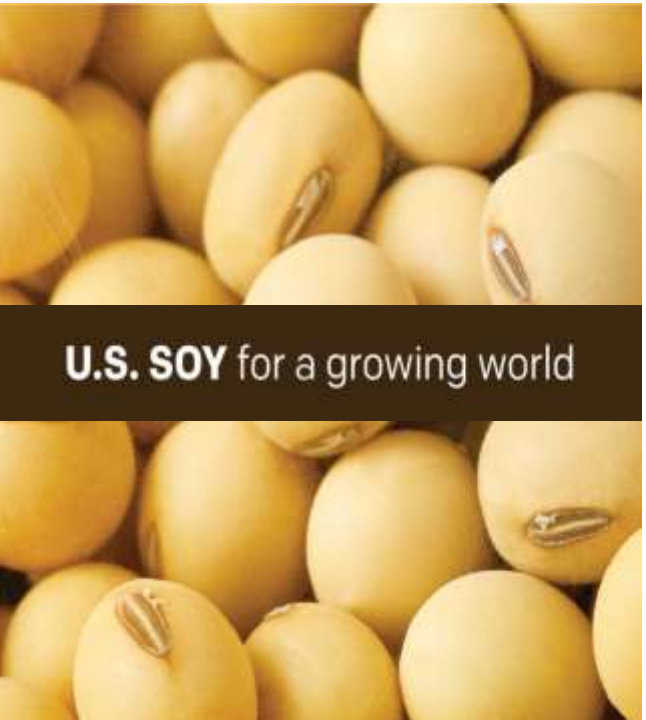
BREAST MYOPATHIES IN COMMERCIAL BROILERS



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Introduction - 1

- In past 30 years

  Live weight increased by 30.2 grams per year

  FCR decreased by 0.036% each year **(Bailey *et al., 2015)***

- In past 15 years

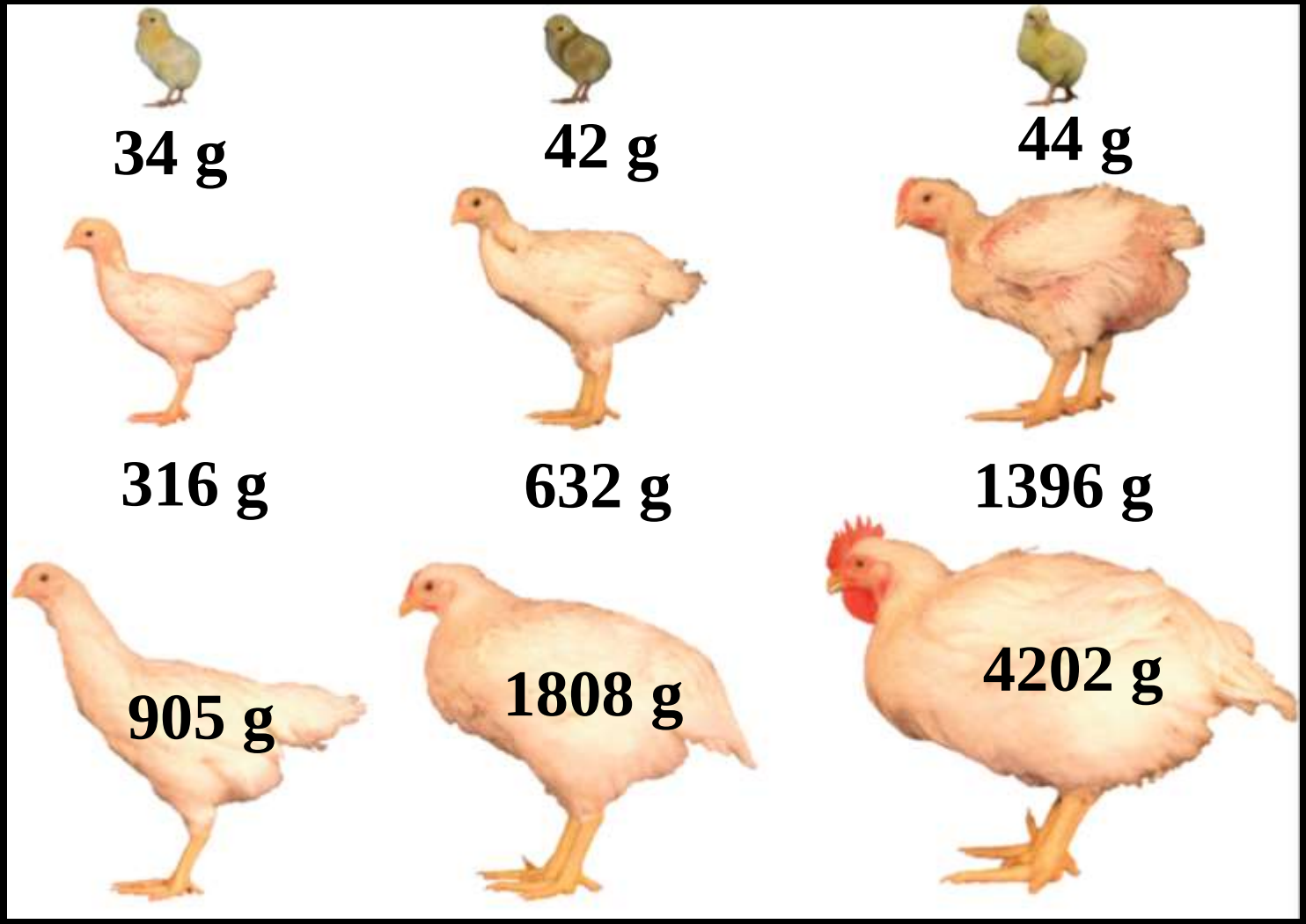
  Mortality decreased by 0.05% per year

  Carcass condemnations decreased - 1.79% to 0.24%
  (Bailey *et al*., 2015)

- 85-90% due to genetic selection; 10-15% due to nutrition
  (Sherwood, 1977: Havenstein *et al*., 1994, 2003)

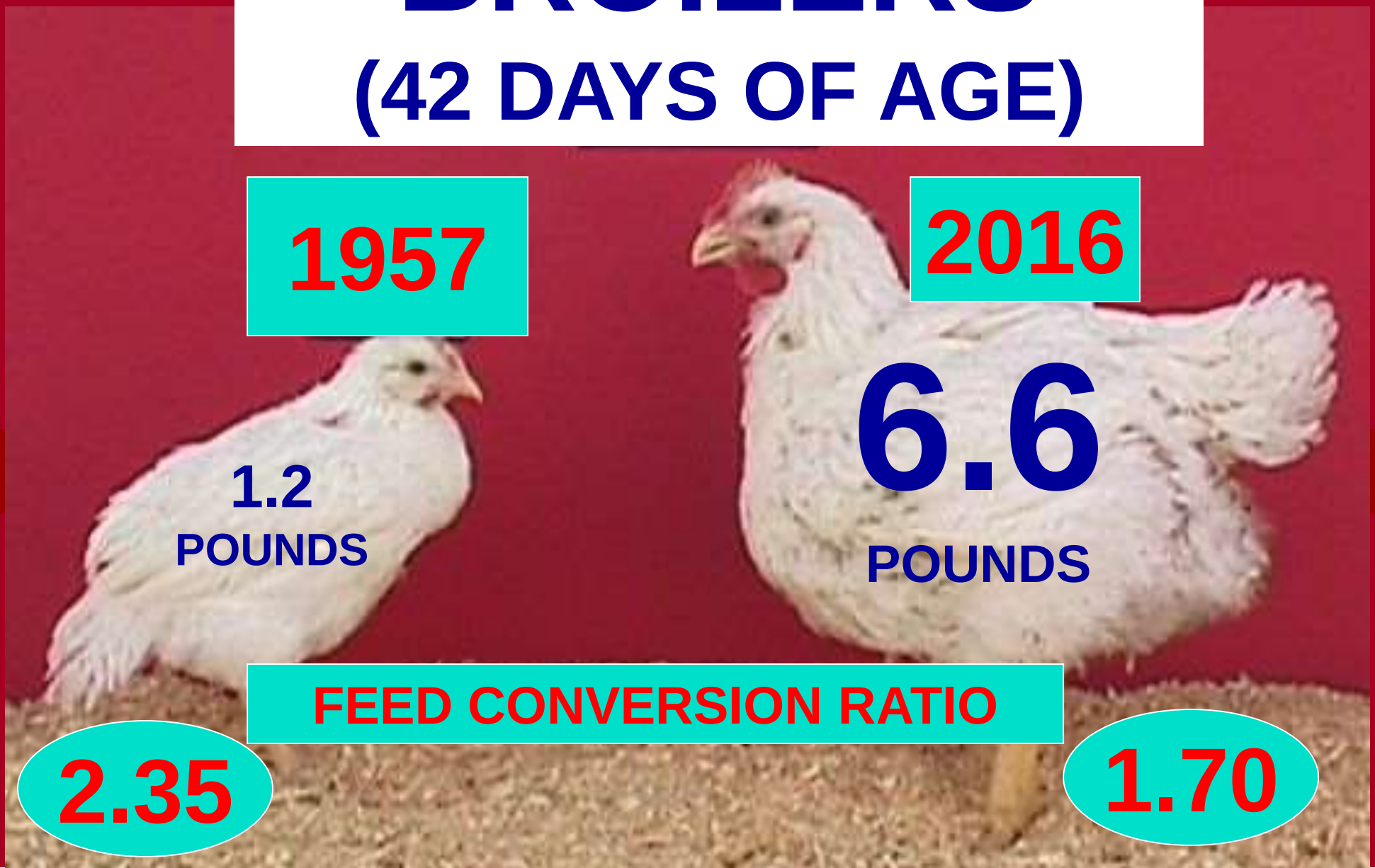
…YEAR…

AGE (DAY)	1957	1978	2005
1	34 g	42 g	44 g
28	316 g	632 g	1396 g
56	905 g	1808 g	4202 g



Source: Zuidhof *et al*. (2014) Poult. Sci.

