Research Institute for
Farm Animal Biology

Early-Life Feeding and Calf Resilience

Linking Nutrition, Behavior & Predictive Data

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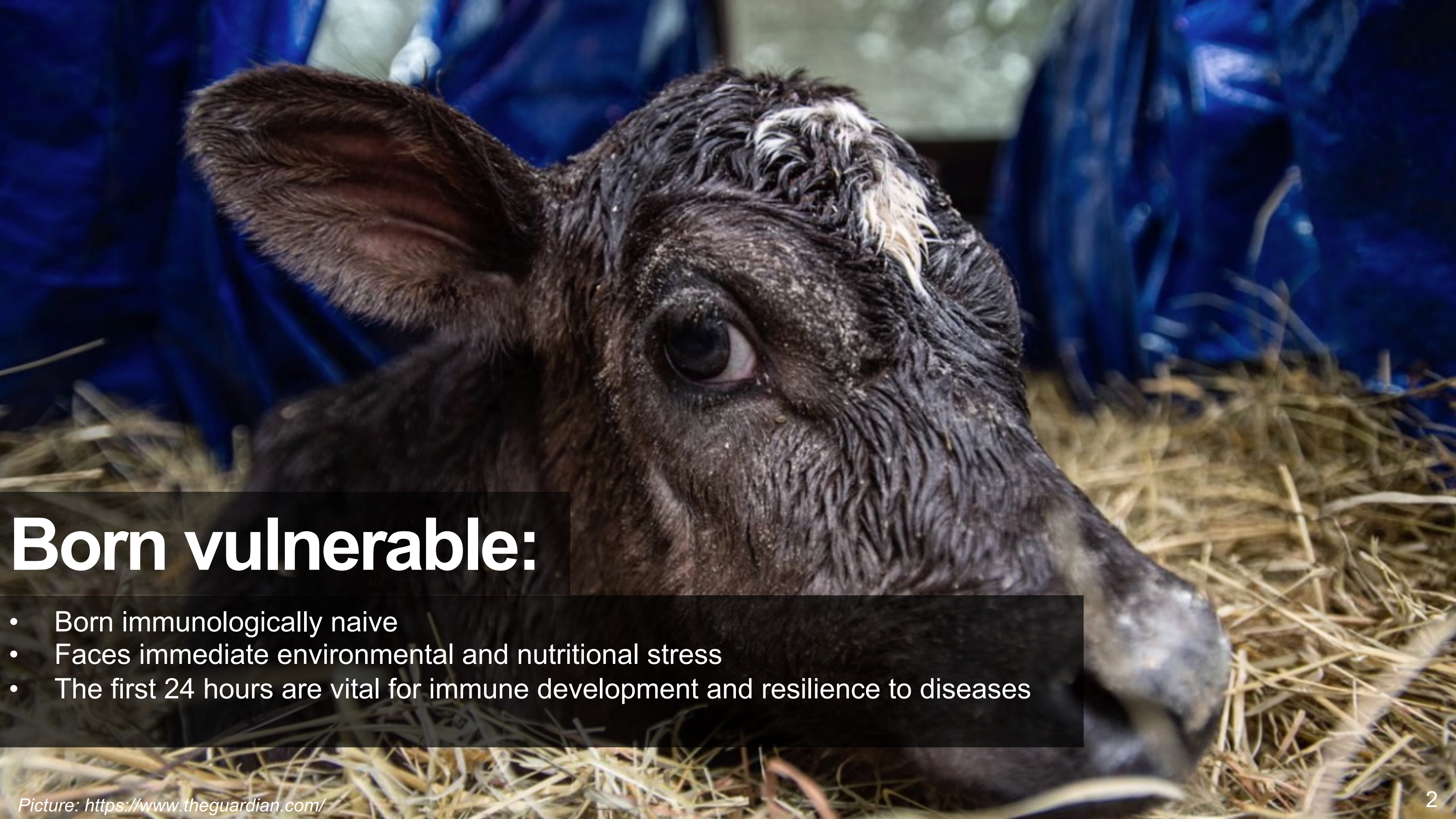
Hannah Dairy Research Foundation



Born vulnerable:

- Born immunologically naive
- Faces immediate environmental and nutritional stress
- The first 24 hours are vital for immune development and resilience to diseases

Picture: https://www.theguardian.com/

Picture: https://www.theguardian.com/

The challenge

- Calf morbidity and mortality → major sources of economic loss
- Early-life disease → reduced growth, poor welfare, lower productivity

Buczinski et al., 2021

Picture: https://www.theguardian.com/

We need to shift our perspective away from simply **treating disease**

toward actively **building resilience**

Concepts and Definitions

- **Resilience:** a multidimensional and context-dependent concept

  originates from diverse disciplines: **ecology, engineering, psychology, and social sciences**

  Rydzak, et al. 2006

- **Resilience:** capacity to tolerate, absorb, cope with, and adjust to changing environmental conditions while retaining key elements of structure and function

  Cinner and Barnes, 2019

Concepts and Definitions

Disease resilience in livestock

- Disease **resilience**: Capacity to maintain/restore homeostasis and function after disturbance (integrates resistance + tolerance).

Resistance (to disease):

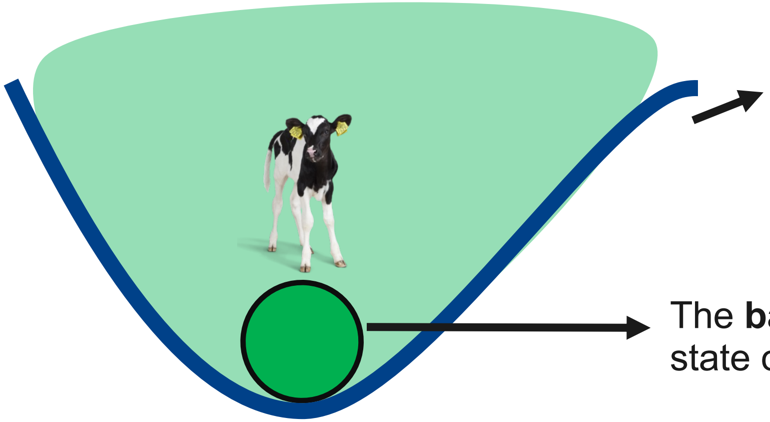
- The ability of animal to reduce the pathogen burden of an infectious agent.

Tolerance (to disease):

- The ability of animal to limit the damage caused by a given pathogen burden.

Nakov et al., 2019

Conceptualize resilience
using the ball-and-cup heuristic model



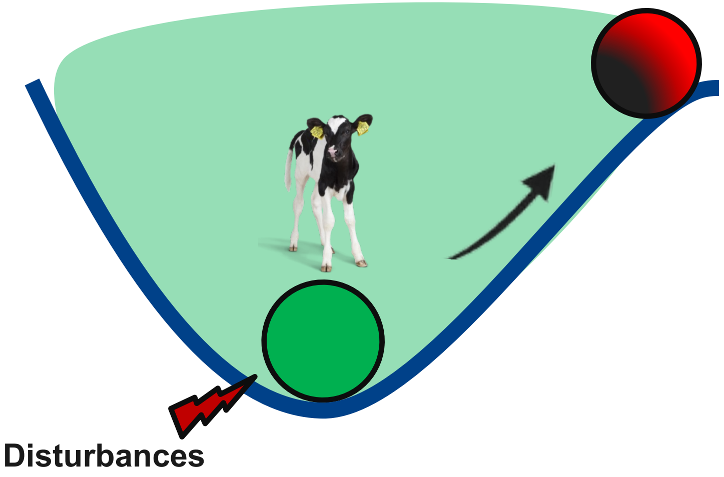
The **cup** represents the stability domain

the set of physiological systems that maintain equilibrium

The **ball** represents the animal’s current state of health and performance

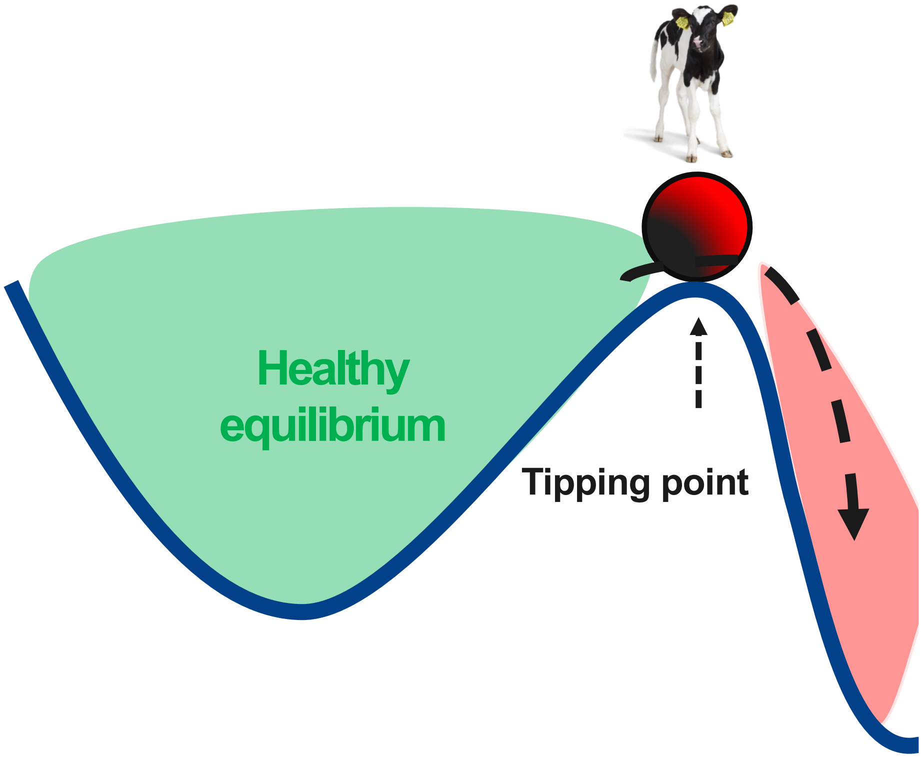
Conceptual Overview: Response to Disturbance

push the physiological state up toward **instability**



Calves are exposed to disturbances
(pathogen exposure or environmental stress)

