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Unmasking mastitis

Farmers, consultants, veterinarians and milk processing companies around the world list 'mastitis detection' as the primary need for development of on-line sensing technology.

But when asked what exactly they wanted to detect and what they thought 'mastitis' referred to, there was much confusion about mastitis and mastitis detection.

The definition of 'mastitis' is specific, while the term is often used to refer to a broad and complex sequence of events. Mastitis as defined by Webster and the *International Dairy Federation* is an 'inflammation of the . . . udder'. If this is 'true mastitis', two interesting questions become obvious:–

1) How can you build a sensor that detects 'inflammation'?

2) Is 'true mastitis' really what everyone wants to detect?

Some people define 'detecting mastitis' when a test of bacterial pathogens is positive, others when SCC reaches a particular level, others when clinical signs such as clots or swelling occur.

All these definitions contain some truth, give some information about udder health or milk quality and are useful in herd health and milk quality management.

A cause-effect spectrum has been developed in conjunction with animal health experts from around the world. This spectrum, ***depicted Figure 1***, gives a clearer perspective about the process commonly referred to as 'mastitis'. It outlines biological causes and physiological and behavioural effects that occur as a bacterial infection progresses.

From this information, sensors can be developed which measure components at different stages of the spectrum, depending on the management decision being sought. The cause-effect spectrum is a generalisation of a 'typical' bacterial infection episode. Its intent is to paint a picture of how various causes lead to their associated effects and how various cause-effect relationships fit along the spectrum.

1) Bacterial infection

The first step in the cause-effect spectrum is the contamination of the teat end with bacteria, followed by bacteria entering the teat and gland.

2) Bacteria replication

As bacteria multiply in the rich nutrient environment of the milk, they produce many different metabolic by-products. One of the most significant is lactic acid or lactate. Aside from measurement of bacteria themselves, the measurement of a bacterial metabolite, such as lactate, would be about the earliest indicator that an infection has occurred. What is done about it at this point is a management decision.

3) Glandular response

Once there is a non-bovine cell or a foreign substance in the system of a healthy normal animal, her natural defence system will detect the cell or substance and react. The first physiological trigger is for the gland to release so-called 'acute phase proteins (APP)', which act as the signal to the immune system to do something. One such APP is called milk amyloid A (MAA).

4) Initial immune system response

Increase in MAA leads directly to the immune system, sending white blood cells or leukocytes to the udder. This is the first instance in the cause-effect spectrum when somatic cell count (SCC) rises. 'Somatic cell' simply means

TABLE 1:	Bacteria in milk	Cell count × 10	Rise in electrical conductivity	Clots in foremilk
Strep. Uberis	2.3	3.1	3.5	5.2
Staph. Aureus	1.1	2.3	2.7	4.2
Sensortec sequence	(2)	(5-7)	(9-10)	(11)

TABLE 1: Sequence of development of easily detectable events (given as the average number of milkings after introduction of the organism) in mastitis caused by Streptococci and Staphylococci. It is taken from Eric Hillerton's paper *'Detectable changes in milk in the pathogenisis of intra-mammary infection – the initial response'* involving 2 different bacteria, and the average number of milkings after infusion of the udder with bacteria that the following increased: bacteria, SCC, conductivity and clots, and how they correspond to the proposed cause-effect spectrum.

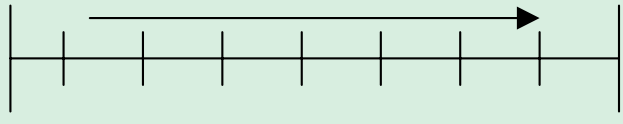

FIGURE 1: Diagram of a cause-effect spectrum.

(From facing page)

'body cell' and includes any cell of bovine origin. This includes mostly white blood cells and mammary epithelial cells, the cells that synthesise milk.