BROILERS
(42 DAYS OF AGE)



BROILER GENETIC ADVANCEMENT

49 DAYS OF AGE

1972

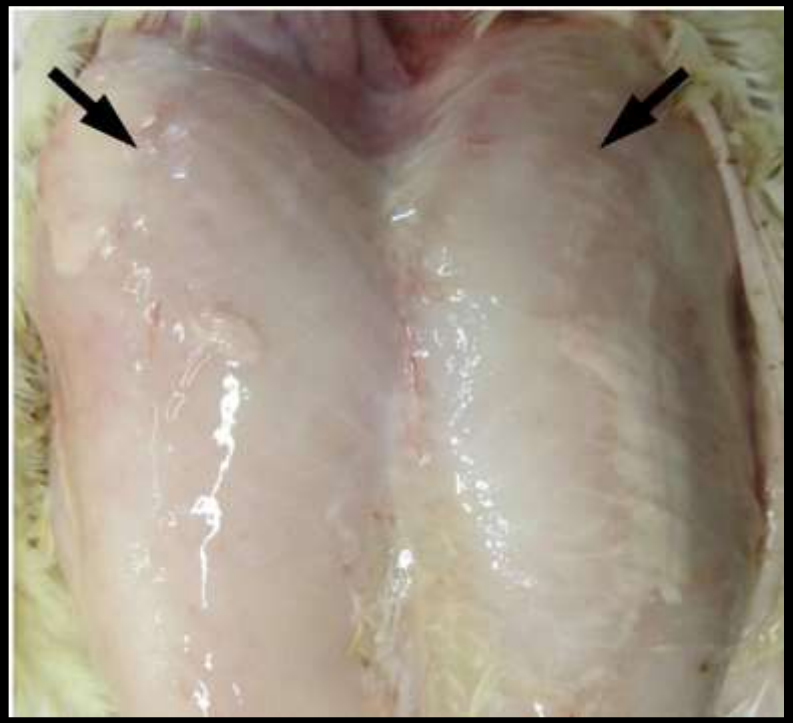
TODAY'S BROILER

- Boneless breast meat very popular
- High breast yield broilers
- Increased bird size ~ 55% > than 6 lbs
- Shorter growth period

SOURCE: WWW.AVIAGEN.COM

Breast myopathies in modern broilers (Bailey et al., 2015)

P. Major



Wooden breast

P. Minor

DPM

P. Major

White striping

DPM, ONE PENALTY FOR GENETIC SUCCESS

(Siller, 1985)

Introduction - 2

- DPM (Green Muscle Disease or Oregon disease) was first described in adult turkeys by Dickinson *et al.* (1968)

- Subsequently described in broiler breeders (Page *et al.* (1975), and broiler chicks (Richardson *et al.* 1980)

DPM in broilers

Bailey et al., 2015

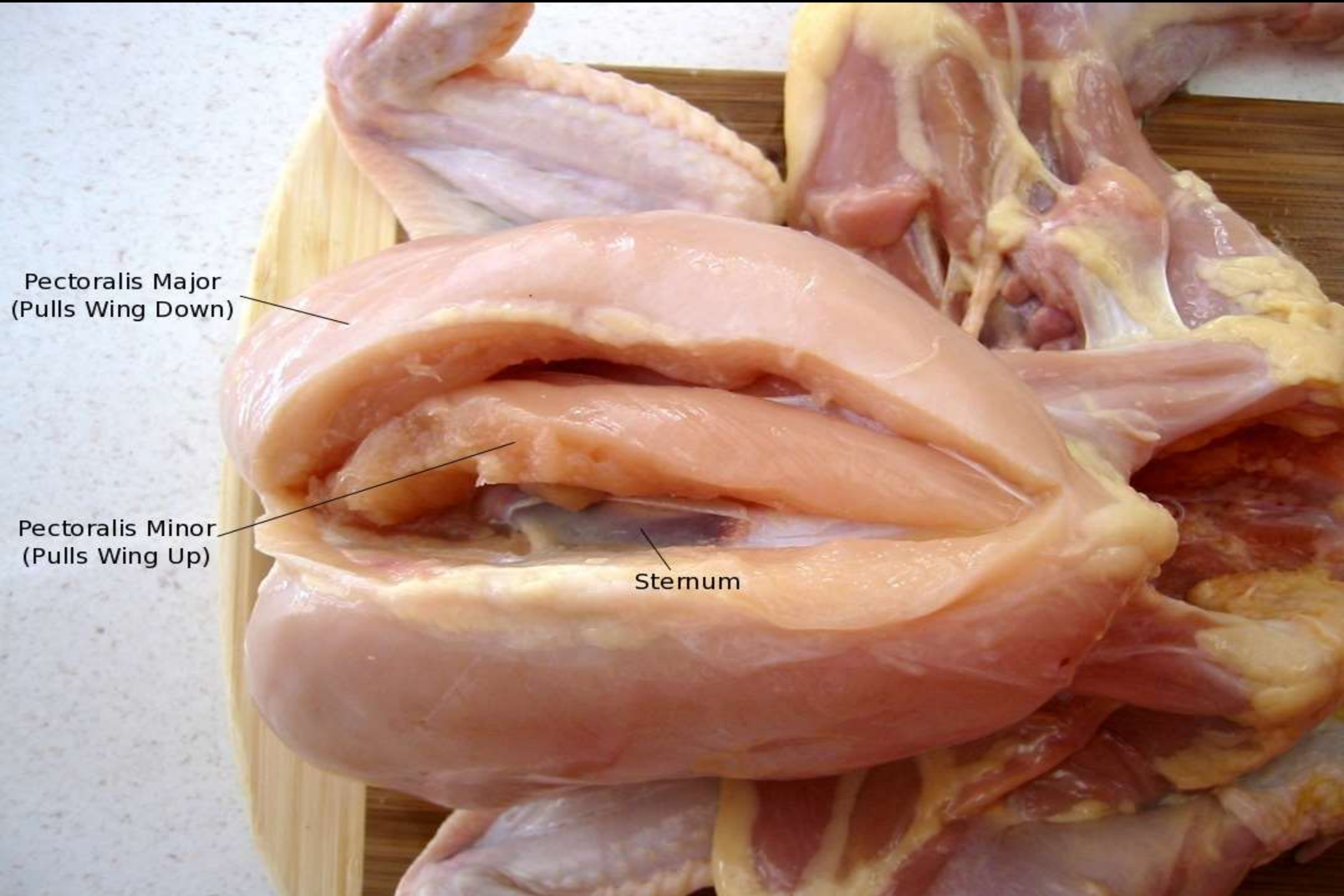
Introduction - 3

- DPM does not usually impair general health of birds. Generally, only found during cut-up and deboning and can be both unilateral or bilateral

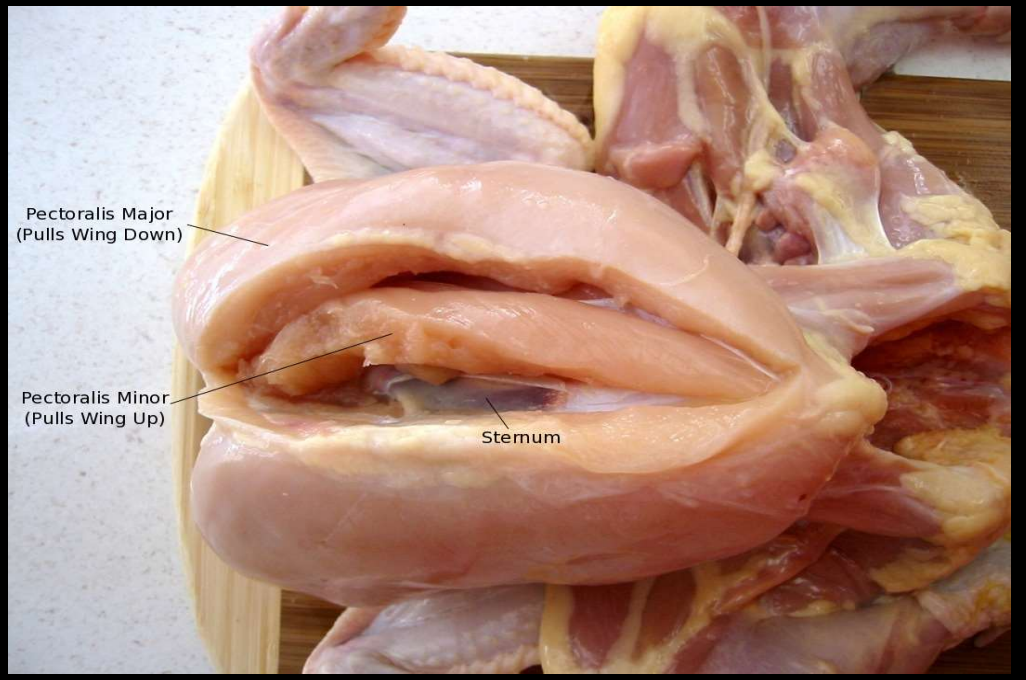
- DPM is not of public health significance but it is aesthetically undesirable and has an economic cost

DPM in broilers

Kijowski and Konstanczak, 2009


Pectoralis Major
(Pulls Wing Down)
Pectoralis Minor
(Pulls Wing Up)
Sternum

Etiology of DPM



- During exercise (wing flapping) a functioning P. minor muscle can increase in volume by 20%

- P. minor is surrounding by fibrous inelastic fascia

- P. minor sandwiched between P. major and sternum

- Pressure within the muscle increases which then impairs the blood supply resulting in a compartment syndrome and ischemia

- Following the ischemia there is rapid necrosis of the tissues and RBC in the muscle giving rise to hemorrhaging and eventually a greenish discoloration of the muscle

Early development of DPM in chickens (Kijowski and Konstanczak, 2009)

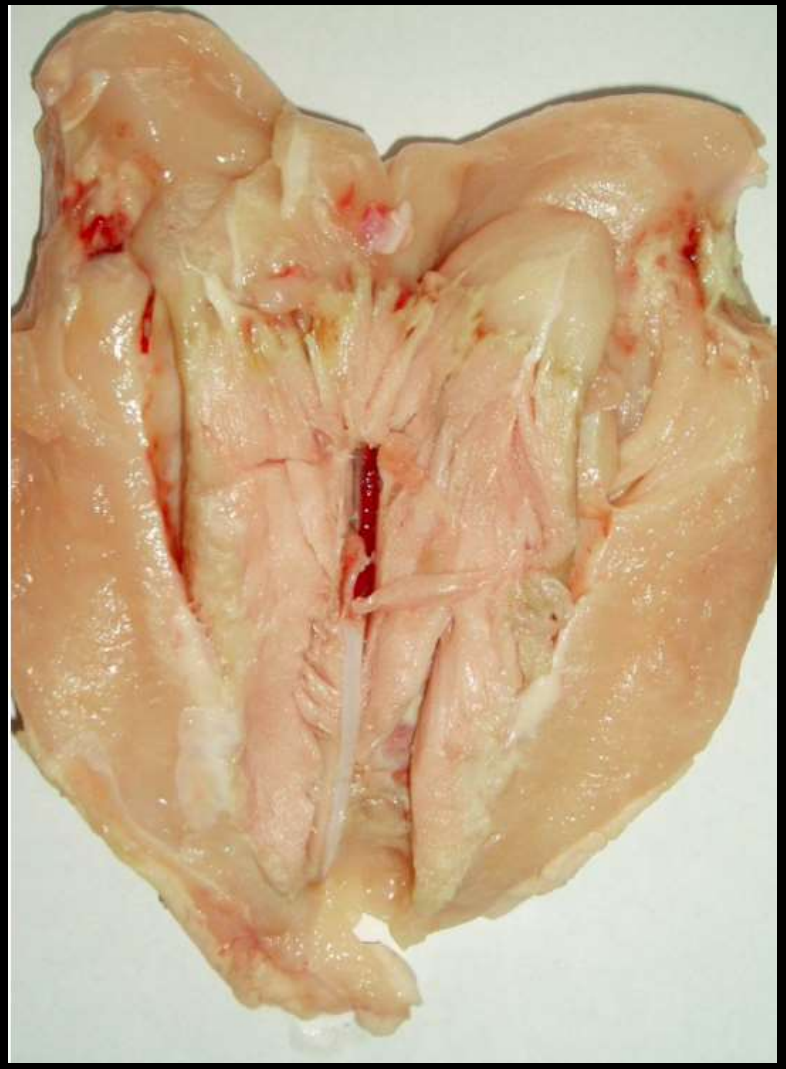
Category 1

Acute inflammatory lesion with numerous hemorrhages

Early development of DPM in chickens (Kijowski and Konstanczak, 2009)