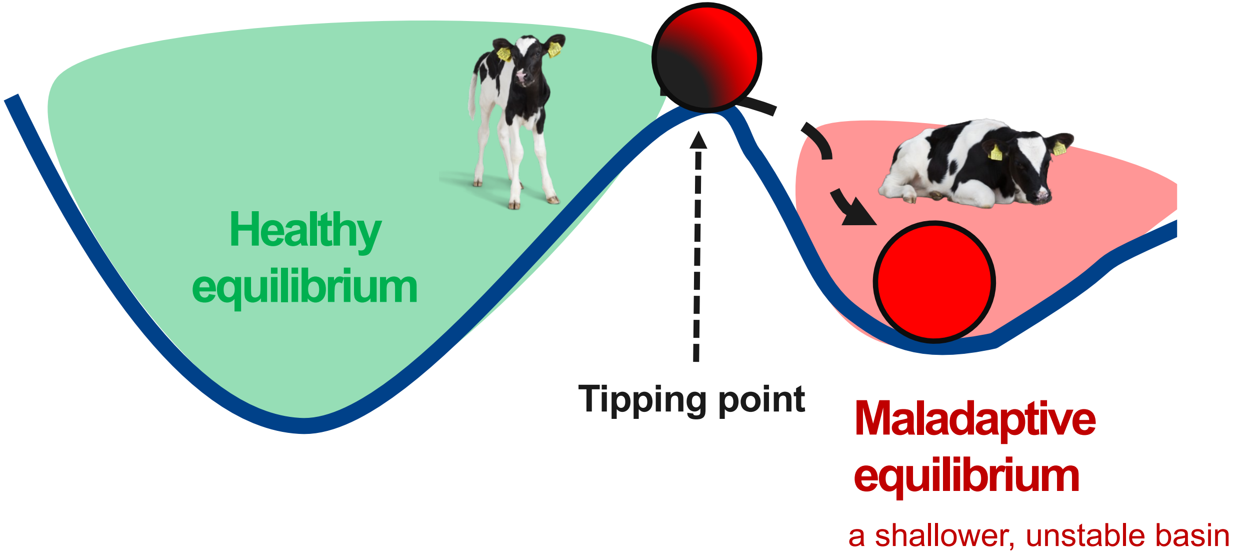
Conceptual Overview: The Tipping Point
in form of 'ball and cup' heuristic



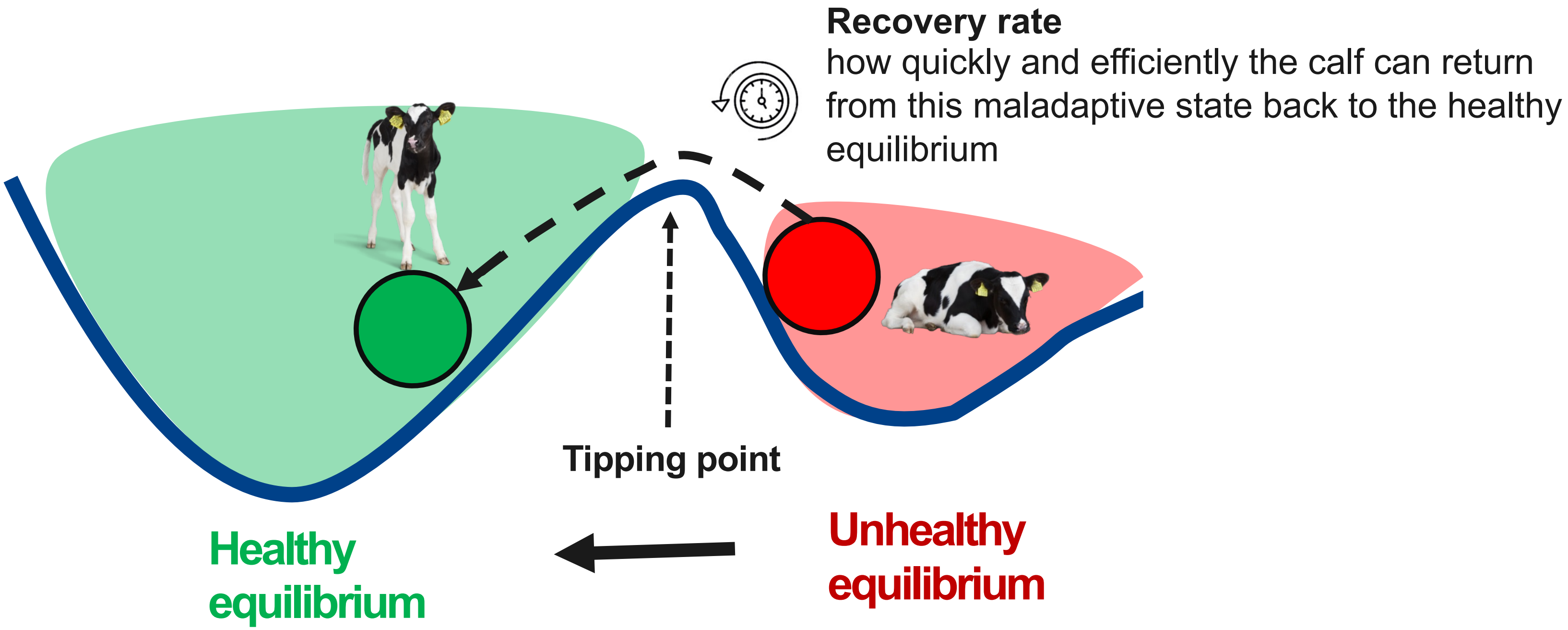
At a certain threshold (**tipping point**) self-recovery mechanisms fail.

Conceptual Overview: Maladaptive Equilibrium

If the disturbance persists or intervention is delayed, the system can move into a new maladaptive equilibrium

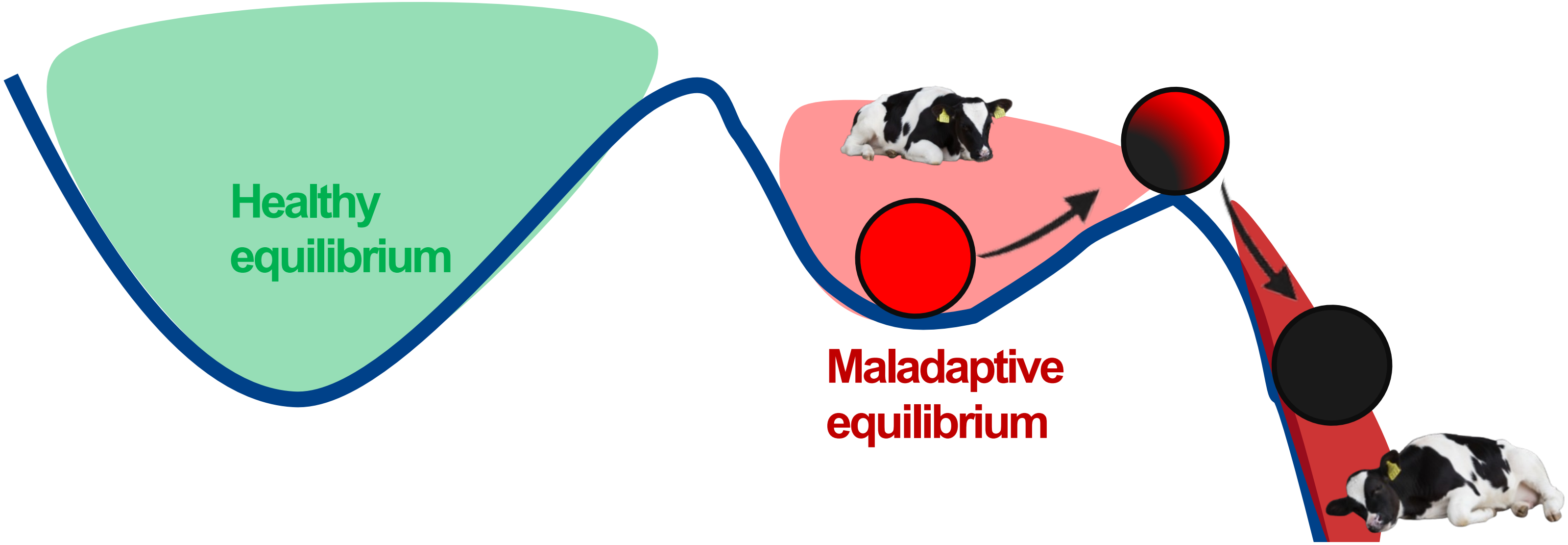


Conceptual Overview: Recovery and Resilience



Conceptual Overview: System Collapse

When stressors are **extreme or prolonged**, and the calf's resilience capacity is **overwhelmed**, the system can move beyond recovery altogether.



