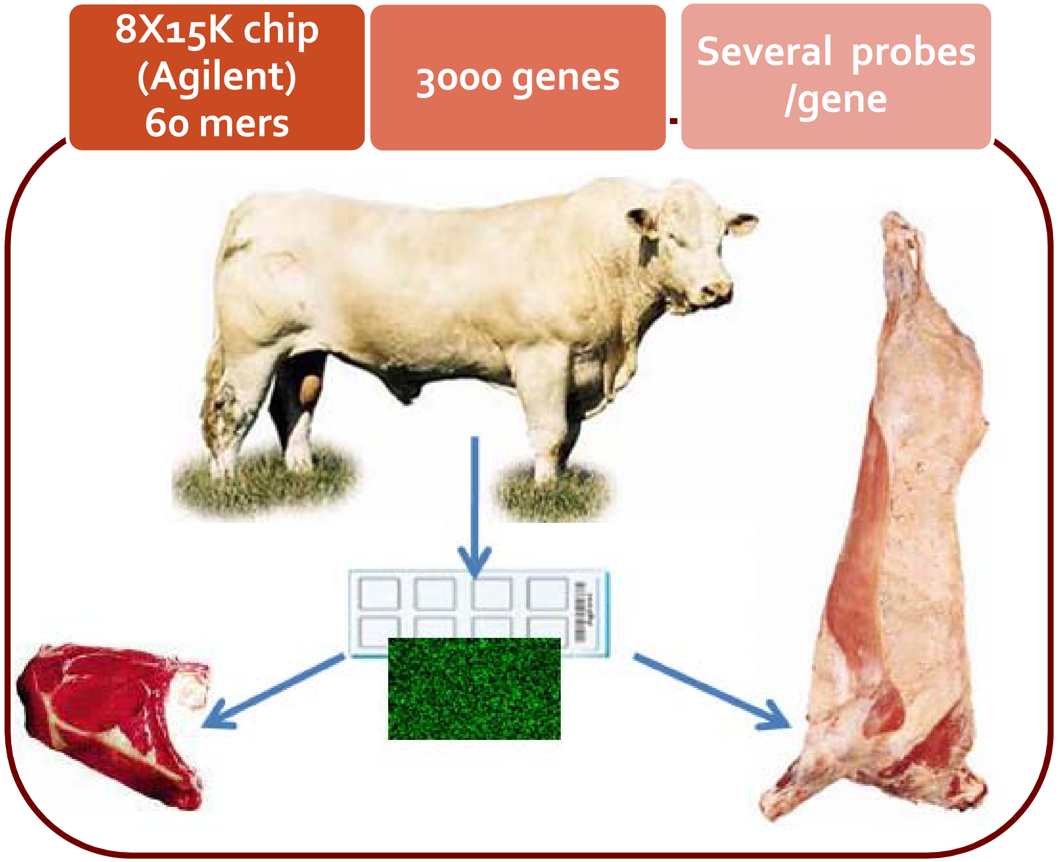
Inra + French Beef Industry
from 2011

from 2015
Reverse Phase Protein Array
nanotechnologies

Use by the Beef industry

Picard et al, 2015,
Cassar-Malek & Picard, 2016

A “meat quality chip” for Beef prediction



+

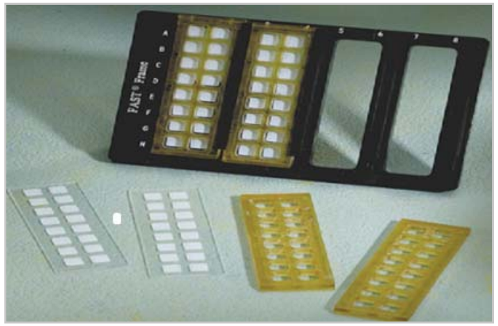
Development of turnkey software

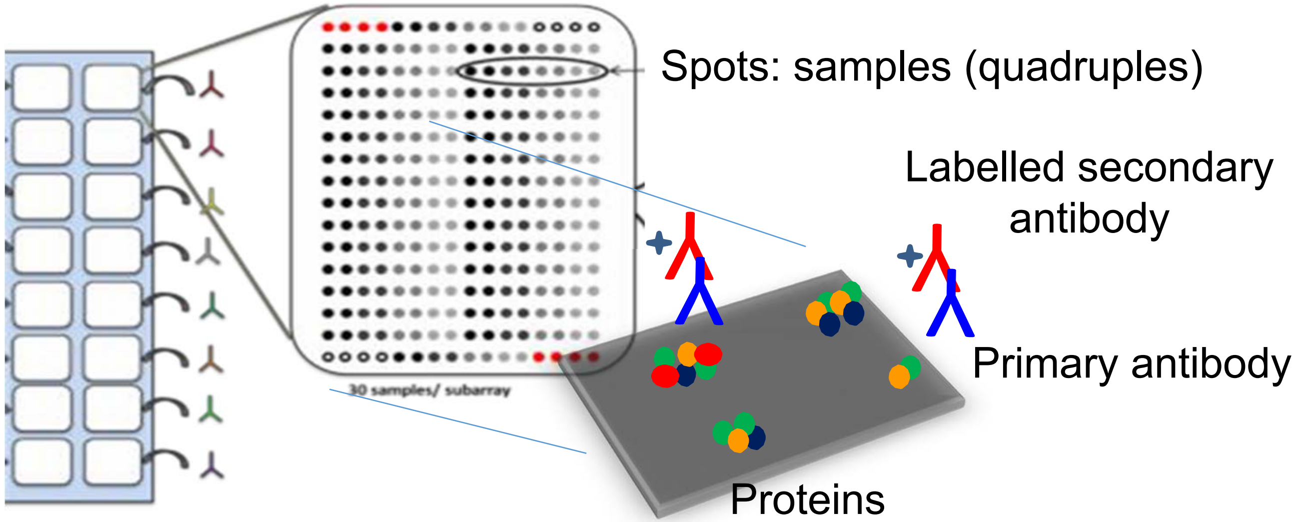
APIS-GENE INTERBEV FranceAgriMer CONSEIL RÉGIONAL AUVERGNE IMAXIO Division DiagnoGene

Hocquette et al. 2012. BMC Veterinary Research, 8:135.

Towards high throughput screening of protein biomarkers

Reverse Phase Protein Arrays, a recent methodology





RPPA

Quantification of the abundance of one biomarker in up to 500 samples

On going project + other methods (nano technologies)

Toward less invasive markers

Search for plasma markers

The plasma perfuses all tissues of the body and thus may contain information on physiological mechanisms and performance.

In livestock animals, plasma proteomics is a promising strategy to identify biomarkers of the potential of meat production.

Take-home messages

- The skeletal muscle tissue is a specialized tissue but heterogeneous in structure.
- The muscles are characterized by their contractile and metabolic properties (isoforms of contractile proteins, preferential metabolic pathway).
- They are involved in different types of movements (fast or slow, short or endurance effort).
- The muscle characteristics can explain only one third of variability in Beef quality (tenderness). Biomarkers are identified for development of « diagnostic » tools.