Category 2

Muscle becomes pink and resembles “fish flesh”



Late stage of DPM in chickens
(Kijowski and Konstanczak, 2009)

Category 3

Progressive degeneration with green necrotic areas

Green color probably due to breakdown of myoglobin under anaerobic conditions

Development of model to study DPM

Procedure for exercise induction of DPM in broilers (Lien *et al.*, 2012)

- Birds raised to a height of 2 meters
- Then allowed to free fall to a height of 1 m
- Each cycle resulted in 4 to 6 wing flaps
- 20 – 25 cycles used

Effect of bouts of wing flapping on DPM in male broilers (Lien *et al.*, 2012)

# Bouts	BW, kg	DPM Lesion, %
0	3.44	0[b]
5	3.23	0[b]
10	3.29	7[b]
20	**3.29**	**33[a]**
SEM	0.075	7.1
P-value	0.2540	0.0040

Each bout = 4 - 6 wing flaps

Timeline for appearance of lesions in female broiler breeders (Wright *et al*., 1981)

- **15 minutes**

  P. minor muscles were pale, swollen and tense. Histologically, there was edema and blood vessels were congested

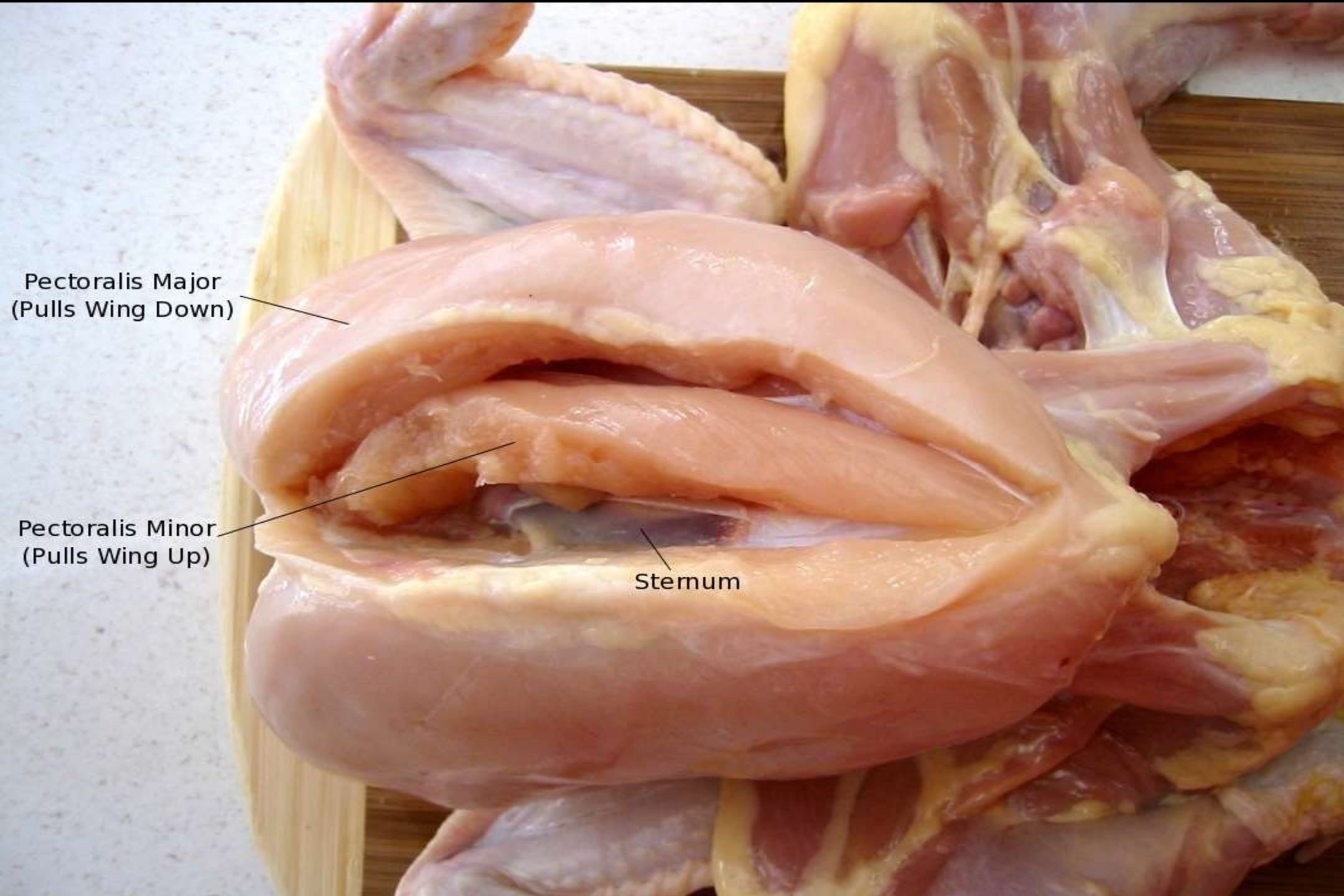
- **1 hour**

  Considerable intramuscular edema evident. Individual muscle fibers widely separated by edema, were round-edged of increased diameter, and some had increased numbers of nuclei

- **9 hours**

  Exudate observed between P. minor and P. major muscles. Other changes similar to 1 hour

Experimental evidence to support etiology

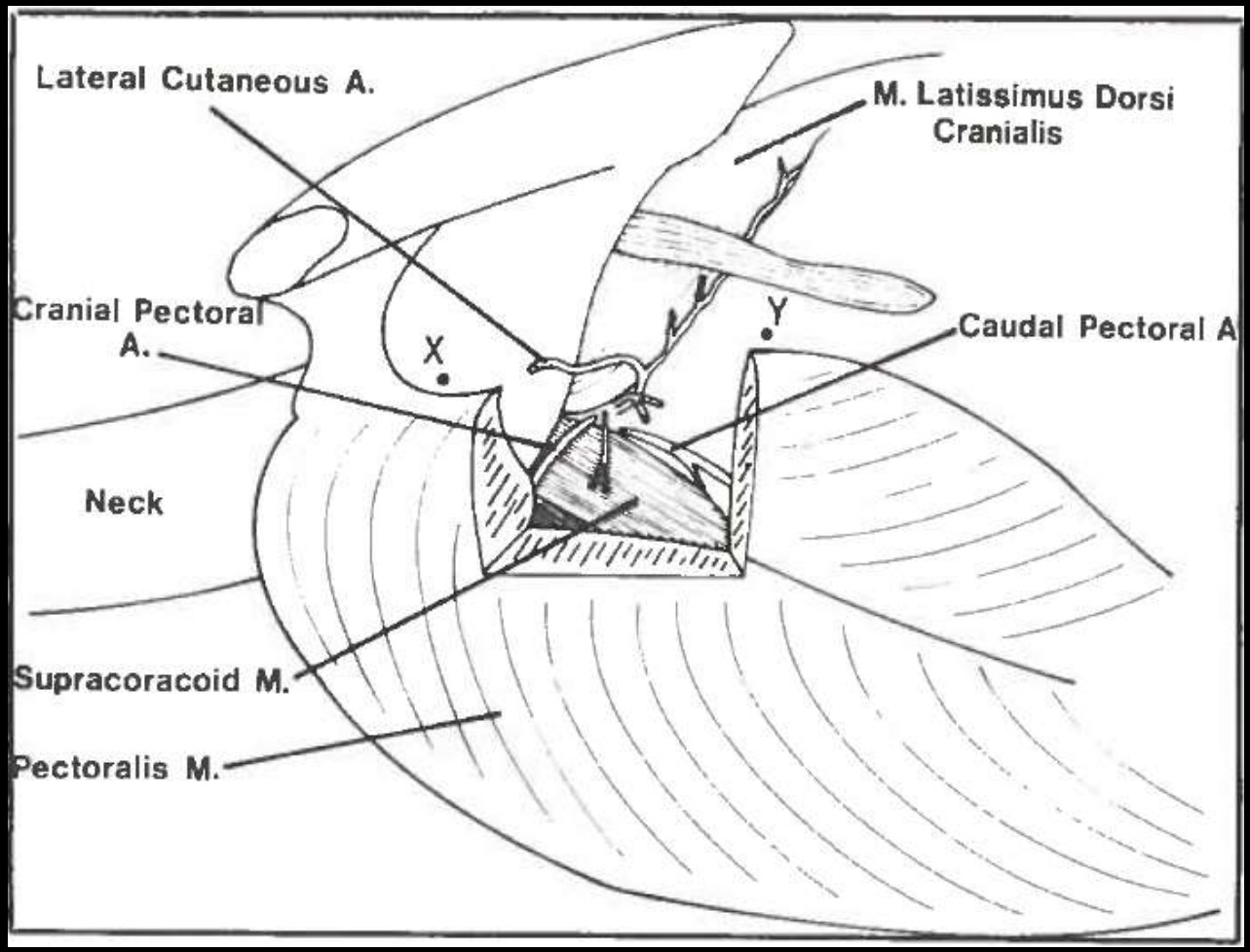

Pectoralis Major
(Pulls Wing Down)
Pectoralis Minor
(Pulls Wing Up)
Sternum

Anatomy and physiology contributing factors for the susceptibility of P. minor muscles to DPM (Kijowski *et al*. 2014)