Factors affecting calf resilience to disease

Prenatal (Maternal) Factors

- Dam immunity, vaccination, and parity (influence colostrum Ig)
- Late-gestation nutrition
- Maternal health status
- Environmental stress
- Genetic background

Postnatal factors

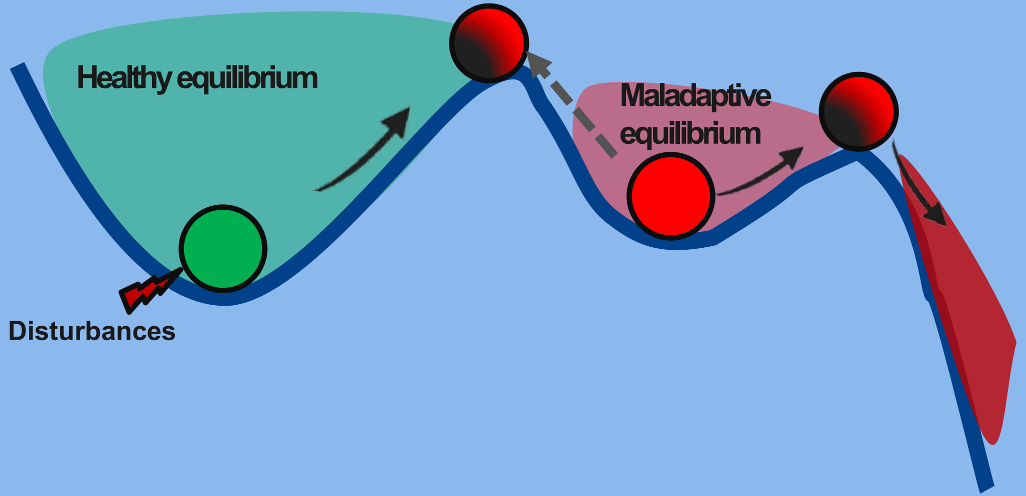
- Passive immunity (colostrum feeding)
- Nutrition (milk feeding)
- Vaccination
- Environmental and social stress
- Hygiene and pathogen control
- Health monitoring and early treatment

Source: Ghaffari, 2020, Osorio 2020, and Lombard et al. 2020, Haagen et al., 2021, Silva, et al., 2023, Diddeniya et al., 2024

Early-life feeding on calf resilience to diseases

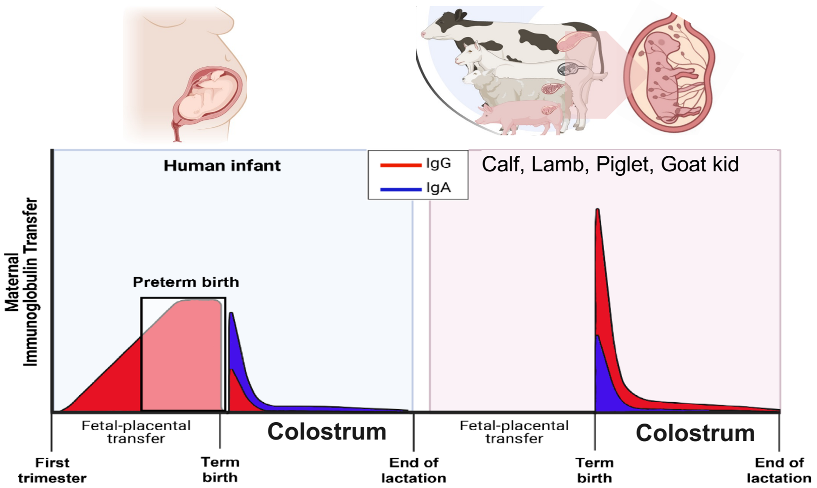
- Passive immunity from colostrum
- Milk feeding allowance
- Behavior data and predictive models for early disease detection and timely action

The role of **colostrum intake** and **passive immunity** in calf **disease resilience**



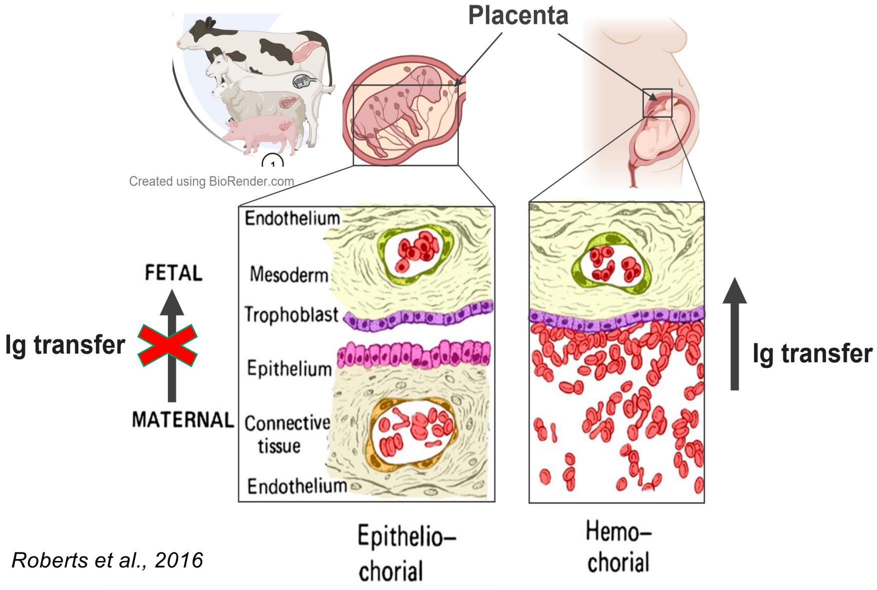
Neonatal Immunity: Born Vulnerable

•Born **agammaglobulinemic** at birth due to the synepitheliochorial placenta
→ No prenatal IgG transfer → depends entirely on colostrum.



Created using BioRender.com

Sangild et al., 2021



Roberts et al., 2016

Successful **transfer of passive immunity** (TPI) is the foundation of early-life **resilience**

Godden et al., 2019

Colostrum feeding standards

Defined in 1980s; validated by mortality risk differences
Gay, 1983; Wells et al., 1996

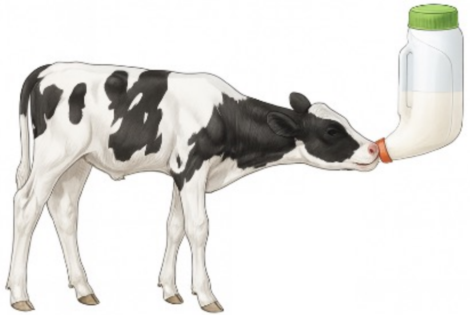
- The benchmark for successful TPI: **serum IgG ≥10 g/L**
- Failure TPI: **serum IgG <10 g/L**
- Measured between **24 h to 7 days** after birth

Serum IgG ≥10 g/L: reduced mortality

- Limited impact on **morbidity**
- Calves with IgG ≥10 g/L still face high risk of illness

Failure of Passive Transfer of Immunity (FTPI): Evidence from Meta-analysis (15 studies)

- Serum **IgG < 10 g/L vs. ≥10 g/L**
- Sampling time: 24–48 h after birth to ensure complete Ig absorption.

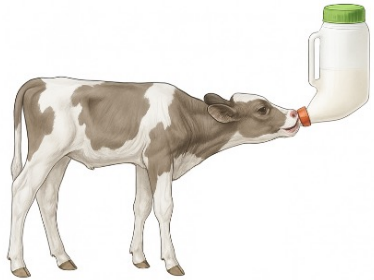


- **Mortality**: 2.12-fold higher (95% CI: 1.43–3.13)
- **Bovine respiratory disease**: 1.75-fold higher (95% CI: 1.50–2.03)
- **Diarrhea**: 1.51-fold higher (95% CI: 1.05–2.17)
- **Overall morbidity**: 1.91-fold higher (95% CI: 1.63–2.24)
- **Growth loss**: –81 g average daily gain per day

Created by Gemini

Raboisson et al., 2016

New TPI Standards (calf-level categories)



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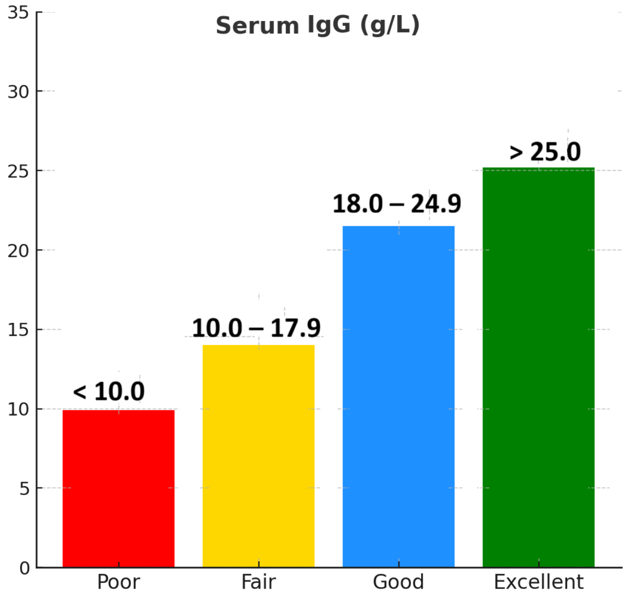
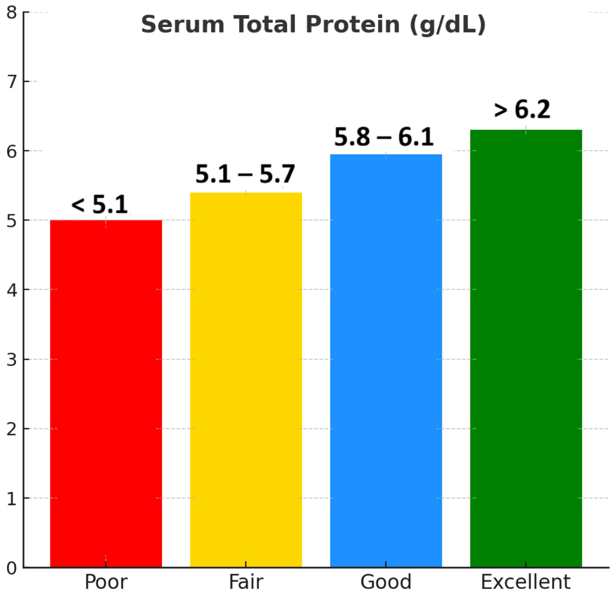