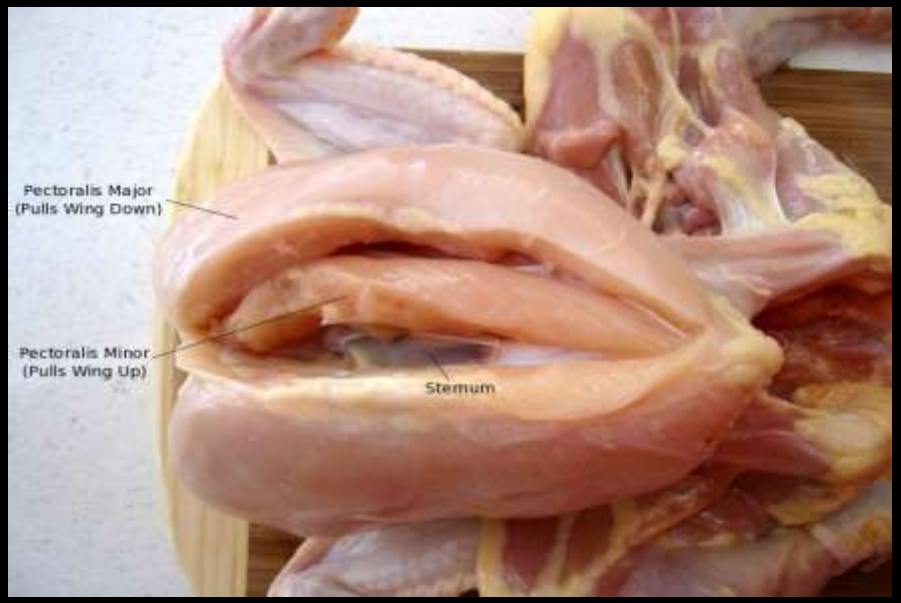
- The major and minor pectoral muscles vary in terms of red (slow-twitch) and white (fast-twitch) cells
- The P. minor is primarily composed of white muscle cells and has low tolerance to fatigue
- Blood is supplied to pectoral muscles by the subclavian vein and thoracic arteries
- Due to greater share of white muscle cells in P. minor muscle it contains lower amounts of myoglobin and has less extensive vascularization. Thus the efficiency of the circulatory system is lower in P. minor compared to P. major

Occlusion of blood vessels supplying the P. minor muscles (Orr and Riddell, 1977)

Occlusion of blood vessels by surgical obstruction caused DPM lesions in turkeys



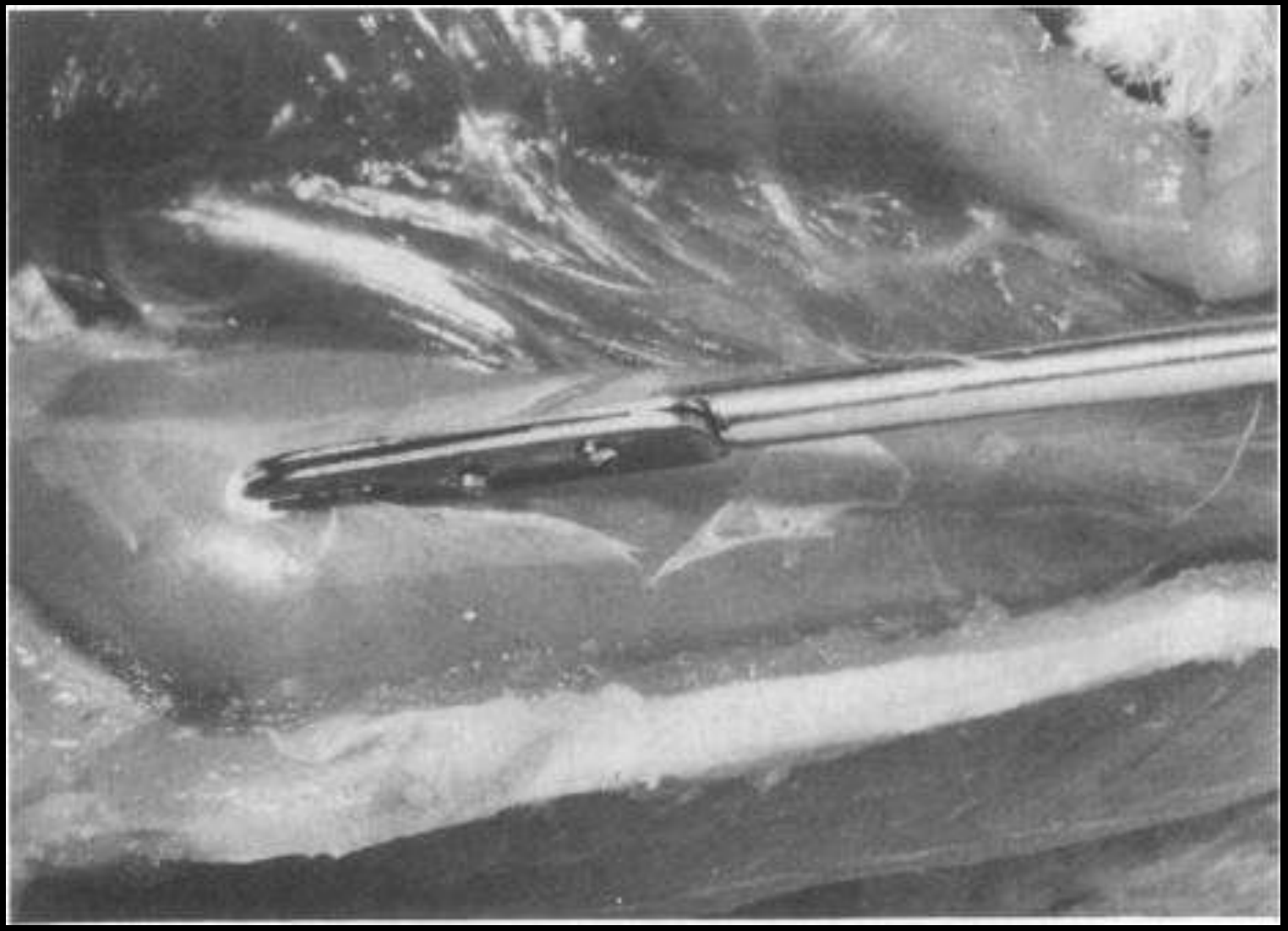
Anatomy and physiology contributing factors for the susceptibility of P. minor muscles to DPM



P. minor encased in a fibrous sheath

P. major simply surrounded by loose connective tissue that moves easily over the muscle surface as muscle profile changes

Fasciotomy of P. minor muscle (Wright *et al*., 1981)



Effect of fasciotomy on DPM induced by exercise in male broiler breeders (Siller *et al.*, 1979)

Incision	Left PM (F)	Right PM
Anterior 3/5	None	Middle 3/5
Full length	None	Posterior 4/5
Full length	None	Middle 2/3
Full length	None	Posterior 4/5
Posterior ½	Second ¼	Middle 3/5
Full length	None	Middle 3/5
Posterior ½	None	Posterior 4/5

Occurrence of DPM

- Bianchi *et al.* (2006)
  - 120,700 birds (Cobb) from 151 flocks in Italy
  - Average incidence 0.84% (range 0 to 16.7%)
  - Average weight 3.14 kg

- Kijowski and Konstanczak (2009)
  - 167,610 birds (Ross) from 47 farms in Poland
  - Average Incidence 0.06 % (range 0% to 1.88%)
  - Average weight 2.5 kg

Occurrence of DPM

- Dinev and Kanakov (2011) - Bulgaria

  2 flocks of 20,000 birds (Ross & Cobb) each

  Average incidence 0.51% (Flock A - 0.37%; Flock B – 0.64%

- In Summary, average incidence = 0.47%

- However, incidences ranged from 0 – 16.7%

- Experimental studies incidences (2.5% to 19%)

Economics of DPM

- **Poland - Kijowski *et al.* (2014)**
  - **Annual Production – 1.55 M tons (2011)**
  - **Mean frequency of DPM = 0.20%**
  - **Mean BW of chickens = 2.4 kg**
  - **Mean weight of P minor with lesions = 85 g**
  - **Value of 1 kg P. minor = $3.82**
  - **Using these numbers annual losses = $448,772**
  - **Assuming 1% DPM losses = $2,243,863**

Economics of DPM

- **USA - Lien *et al*. (2011)**

  Average Incidence 0.70%

  Annual losses = $16,000,000

  Processor slaughtering 1 M birds/wk (3.15-3.60 kg)

  Losses = $350,000

Recent study looking at the genetic basis for breast muscle myopathies (BMM) (Bailey *et al.*, 2015)

Study addressed the hypothesis that genetic selection for increased breast yield contributed to the onset of BMM

The genetic basis of pectoralis major myopathies in modern broiler chicken lines (Bailey *et al.*, 2015)

- Data used from records of breast meat production traits as part of the Aviagen breeding program

- Two purebred commercial broiler lines with differing selection history and breast meat yield were used

- Line A is a high breast meat yielding bird (29.4%) and line B is a moderate breast meat yielding bird (21.7%)

- The phenotypic data spans 6 generations, and collected over 4 years from 219 flocks

Number of records for each trait used in the analysis of the two lines (Bailey *et al.*, 2015)

Trait	Line A	Line B
Body weight	316,125	362,305
Breast yield	49,071	64,994
DPM	**49,071**	**64,994**
Wooden breast	41,702	55,797
White striping	42,578	56,837

Incidence of myopathies in two lines of broilers (Bailey *et al.*, 2015)

Trait	Line A	Line B	h^2
Body weight, kg	2.33	1.91	
Breast yield, %	29.4	21.66	
DPM, %	**6.96**	**0.41**	**0.06**
Wooden breast, %	3.19	0.16	0.09
White striping, %	49.6	14.46	0.34

For DPM, heritability was very low (h^2 = < 0.1) with 90% of variance attributed to non-genetic effects

Most important risk factors for DPM (Kupinska, 2013)

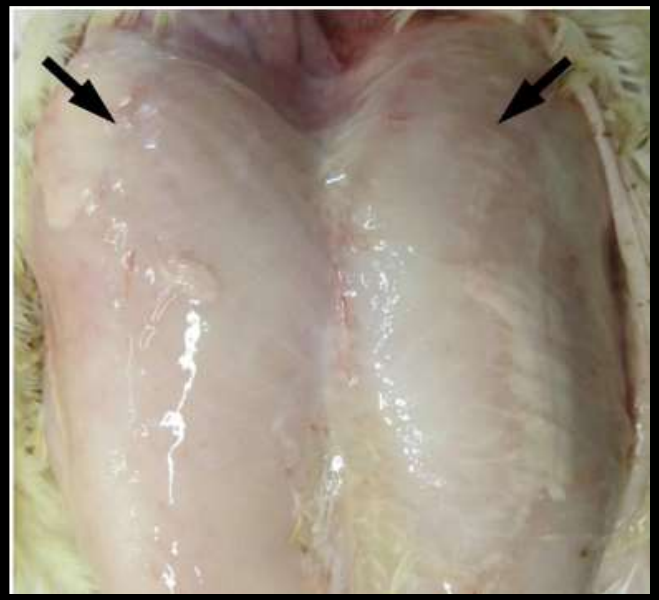
1. Disturbed flock hierarchy
2. Catching by wings
3. Inappropriate handling by staff
4. Violent actions
5. Scaring
6. Flock thinning and selection
7. Excessive amounts of light
8. Noise and novel sounds around house
9. Excessive stocking rates
10. Any activity that disturbs the birds

Flock Management Guidelines to limit DPM (Bilgili and Hess, 2008)

- Do Not Stress or Frighten Birds
- Limit Sudden and Excessive Wing Exercise
- Control Overall Flock Flightiness

WHITE STRIPING (WS) AND WOODEN BREAST (WB)

Breast myopathies associated with increased growth rate and increased breast meat yield



WB

WS

White Striping in broilers (Bailey *et al.*, 2015)

- WS characterized by occurrence of white striations on chicken fillets and thighs
- The striations run parallel to the direction of the muscle fibers
- There can be varying degrees of striations
- Because WS can easily be seen on surface of raw chicken breast fillets, condition affects the visual appearance of the breast fillets

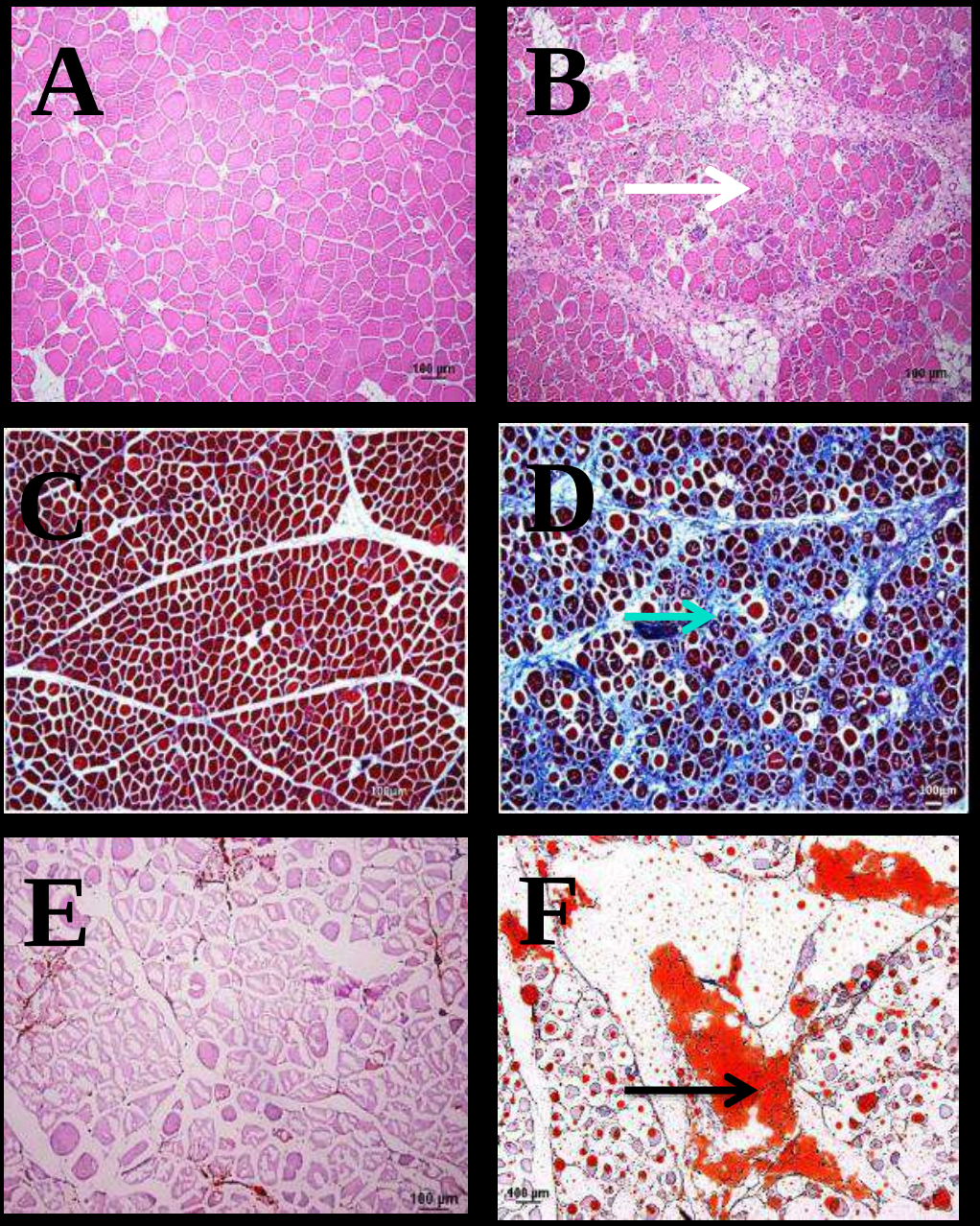
Histology of WS (N vs S: Kuttappan *et al.* (2013)

- A (H&E) Normal no WS
- B (H&E) Muscle degeneration and infiltration of inflammatory cells

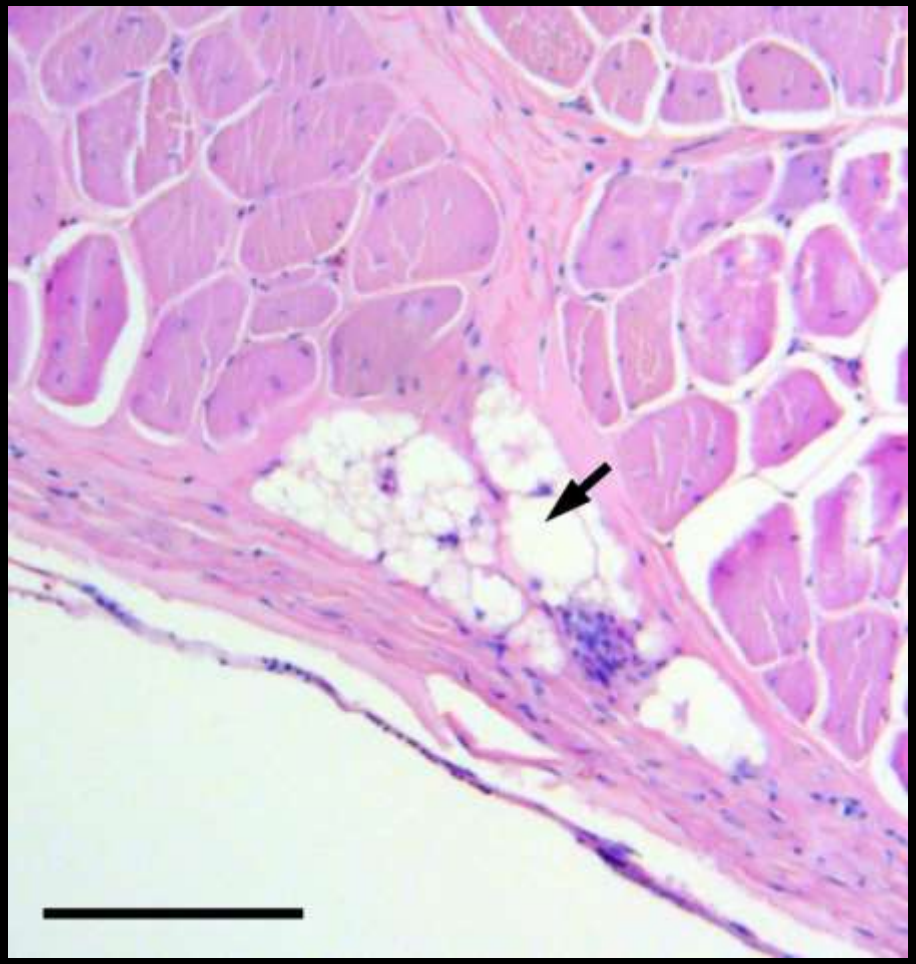
- C (MT) Normal
- D (MT) Fibrous tissue invading interstitial spaces

- E (ORO) Normal no WS
- F (ORO) Presence of fat tissue

H&E = Hematooxylin and eosin
MT = Masson's Trichrome
ORO = Oil Red O



White Striping in broilers (Bailey *et al.*, 2015)



Histomicrograph of a breast fillet affected by white striping. The white stripe is composed of adipose tissue (arrow). Black bar shows scale (100 μm).

WS - Histological characteristics (Kuttappan *et al*., 2016)

- Myodegeneration and necrosis
- Fibrosis
- Lipidosis
- Regenerative changes

Gene expression changes in WS breast muscle of broilers (Vignale *et al*., 2016; In Press)

- BM synthesis rates unchanged (WS vs N).
  BM degradation rates increased (WS vs N)

- Increased expression of **MuRF1** and **Atrogin-1**. Genes specific to muscle and are responsible for protein degradation

- Lower expression of **IGF-1** observed in WS muscles. **IGF-1** is involved in down regulation of **MuRF1** and **Atrogin-1**

Gene expression changes in WS breast muscle of broilers (Vignale *et al*., 2016; In Press)

- Significant increase in expression of lipoprotein lipase (LPL), and a decrease in expression of fatty acid synthethase (FAS) in muscle of SEV vs N muscle

- Result is higher muscle degradation that leaves space for fat deposition as well as more fat mobilization

Hematologic and serum profiles of broilers with WS (Kuttappan *et al*., 2013)

- Hematological, serum metabolite, and electrolyte profile of WS birds not different from NORM birds

- Results suggest that there are no systemic infections or inflammatory conditions

- Elevations observed in 5 of 6 serum enzymes measured (ALA, ALP, AST, CK, LDH) in WS vs NORM birds

- **Results confirm muscle damage**

Occurrence of WS

- **Petracci *et al.* (2013) - Italy**

  28,000 birds breast fillets from 56 flocks

  Processed at 45 to 54 d of age (2.75 kg)

  Incidence was 12% (8.95% moderate; 3.1% severe)

- **Ferreira *et al*. (2014) - Brazil**

  25,250 birds (Cobb) single shift at processing facility

  Processed at 42 d of age (3.2 kg)

  Incidence was 9.84% (7.38% moderate; 2.46% severe)

Occurrence of WS

- Lorenzi *et al.* (2014) - Italy

  70 flocks of medium (n= 37; 2.2-3.0 kg) and heavy (n= 33; 3.0 – 4.2 kg) birds

  500 breasts/flock sampled for a total of 35,000 breasts

  Overall incidence was 43% (36.8 % moderate; 6.2% severe)