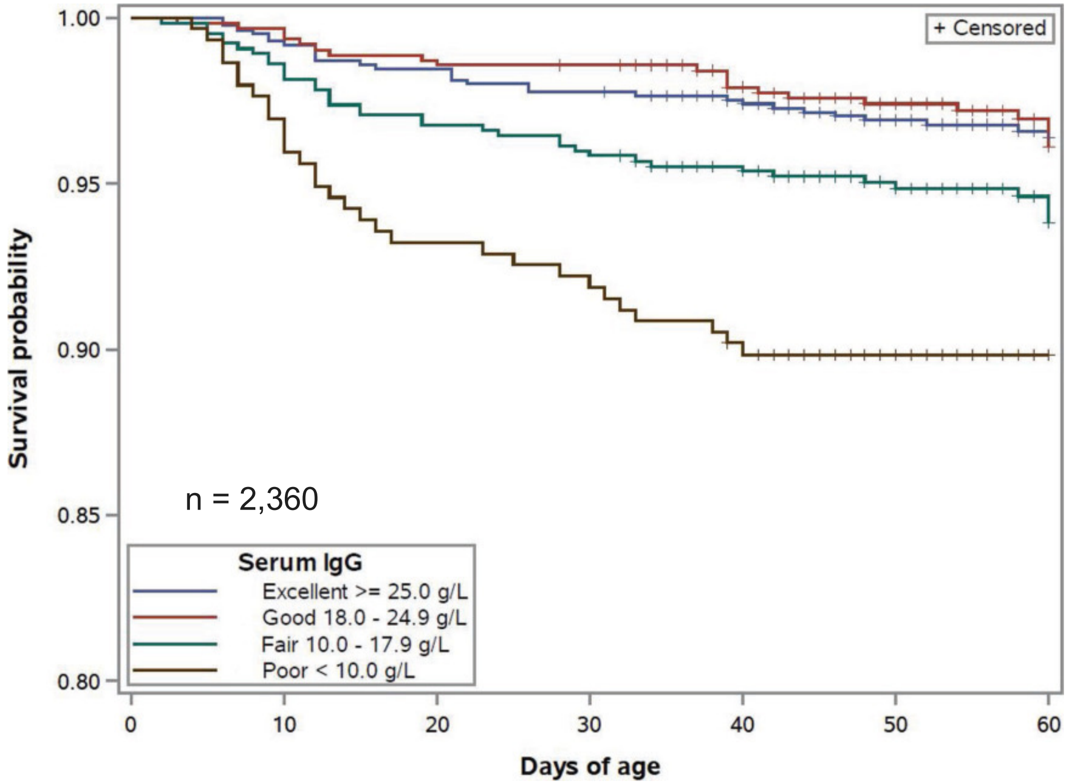


Based on data from 2,360 calves across 103 US dairies

Lombard et al. JDS 2020

Colostrum IgG and Survival

Serum **IgG ≥ 18 g/L (ideally ≥ 25 g/L)** significantly enhances calf **survival**



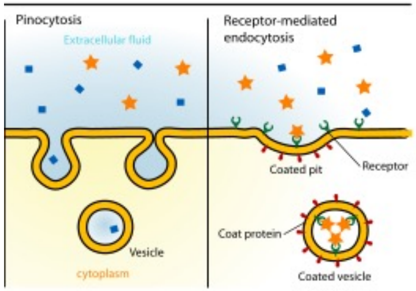
Urie et al., 2018: Lombard et al. 2020


Cleanliness
Quantity
Quickness
Quality
Created by Gemini
Optimizing
Colostrum Delivery

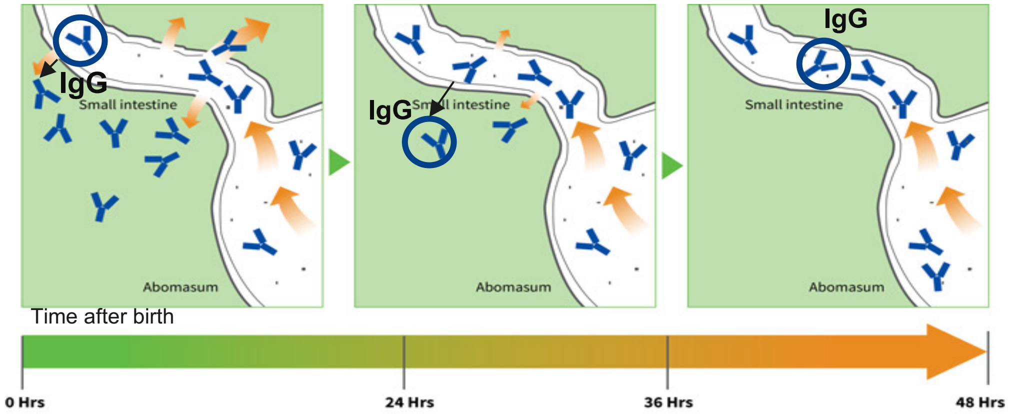
Quickness

- **Absorption window:** up to **24 h**, efficiency peaks within **first 6 h**
- **Goal:** feed colostrum as soon as possible after birth
- **Early feeding =** higher IgG uptake, lower FTPI risk

Stott et al., 1979; Godden et al., 2019



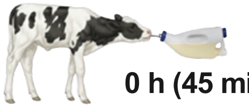
Jochims, 1994; Kaup, 1996, Zhu, 2020



Picture: agrivantage.com

Case study: Delaying colostrum intake

Fed colostrum after birth:

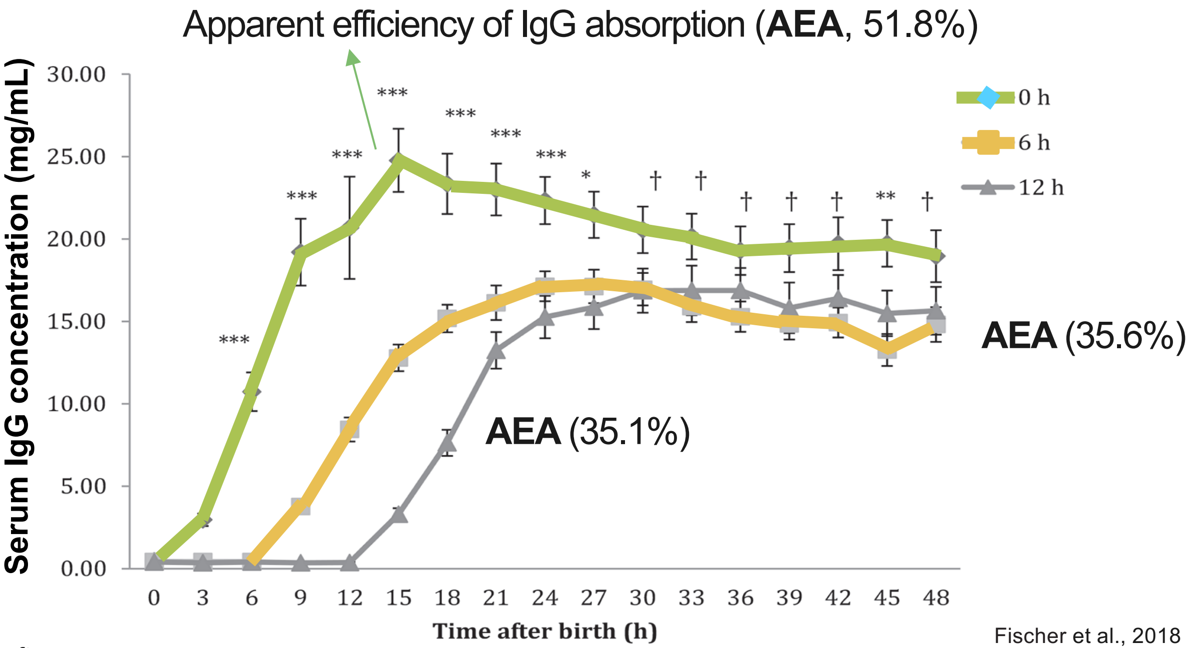


0 h (45 min)
n = 9

6 h
n = 9

12 h
n = 9

- Pooled, heat-treated colostrum
- (62 g of IgG/L; 7.5% of BW)
- Milk replacer: 2.5% BW per meal every 6 h thereafter



Fischer et al., 2018

Delayed feeding reduced AEA and delayed peak IgG appearance.