- Russo *et al.* (2015) - Italy

  57 flocks of broilers from Northern Italy

  Medium (2.59 kg); incidence = 70.2%

  Heavy (3.64 kg); incidence = 82.51%

Incidence of WS in broilers under commercial conditions (Lorenzi *et al.*, 2014)

Item	Flocks (n)	Age (d)	LWT (kg)	GWT (g/d)	Incidence (%) Mod	Severe
Market Class						
Med-F	22	47.7	2.67	56.1	21.7	2.6
Med-M	15	48.0	2.68	56.4	31.1	2.8
L-Heavy-M	17	53.3	3.55	66.5	45.2	7.5
S-Heavy-M	16	54.4	3.95	72.6	48.8	11.5
SEM					0.02	0.01
Probability					<0.001	<0.001

Med-F &M = 2.2–3.0 kg; L-heavy-M = 3.0– 3.8 kg; S-heavy-M = 3.8-4.2 kg

Incidence of severe WS in processing plants

(Courtesy of Dr. Casey Owens, University of Arkansas

~8.5 + lbs

~7 lbs

Effect of WS on consumer acceptance of raw broiler breast meat (Kuttappan *et al.*, 2012)

Degree of WS	Individual Fillet Picture		Tray-pack picture
	Hedonic Score	White area	Purchase intent Score
NORM	6.9[a]	8.42[c]	3.6[a]
MOD	6.1[b]	28.55[b]	2.4[b]
SEV	4.5[c]	54.80[a]	2.5[b]
Pooled SEM	0.1	3.77	0.1

[abc]Means within a row with different superscripts are different $P < 0.05$

Hedonic Score: 1 = dislike extremely; 9 = like extremely

Purchase-intent score: 1 = definitely would not buy; 5 = definitely would buy

Effect of WS on marinade uptake and marinade quality traits (Petracci *et al.*, 2013)

Item	Degree of WS		
	Normal	Moderate	Severe
N	51	51	51
Marinade uptake (%)	12.67^{a}	10.97^{b}	7.92^{c}
Purge loss (%)	1.82^{b}	1.97^{ab}	2.11^{a}
Cook loss (%)	14.59^{b}	14.84^{b}	15.93^{a}
Total Yield (%)	83.86^{a}	83.47^{a}	82.23^{b}
Shear force (kg/g)	1.83^{b}	1.89^{b}	2.09^{a}

^{abc}Means within a row with different superscripts are different $P < 0.05$

Effect of WS and WB on marinade uptake and cooked meat quality traits (Mudalal *et al.*, 2014)

Item	Normal	WS	WB
Raw Meat			
Marinade uptake (%)	13.15^{a}	9.33^{b}	6.94^{c}
Purge loss (%)	1.30^{a}	1.20^{ab}	1.30^{a}
Cooked Meat			
Cook loss (%)	15.30^{b}	15.00^{b}	17.40^{a}
Total Yield (%)	94.50^{a}	92.00^{b}	87.30^{c}
Shear force (kg/g)	1.25^{b}	1.38^{b}	1.45^{ab}

^{abc}Means within a row with different superscripts are different $P < 0.05$

Intensity scores (0 – 15) of sensory analyses of texture attributes of cooked breast fillets (Brambila *et al.*, 2016)

Attributes	NORM	MOD	SEV	SEM	P-value
Cohesiveness	6.3^{ab}	5.8^{b}	6.8^{a}	0.6	0.005
Hardness	6.1^{b}	6.0^{b}	6.6^{a}	0.4	0.003
Juiciness	3.5	4.0	3.9	0.5	0.163
Break down rate	8.7	8.5	9.0	0.5	0.094
Chewiness	4.9^{ab}	4.6^{b}	5.4^{a}	0.5	0.014

WS affects sensory texture characteristics of cooked broiler BM

Economics of WS

- Incidence much higher than DPM (Avg 43% vs 0.47%)
- WS affects both appearance and sensory quality of breast fillets
- Economic cost of WS may be much higher that of DPM

Approaches to combat WS

- Kuttappan *et al*. (2012) - Increase in WS in birds fed high energy diet to achieve higher body weights and breast yield
- Reduce energy content of diets
- Raise birds to lighter weights
- Identify markers for WS in live birds
- Genetic selection (h^2 = 0.34, 0.65)

Incidence of myopathies in two lines of broilers (Bailey *et al.*, 2015)

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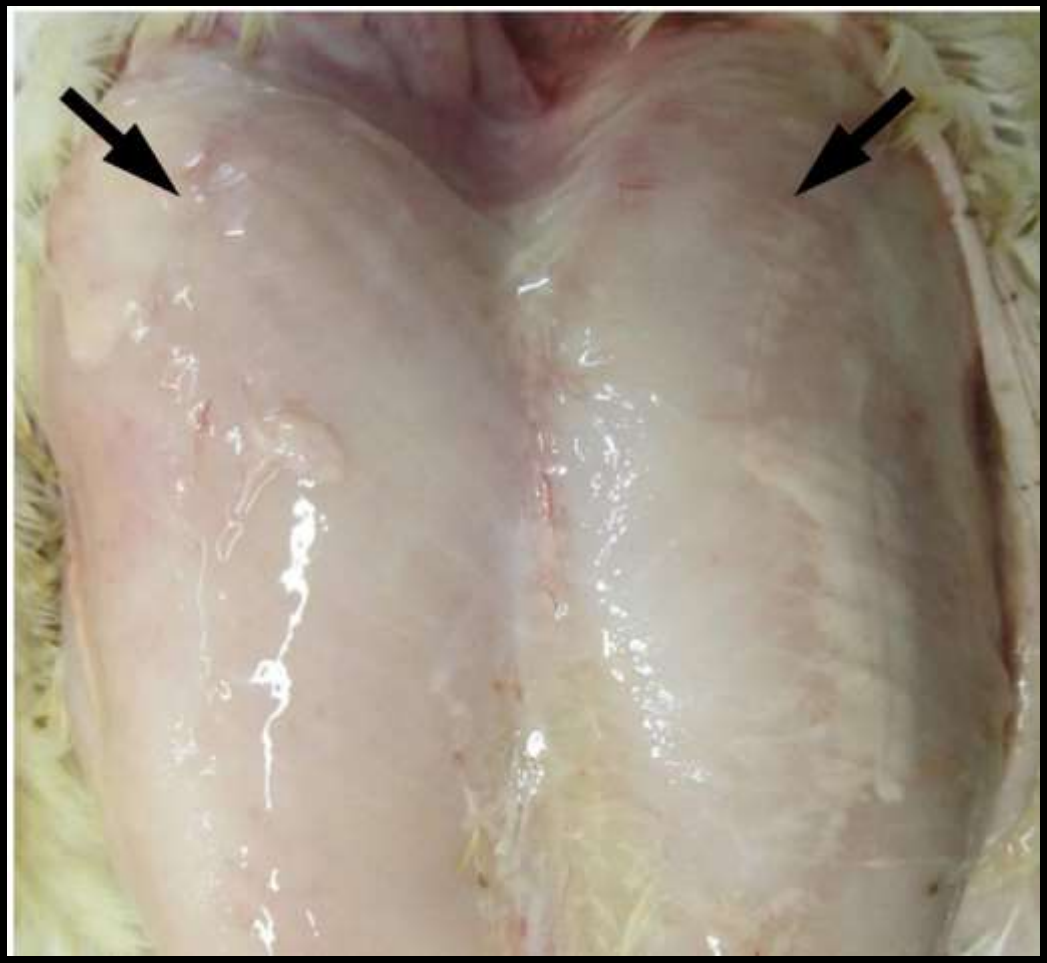
White striping, %	49.6	14.46	0.34
(WS) Alnahhas *et al., 2016*			0.65

For WS, heritability was ($h^2 = 0.5$) with 50% of variance attributed to non-genetic effects

WOODEN BREAST MYOPATHY

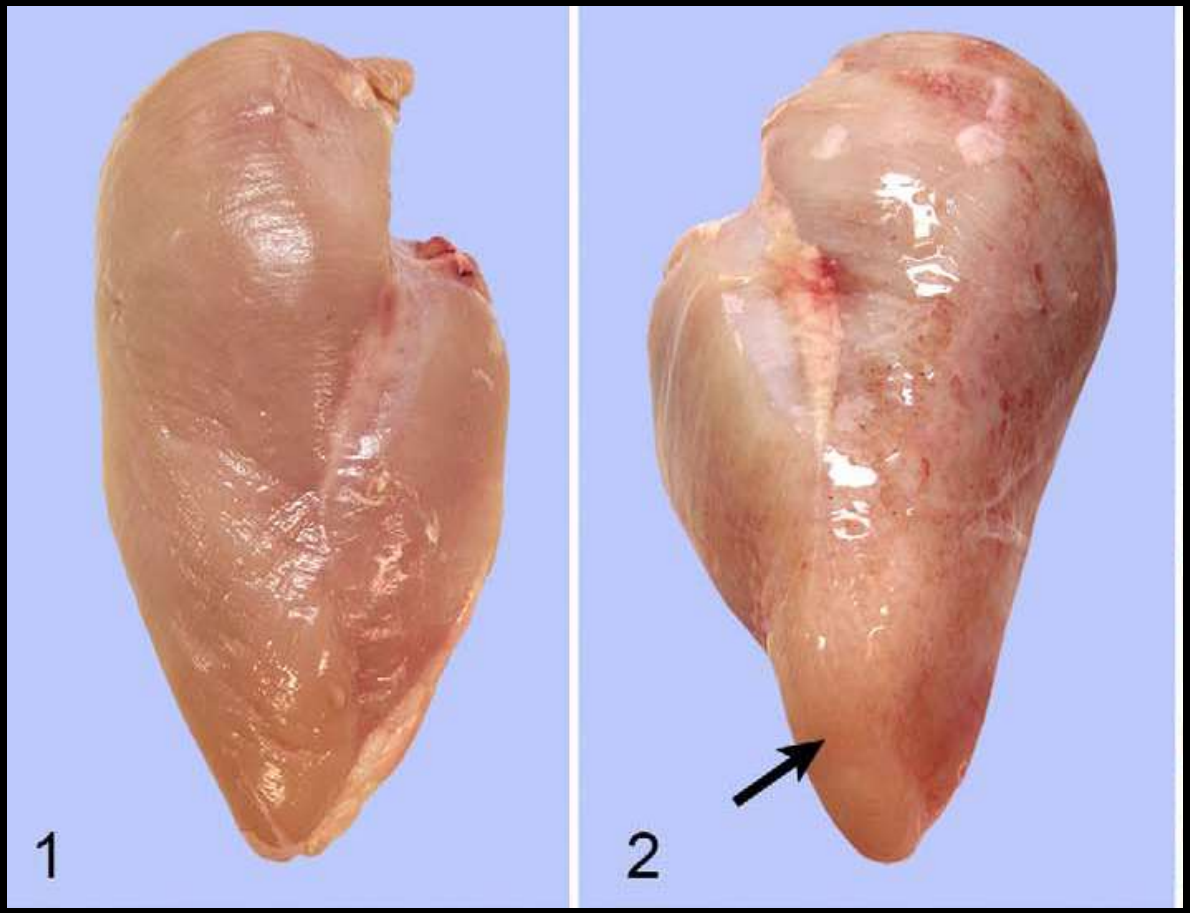
Wooden Breast in broilers (Bailey *et al.*, 2015)



Breast muscle from 42-day-old broiler. Muscle is pale with an exudate over the surface. Arrows indicate where muscle is typically firm to the touch.

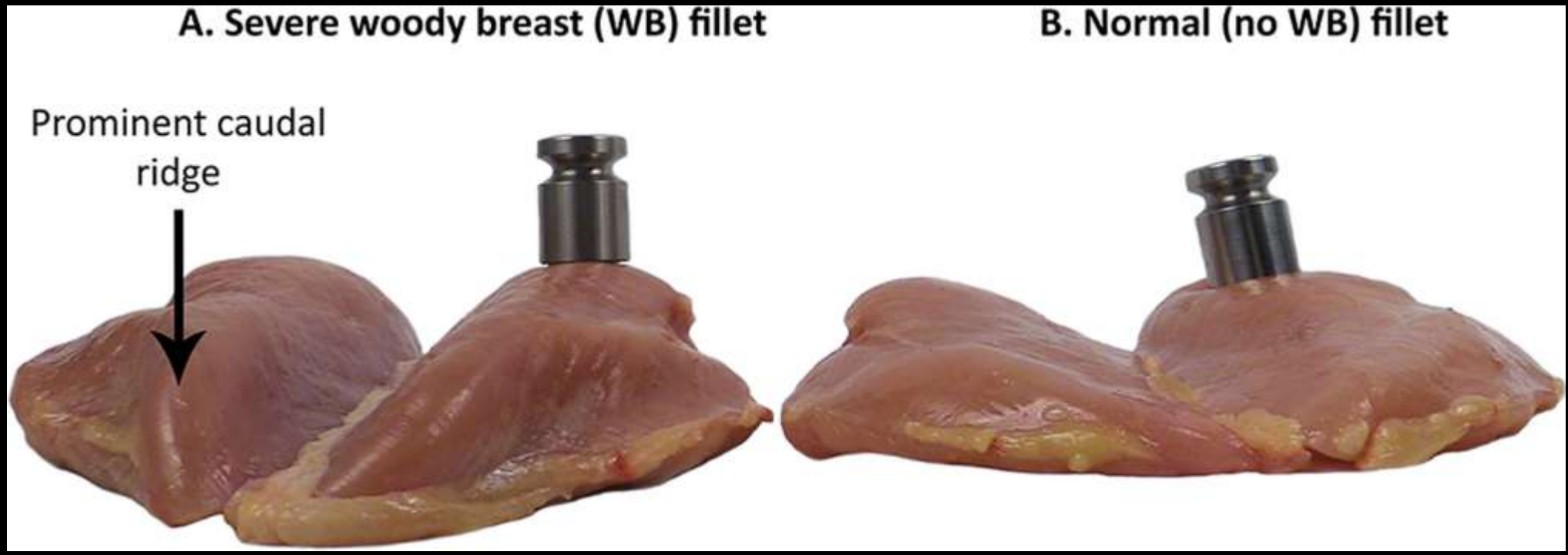
Characteristics of Wooden Breast

- Hard P. Major muscle
- The muscle is bulging, pale, and covered with clear viscous fluid
- A ridge-like bulge can be seen at the caudal end of the muscle
- Surface covered with scattered petechiae or small hemorrhages



Sihvo *et al.* (2013)

Normal and Wooden breast fillets (Kuttappan *et al*. 2016)



Petechial hemorrhaging in WB

Courtesy of Dr. Casey Owens, Univ. of Arkansas

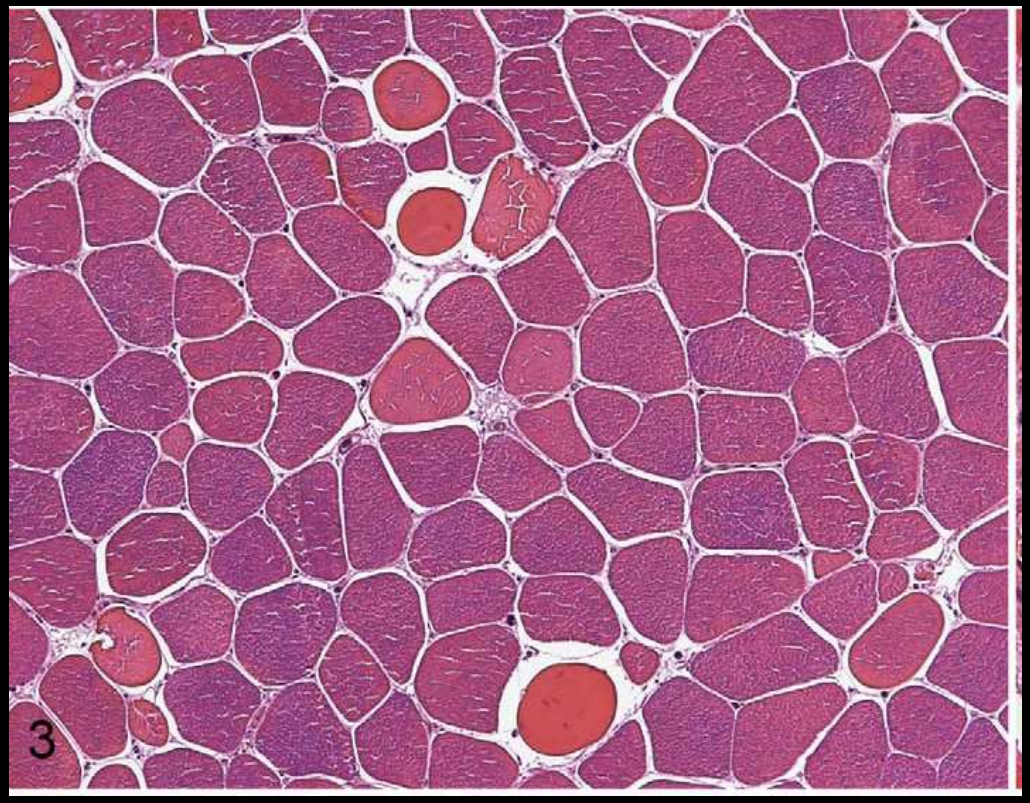
Muscle Separation in Raw Fillet "Spaghetti" meat or Frayed meat in WB

Courtesy of Dr. Casey Owens, Univ. of Arkansas

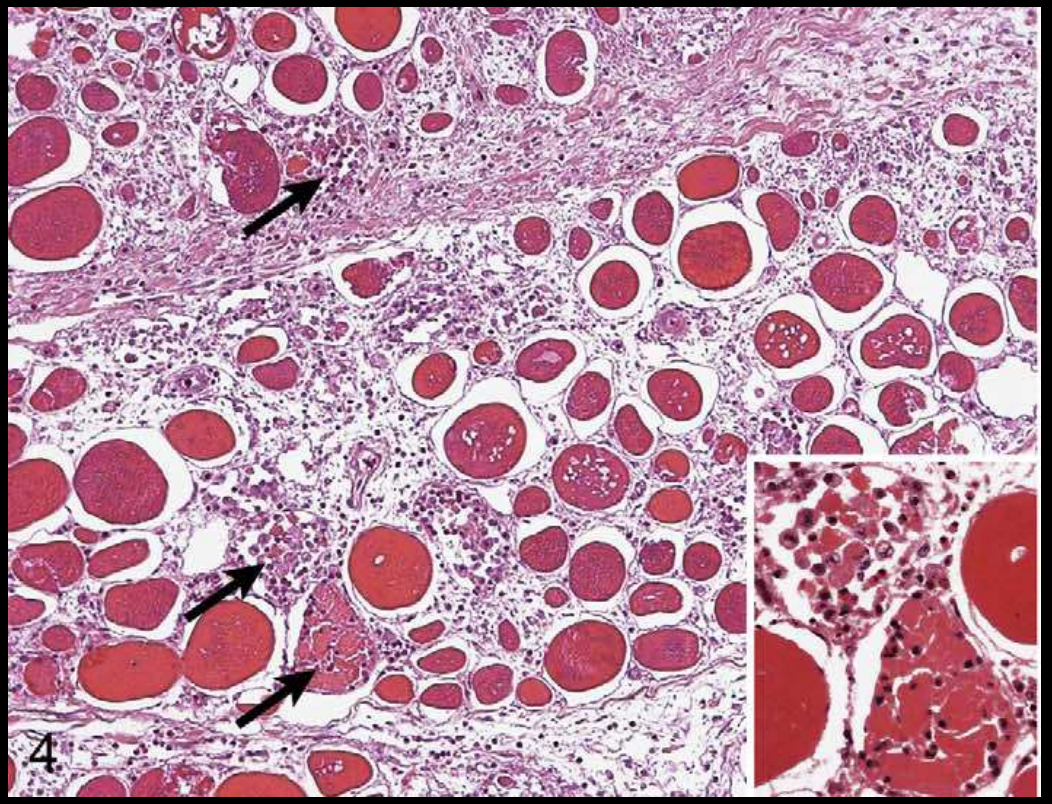
WB - Histological characteristics (Kuttappan *et al.*, 2016)

- Myodegeneration and necrosis
- Fibrosis
- Lipidosis
- Regenerative changes

Wooden Breast (Sihvo *et al.*, 2013)