Quality & Cleanliness

High-quality colostrum indicators

- **IgG concentration ≥ 50 g/L**
  - Measured by radial immunodiffusion or estimated using a Brix refractometer (≥22%)
- **Bacterial contamination**
  - Bacteria bind to IgG, reducing absorption efficiency
  - **Total bacteria:** <100,000 CFU/mL **Coliforms:** <10,000 CFU/mL

Godden et al., 2019

High-IgG Colostrum: an immune- protein–rich matrix

Feeding **high-IgG colostrum** supplies not only *more antibodies* but also a **broader immune proteome**

Colostrum samples from 18 primiparous Holstein cows

Grouping: Colostrum categorized by IgG level

- Poor (≤ 42 g/L)
- Average (42–53 g/L)
- Excellent (≥ ~65 g/L)

→ Proteomic profiling

IgG Group	Proteomic Traits
Excellent (n = 6)	↑ **Immune proteins:** complement factors (C3, C4, C5), complement regulators (Factor H, C4BP), serpins (SERPINA1, SERPINF2) → **supports innate + anti-inflammatory defence** ↓ **Nutrient proteins:** caseins (α-, β-, κ-casein) ↓ **Oxidative enzyme:** xanthine oxidase
Average (n = 5)	Intermediate immune–nutrient balance
Poor (n = 7)	↓ Immune proteins • ↑ Caseins • ↑ Xanthine oxidase

Castillo-Lopez et al., 2025

Optimal Colostrum Volume

Optimal colostrum volume depends on **calf body weight**.

Which feeding rate optimizes IgG uptake: **6%, 8%, 10%, or 12%** BW?

Case study: Quantity of colostrum intake

(7% BW)
- Volume **2.6 L**
- Total IgG intake **~313 g**

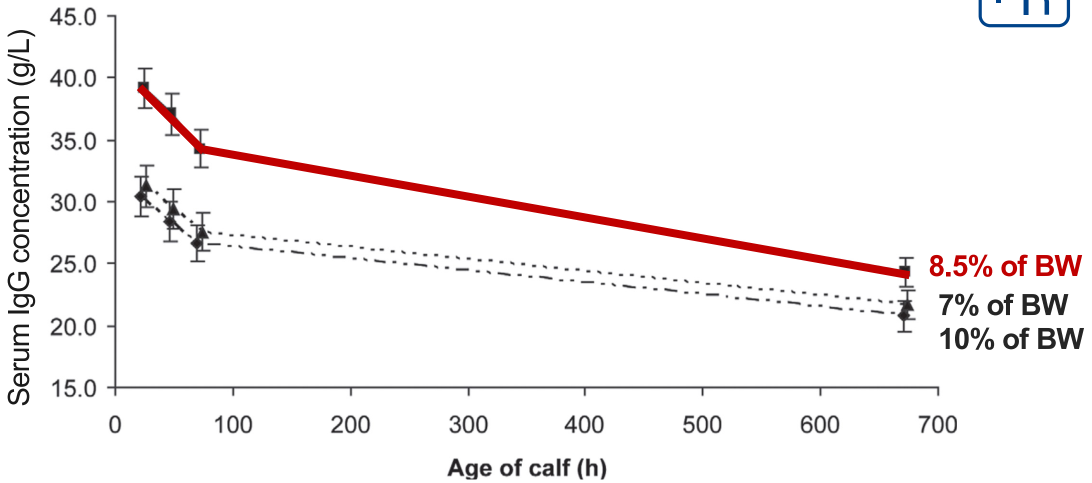
(8.5% BW)
- Volume **3.2 L**
- Total IgG intake **~357 g**

(10% BW)
- Volume **3.8 L**
- Total IgG intake **~381 g**

Created by Gemini

Conneely et al., 2014 JDS

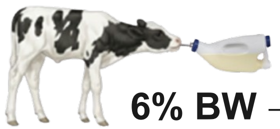
- Pooled colostrum from freshly calved cows
- Fed via stomach tube
- Administered within 2 h of birth



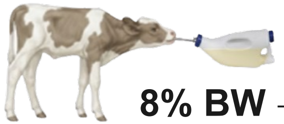
Apparent Efficiency of Absorption (AEA):
- 7% BW (26%)
- **8.5% BW (38%)**
- 10% BW (29%)

Abomasal distension caused by **larger volumes** of colostrum may slow **abomasal emptying**, reducing IgG absorption efficiency.

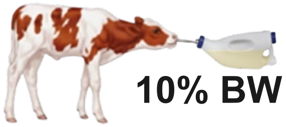
Case study:
Quantity of colostrum intake



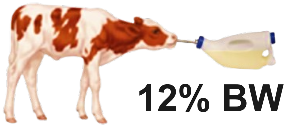
6% BW → 2.3 L (2.0–2.8)



8% BW → 3.1 L (2.5–3.9)



10% BW → 4.0 L (3.5–4.5)

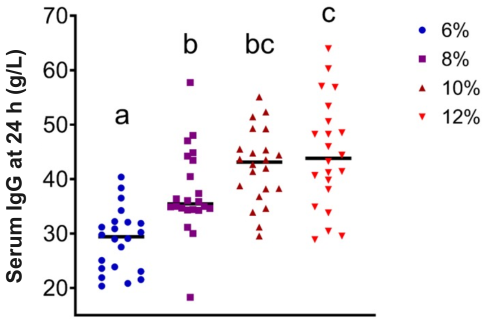


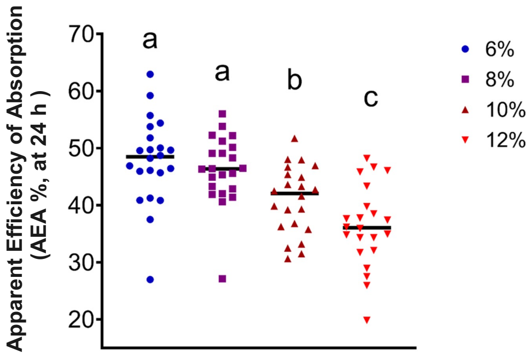
12% BW → 4.8 L (4.2–5.6)

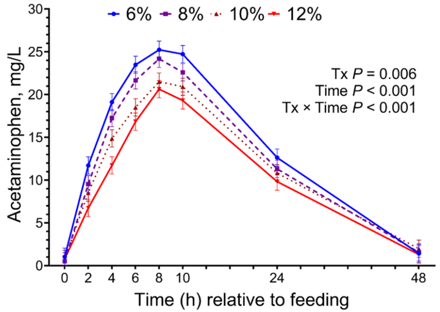
Created by Gemini

n = 22 per group
Birth BW = 40 kg (31.8–49.1)

Pooled colostrum:
Single meal ≤2 h via tube
Brix 24.2%; IgG 86.7 g/L







Abomasal retention at 8 h
(plasma acetaminophen marker)

Increasing colostrum volume **>10% BW**

↓

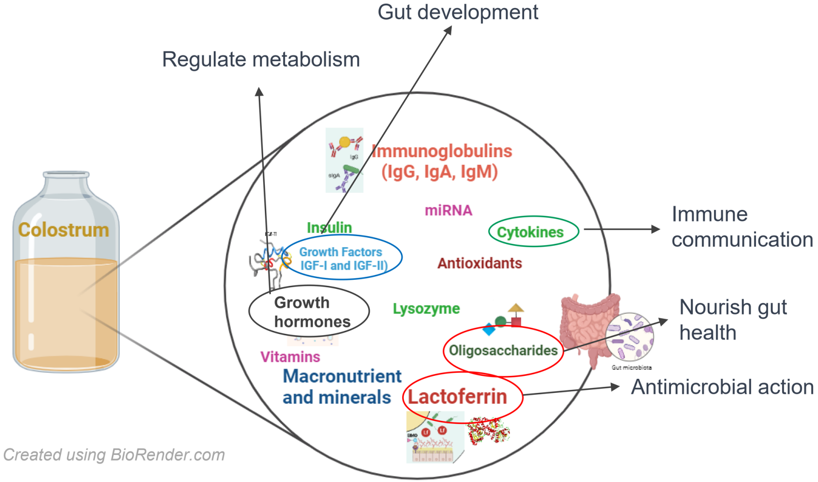
Increasing abomasal retention

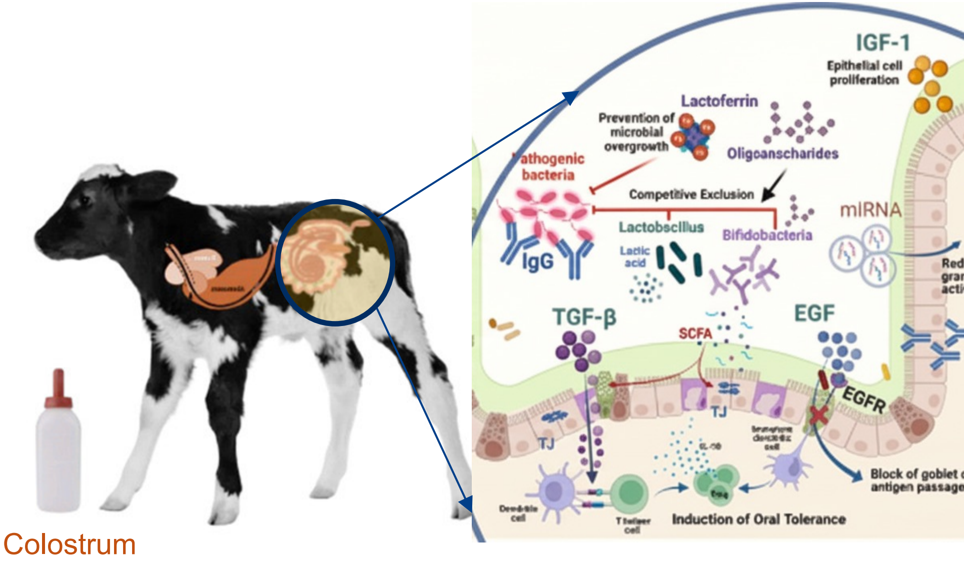
↓

delay in **IgG delivery** to the absorption site → **reduced AEA**

Frederick et al., 2025, JDS

Beyond IgG: Colostrum supports gut development and builds intestinal resilience

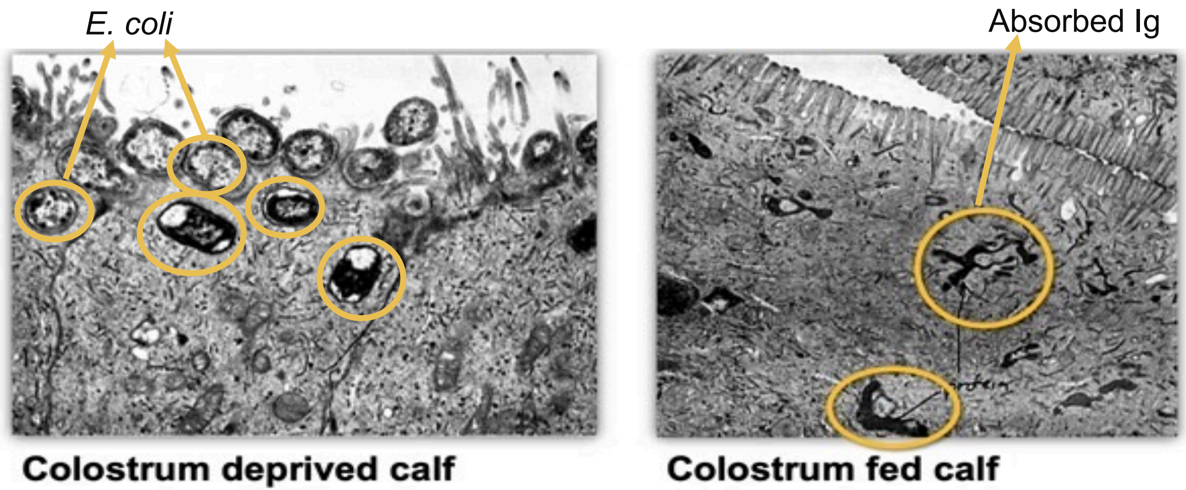




Sources: Malmuthuge et al., 2001; Liang et al., 2014; Hammon et al., 2020; Ghaffari et al., 2021; Rostoll-Cangiano et al., 2025; Renaud and Steele, 2025

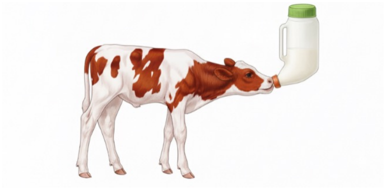
Case study: Colostrum protects the gut barrier against *E. coli* translocation

Electron microscopic of apical ends of ileal epithelial cells



- 24 hours after *E. coli* exposure, calves were euthanized, and samples (jejunal and ileal regions) were collected.

Received *E. coli O55:B5:H7* suspended in sterile saline via a stomach tube (1 × 10^7 bacteria in 1 L of saline) between 2 to 6 h after birth (n = 4).



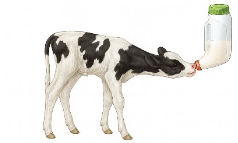
Created by Gemini

Received colostrum first (1 liter of colostrum, 2 to 6 hours after birth), followed by *E. coli O55:B5:H7* 1 h later (n = 2).

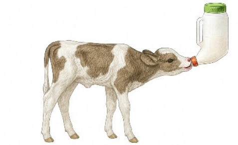
Corley et al., 1977 JDS

Case study: Colostrum activates innate immunity

via pattern-recognition receptors and barrier integrity



Milk-based formula
(n = 7)



Colostrum
(n = 7)

Holstein calves
(45.9 ± 1.0 kg)

Created by Gemini

Feeding:

- Bottle-fed twice daily from birth to day 3, once on day 4
- formula matched colostrum nutrients but lacked bioactives (IGF-I, insulin)

Sampling:

- Euthanized on **d 4** (2 h post-feeding)
- Mucosa from **duodenum, proximal/mid/distal jejunum, ileum**

Genes analysed:

- Immune sensing: *TLR1–10*
- Antimicrobial defense: *DEFB1, PGLYRP1*
- Barrier integrity: *CLDN1, CLDN4, OCLN*

Ghaffari et al. 2021, JDS

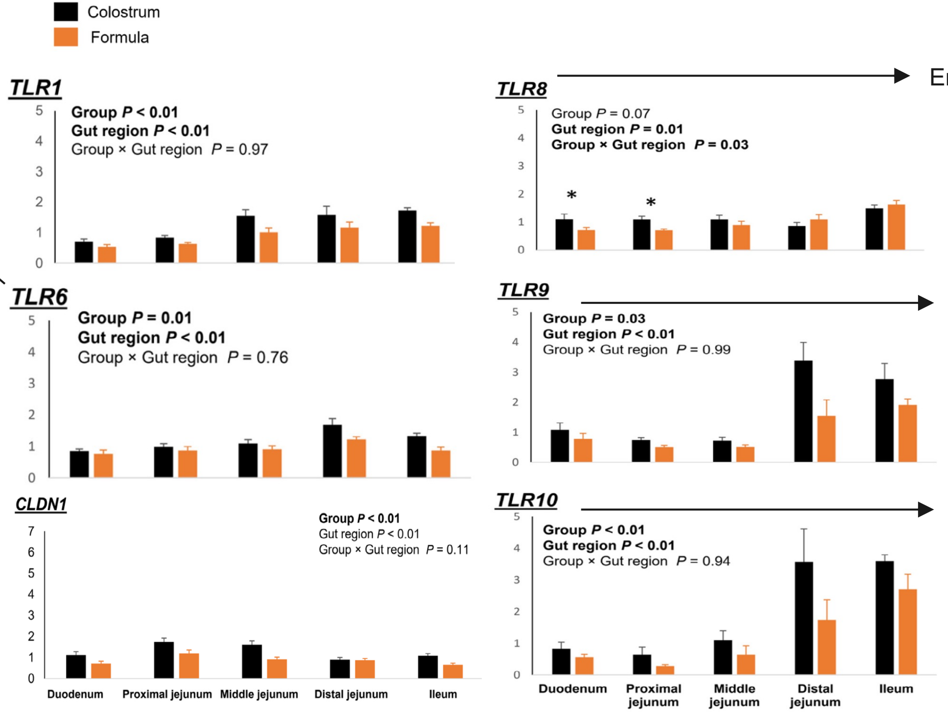
Case study: Colostrum activates innate immunity

via pattern-recognition receptors and barrier integrity

Enhanced epithelial sensing of beneficial microbiota and repair of mucosal barriers

Enhanced tight junctions, improved gut barrier integrity

Created by Gemini



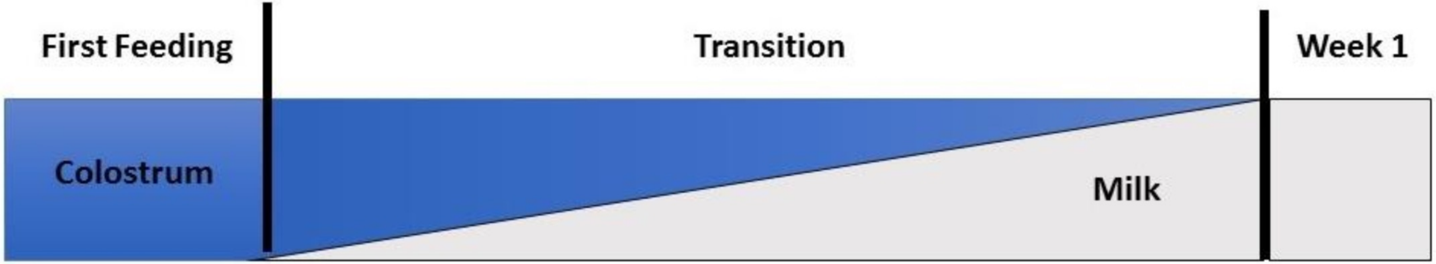
Enhanced antiviral defense

Promotion of mucosal tolerance and antimicrobial peptide synthesis

Prevent excessive inflammation and maintain immune homeostasis

Ghaffari et al. 2021, JDS

Beyond Day 1: Extended colostrum or transition milk feeding



Ghaffari et al., 2016 77th Minnesota Nutrition Conference

Extended colostrum feeding: Evidence from studies

Transition milk
or colostrum supplement

3 days

Pyo et al. 2020

4 days

Conneely et al. 2014;
Van Soest et al., 2020;
Berge et al. 2024

2 weeks

Kargar et al., JDS 2020

- Improved growth and intestinal development
- Improved health scores
- Reduced *Cryptosporidia* shedding
- Reduced diarrhea and respiratory disease; enhanced resilience