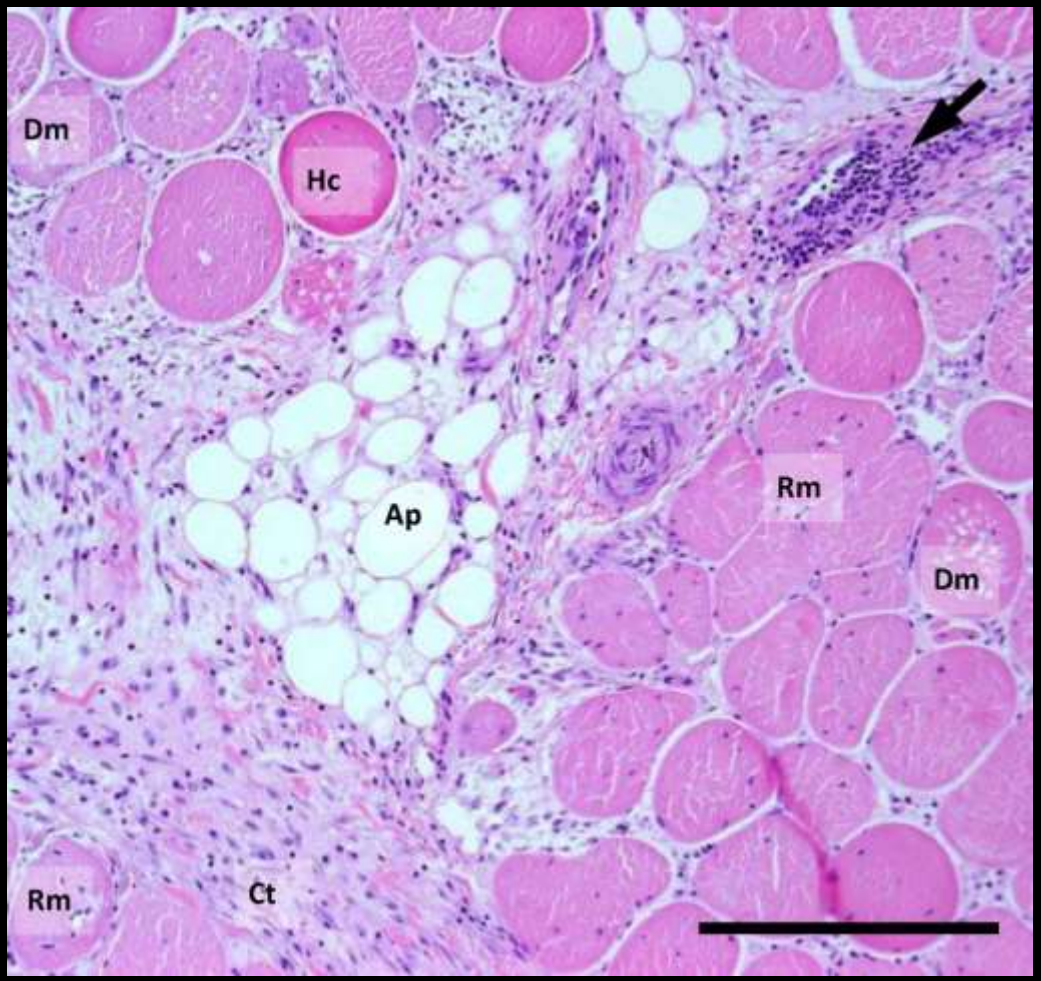


Normal muscle



Reduced number of muscle fibers
Variable sized muscle fibers
Degenerated muscle fibers - Arrows

Breast muscle affected by “Wooden Breast” (Bailey *et al*., 2015)



Breast muscle affected by WB. Degenerating muscle fibers (Dm), regenerating fibers (Rm), adipose tissue (Ap), hypercontracted fibers (Hc), increased connective tissue (Ct) and cellular infiltration (arrow).

Occurrence of WB

- WB can affect 10% of a flock but in some cases can reach 50% of flock (Owens, 2014)

- Kindlein *et al.* (2015) - Brazil

  Commercial processing plant

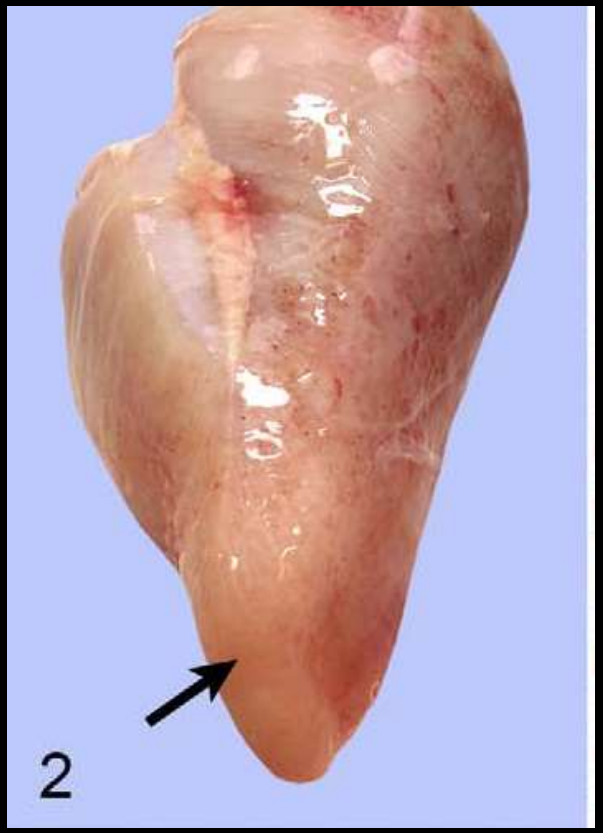
  504 fillets at each time period

  35 days – ABW (2.62 kg) - 32.1%

  42 days – ABW (3.37 kg) - 89.5%

Occurrence of WB

- Trocino *et al.* (2015) - Italy
  University Study
  256 carcasses studied
  46 days – ABW (3.2 kg)
  Females – 8.0%
  Males – 16.3%



Incidence of moderate and severe WB in processing plants

(Courtesy of Dr. Casey Owens, University of Arkansas

~8.5 + lbs

~7 lbs

Effect of WS and WB on marinade uptake and cooked meat quality traits (Mudalal *et al.*, 2014)

Item	Normal	WS	WB
Raw Meat			
Marinade uptake (%)	13.15^{a}	9.33^{b}	6.94^{c}
Purge loss (%)	1.30^{a}	1.20^{ab}	1.30^{a}
Cooked Meat			
Cook loss (%)	15.30^{b}	15.00^{b}	17.40^{a}
Total Yield (%)	94.50^{a}	92.00^{b}	87.30^{c}
Shear force (kg/g)	1.25^{b}	1.38^{b}	1.45^{ab}

^{abc}Means within a row with different superscripts are different $P < 0.05$

Changes in breast muscle due to selection for improved growth and breast muscle yield (Velleman and Clark 2015)

- Increase in larger diameter muscle fibers
- Decreased capillary blood supply to the muscle
- Reduced connective tissue spacing between muscle fiber bundles and muscle fibers
- Increased myofiber degeneration

Gene expression analysis of 3 genetic lines of broilers (Velleman and Clark, 2015)

Gene	Line A (WB)	Line A (N)	Line B (WB)	Line B (N)	Line C (N)
MYODI	16.3^{a}	7.3^{bc}	12.1^{ab}	10.9^{abc}	6.0^{c}
Myogenin	19.4^{a}	2.7^{b}	19.7^{a}	3.6^{b}	1.4^{b}
Decorin	43.1^{a}	6.6^{c}	25.8^{b}	3.9^{c}	1.6^{c}
Myostatin	22.7^{a}	12.0^{b}	16.2^{ab}	16.1^{ab}	7.3^{b}
TGF-β	5.4^{a}	2.3^{bc}	4.2^{ab}	1.6^{bc}	1.2^{c}

$^{abc}P < 0.05$)

A & B fast growing lines, C slower growing line

Gene expression changes in WB breast muscle of broilers (Velleman and Clark 2015)

- Expression of **Myogenin** (myogenic transcriptional factor responsible for repair of damaged muscles) higher in WB
- Expression of **MYODI** (transcriptional regulatory factor involved in muscle regeneration) higher in WB
- Expression of **Decorin** (regulates cell growth and collagen crosslinking) higher in WB
- Gene expression analyses suggest WB can result in excessive collagen crosslinking from very high levels of **Decorin**

Gene expression (RNA sequencing)changes in birds with WB (Mutryn *et al*., 2015)

- Intracellular build up of Ca due to loss of Ca homeostasis

  - Impact on membrane integrity

- Hypoxia

  - Loss of oxygen homeostasis in cells

- Oxidative stress

- Increase production of ROS

- Fiber-type switching

  - Fast twitch to slow twitch fibers in response to muscle damage

- Cellular repair

- Compensate for muscle damage

Approaches to combat WB

- Nutrition & management
- Reduce energy content of diets
- Raise birds to lighter weights
- Genetic selection ($h^2 = 0.097$)

Incidence of myopathies in two lines of broilers (Bailey *et al.*, 2015)

Trait	Line A	Line B	h^2
Body weight, kg	2.33	1.91	
Breast yield, %	29.4	21.66	
DPM, %	6.96	0.41	0.06
Wooden breast, %	3.19	0.16	0.09
White striping, %	49.6	14.46	0.34

For WB, heritability was (h^2 = < 0.1) with 90% of variance attributed to non-genetic effects

Characteristics of other myopathies (Kuttappan *et al.* 2016)

- **Hereditary muscular dystrophy**
  - **Condition caused by homozygous recessive gene**
  - **Condition not reported in modern strains**
  - **Report indicates a strong non genetic component**
- **Nutritional myopathy (NM)**
  - **White striations on breast and leg muscles**
  - **Adequate levels of Vitamin E, cystine, methionine and Se effective in preventing NM but not WB & WS**

Characteristics of other myopathies (Kuttappan *et al.* 2016)

- **Deep pectoral myopathy**
  - **Characteristics different**
- **Toxic myopathy (ionophores)**
  - **Gross and histological lesions similar**
  - **Myopathies occurs within therapeutic dose**
- **Pale Soft and Exudative (PSE) Meat**
  - **Due to rapid drop in pH in post mortem period**
  - **No difference between PSE and N with respect to tenderness and flavor**

Economic Costs to USA Poultry Industry (Kuttappan *et al*., 2016)

- US Industry produces 53 billion pounds live weight annually
- Equates to 12 billion pounds of breast meat (23% breast yield)
- Incidence can result in $200 million loss per year
- Due to decreased yield (e.g. trimming, drip loss etc.) and/or lost value due to downgrading or discarded product

Summary and Conclusions -1

- DPM one of 3 BMM in modern broilers
- Etiology of DPM has been fully described and confirmed experimentally
- Incidence of DPM relatively low but can be high on individual farms, and is costly to poultry industry
- Improvement by genetic selection?? (h^2 = < 0.1)
- Flock management best approach to decrease DPM

Summary and Conclusions - 2

- WS one of 3 BMM in modern broilers
- Characteristics of WS has been described but the underlying cause of WS still to be determined
- Incidence of WS higher than DPM and negatively affects both consumer acceptance and sensory traits making it costly to poultry industry
- Improvement by genetic selection ? (h^2 = 0.34-0.65)
- Nutritional and management approaches

Summary and Conclusions - 3

- WB one of 3 BMM in modern broilers
- Characteristics of WB have been described but underlying cause of WB still to be determined
- Incidence of WB higher than DPM and negatively affects both consumer acceptance and sensory traits making it costly to poultry industry
- Improvement by genetic selection ?? (h^2 = < 0.1)
- Nutrition and management

Thank You ?????

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