Inconsistent results

- **3 days** → No measurable effect on growth or health *da Silva et al. 2023*
- **5 days** → No growth difference but fewer health disorders (trend) *Ostendorf et al., 2025*

Role of **milk allowance** in **calf disease resilience**

Milk Allowance Levels

Conventional (~10% BW; 2–5 L/day)

- Restricts growth and compromises welfare
- Promotes early starter intake

Created by Gemini

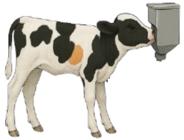
Elevated to Ad libitum (>20% BW; 8–15+ L/day)

- Improves growth, welfare and natural suckling behavior
- Stimulates organ development via IGF-axis activation
- Enhances metabolic and immune function
- Rumen maturation delayed early, normalized with gradual weaning

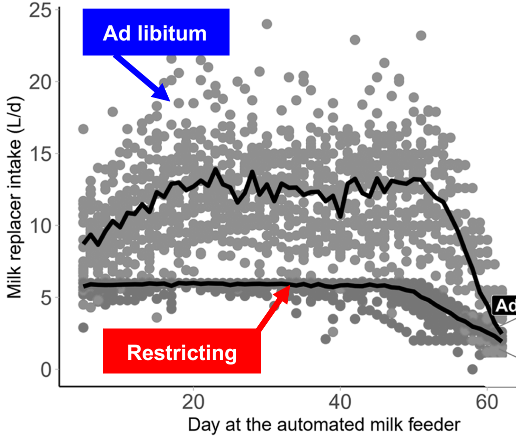
Sources: Jasper & Weary, 2002; Schäff et al. 2016; Frieten et al. 2017; Soberon & Van Amburgh 2017; Hammon et al. 2018; Ollivett et al. 2012; Ballou et al. 2015; Koch et al. 2019.; Hammon et al., 2020; Welk et al., 2023

Case study: Effect of milk intake on growth performance

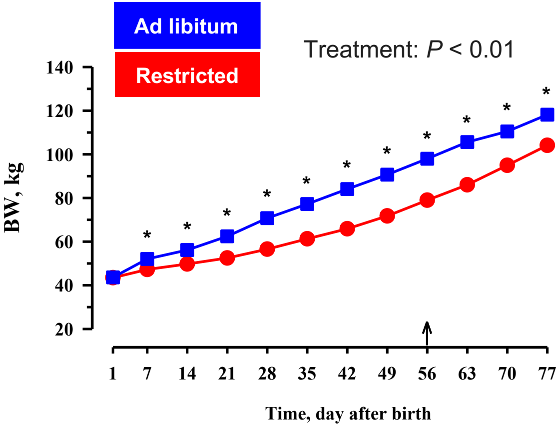
Restricting milk replacer
(6 L/d; n = 32)



Free access to milk replacer
(up to 25 L/d; n = 32)



Frieten et al., 2017 JDS



Restricting
63 kg

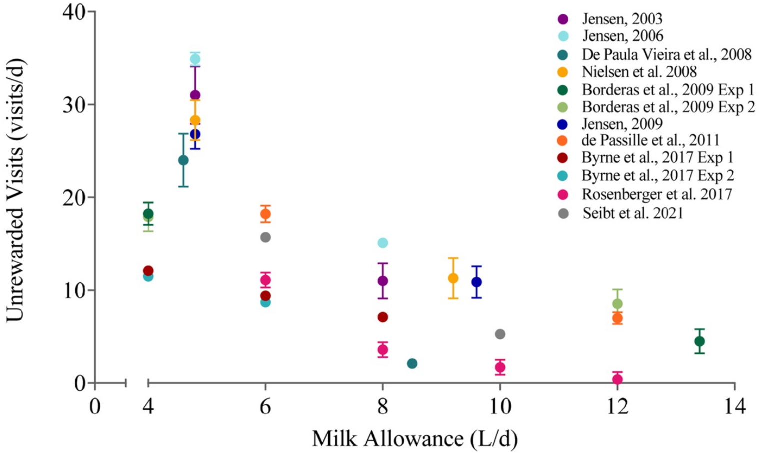
Ad libitum
83 kg

Body weight at 7 weeks of age

Meta-analysis: Evidence from 47 studies

Milk allowance categories:

- Low allowance: 4-7 L/day
- High allowance: 8-12 L/day or free access



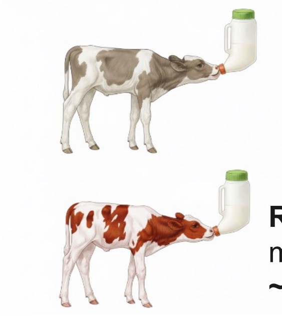
Effects of Higher Milk Allowance

- Over 85% of studies reported greater ADG and final body weight during the preweaning period
- Starter intake was lower preweaning but compensated after weaning
- No consistent effect on diarrhea or respiratory disease
- Calves showed less hunger (less unrewarded visits) and more locomotor play

Welk et al., JDS 2023

Case study: Milk allowance and calf resilience to infection

- **20 Holstein calves** orally infected with *Cryptosporidium parvum* (1 × 10^6 oocysts, day 3)



High-fed:
milk replacer
8–11 L/d

Restricted:
milk replacer
~4 L/d

Duration: 21 days; no starter feed

Key findings

High-fed vs. restricted calves :

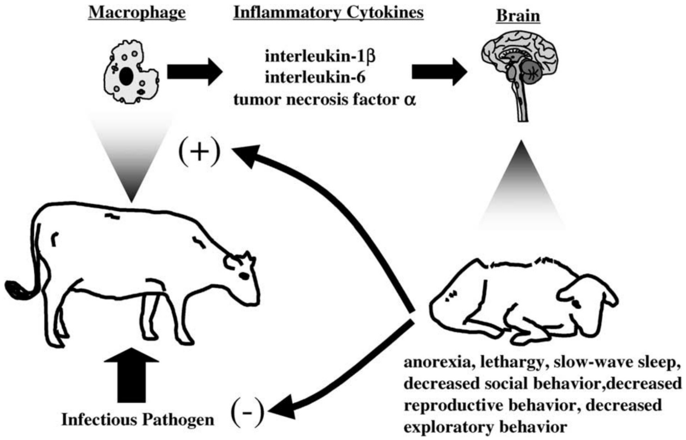
- **Oocyst shedding:** No difference in onset, duration, or total shedding between groups.
- **Faster diarrhea recovery**
- **Higher daily gain** (+0.43 vs –0.05 kg/d)
- **Better feed efficiency** (+132 vs –31 g gain/kg DMI)
- **Greater lymphocyte counts,** indicating stronger immune maturation.

Ollivett et al., 2012

Calf Resilience to Disease:
Role of **Sickness Behavior**

What is sickness behavior?

- Adaptive, coordinated neuroimmune response to infection
- Helps conserve energy and prioritize immune function for recovery.



Johnson, Vet. Immunol. Immunopathol 2002

Importance:

- Sickness behavior signals early immune activation before clinical symptoms appear.
- Early detection allows for proactive management, improving recovery and reducing the risk of disease spread.

Sickness Behavior in Calves

Key sickness behaviors identified

- Reduced **milk intake**, **drinking speed**, and **starter intake**
- Fewer **rewarded/unrewarded feeder visits**
- Increased **lying time**, fewer **lying bouts**, and lower **step counts**
- Decreased **activity** and **exploration behavior**

Ghaffari et al., 2020; Belaid et al., 2020; Duthie et al., 2021: Cantor et al., 2022

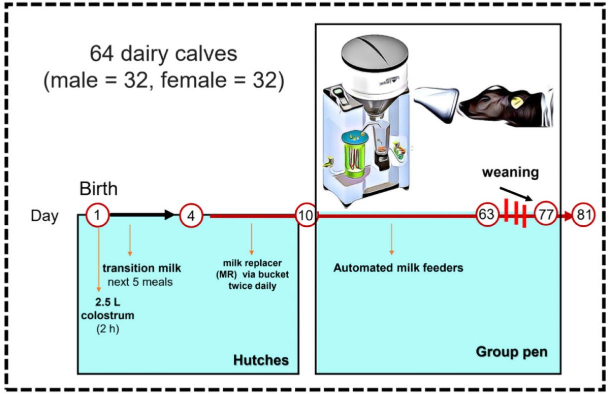
Picture and video:
Förster-Technik GmbH and Lely.com

Automated Milk Feeder (AMF) record individual feeding events, providing a rich dataset on feeding behavior

Ghaffari et al., 2020

Case study: Automated detection of calf disease using deep learning

Study design



Data recording

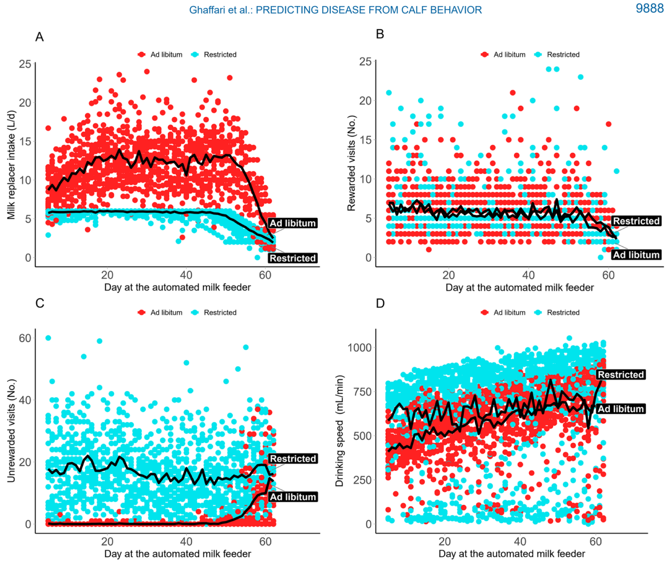
Sensor-Derived Feeding Behavior Data

- Milk replacer intake
- No. of rewarded visits
- No. of unrewarded visits
- Drinking speed
- Milk replacer allowance

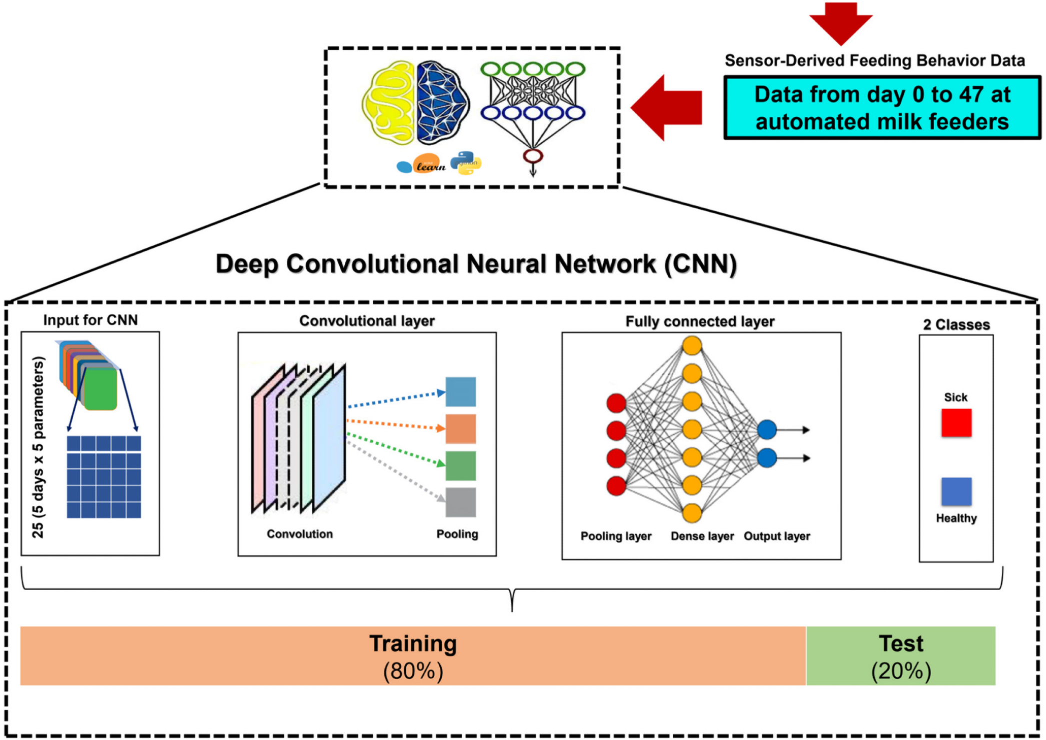
Daily Health Record

- Respiratory disease (score ≥ 2)
- Diarrhea (fecal score ≥ 3)

Calf illness defined as diarrhea and respiratory disease



CNN Model Optimization



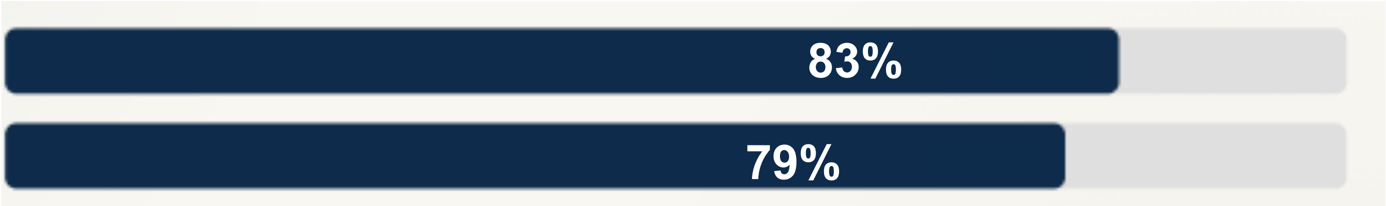
CNN model tuned to achieve **≥80% sensitivity** to minimize **false negatives (FN)**.

Ghaffari et al., JDS 2022

CNN Model Performance

Sensitivity

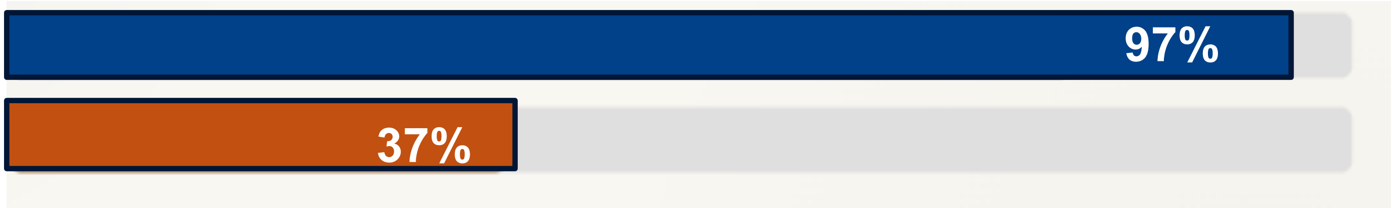
Specificity



Sensitivity	the correctly identified sick calves / all sick calves: TP/(TP + FN)	
Specificity	the correctly identified healthy calves/ all healthy calves: TN/(TN + FP)	

NPV
(Negative Predictive Value)

PPV
(Positive Predictive Value)



It means that only 37% of positive alerts are true sick calves

PPV	The proportion of sick calves on the alarm list **(all calves predicted sick**): TP/(TP + FP)
NPV	The proportion of healthy calves without alarms (**all calves predicted healthy**): TN/(TN + FN)

Ghaffari et al., JDS 2022

Challenges

Low disease prevalence scenario

- Low daily disease prevalence causes a high false-positive rate
- Even a well-performing model can generate many false alerts when most calves are healthy

The external validation gap

- Out of **129** commercial sensors reviewed by Stygar et al. (2021), only **18** were externally validated

14%

externally validated

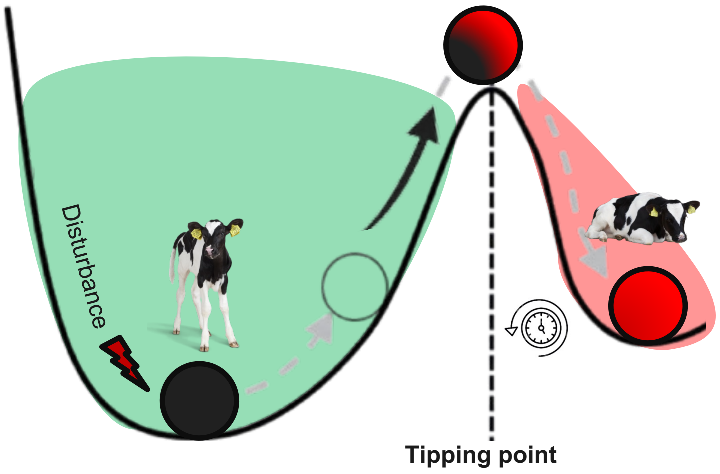
The regulatory context

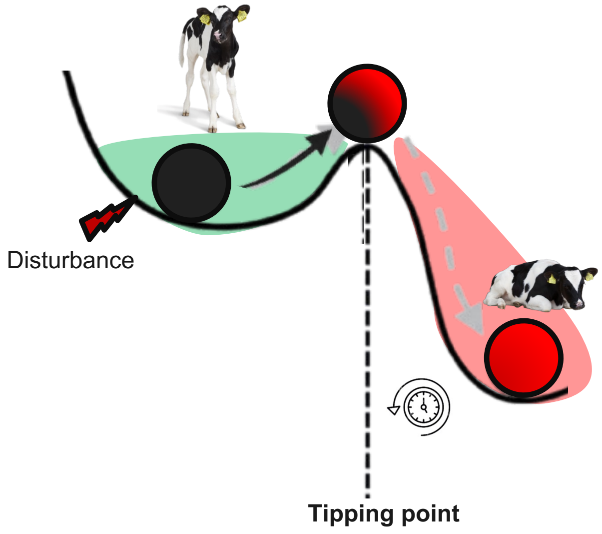
- EU Council Directive 98/58/EC mandates daily visual inspection. Automated systems are intended to **support**, not **replace**, human husbandry.

Take-Home Messages

- Calf resilience is **dynamic**, shaped by genetic, nutritional, and environmental factors before and after birth.

- Successful passive immunity transfer enhances resilience
(deeper stability basin, reduced tipping-point risk, faster recovery)





Take-Home Messages

Successful passive immunity transfer:

- Feed **8–10% BW** of clean, high-quality colostrum (IgG ≥ 50 g/L) within 2 h after birth to ensure strong immune protection.
- Extend **colostrum feeding** and provide **higher milk allowance** (20% BW) to enhance immune function, gut health, and resilience to disease.

- Although **sickness behavior** signals early immune activation and presents an opportunity for timely intervention before clinical symptoms appear, most current disease alarm systems are more **hype** than **reality**.

Thank you

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