The initial leukocyte response leads to an increase in SCC levels but, because of high baseline variation in SCC from cows due to factors such as breed, parity, stress, milking interval and other diseases, this initial rise in SCC is usually too small and too variable to be measured reliably.

5) Initial tissue damage

If the infection has not been cured, bacterial levels eventually rise to the stage that they begin to damage the mammary epithelium. As this occurs, SCC continues to rise, still due mostly to a further influx of leukocytes, but also a result of dying and sloughing mammary epithelial cells. Somewhere at this stage in the spectrum, SCC becomes measurable over and above the baseline variation. Also, at this stage, initial tissue damage leads to release of 'healing enzymes', such as NAGase.

6) Internal mammary swelling ('inflammation' or 'true sub-clinical mastitis')

If the infection progresses, the mammary epithelium starts to swell. This swelling is internal and cannot be seen or felt by the observer.

7) Increasing tissue damage

Again, if the infection has not been cured, damage to the mammary epithelium worsens. This may lead to extreme SCC increases as damaged epithelial cells slough off into the milk, perhaps taking SCC levels into millions of cells per millilitre.

Once epithelial cells start to become significantly damaged, the milk yield would be affected. Whether this translates into a decline in milk yield from the udder probably depends on what the major rate-limiting factor is for the cow's milk production, either the milk producing capacity of the udder or the level of nutrition. Research suggests that if nutrition level is rate-limiting, the equivalent of 3.5 quarters can convert all food nutrients available for milk production equally as well as 4 healthy quarters. So, drops in milk yield at this stage are unlikely to solely identify the stage of infection.

8) Blood-milk barrier break-down

If epithelial swelling worsens, the alveoli in the gland start to break down, the so-called blood-milk barrier is breached, triggering leakage into the gland. While an 'effect', this key step is in itself a 'cause' that triggers significant effects.

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9) Influx of extra-cellular fluid into the milk

Breakdown of the blood-milk barrier permits extra-cellular fluid to enter the gland and mix with the milk. Extra-cellular fluid components, such as chloride, sodium, hydrogen, potassium and hydroxide ions enter the milk. If the damage to the blood-milk barrier is bad enough, even red blood cell levels in milk may rise at this stage.

10) Ionic effects

Influx of ions into the milk leads to a decrease in the complex impedance of the milk and an increase in milk pH. The most common way of measuring the complex impedance is by electrical conductivity. There are now systems on the market that can do this by inductance as well. Due to biological variations in the complex impedance, the most effective way to diagnose udder tissue damage is to measure the complex impedance of individual quarters and then compare values between the 4 quarters.

11) Clots, external swelling, redness

Once the blood-milk barrier is breached, visible changes in the milk and the udder start to occur. This can include clotting, external swelling and redness of the gland and wateriness of the milk. By definition, this is the start of 'clinical' symptoms.

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12) Milk yield, milk temperature, activity

Once clinical symptoms start occurring, the cow has progressed to a stage of visible illness. So much of the udder tissue is now damaged that there is often a significant drop in milk yield. Severity of reduced milk yield and other clinical symptoms varies according to whether infection is mild, severe, acute or per-acute. The cow may run a fever, so the body and thus milk temperature rises. If the cow is really sick, her activity level drops.

13) Death of animal

An acute or per-acute infection may eventually reach its final conclusion with death of the animal.

If this spectrum doesn't seem complex enough, note that the cow can self-cure or cure with treatment at any time along the cause-effect spectrum.

Scientists are still debating finer details of this cause-effect spectrum, but many conclusions can be drawn:–

- 'Mastitis' is an amazingly complex sequence of events.
- There are many unknown variables and reasons. Each cow has a highly individual response and a specific baseline of measurable indicators.
- To develop a 'mastitis sensor' could be likened to developing a 'personality' sensor. Some objective tests are available, but no two experts will agree on exactly the same classification of a particular individual.
- The further along the cause-effect spectrum away from the cause, the higher the probability that the physiological or behavioural effect can be caused by something other than bacterial infection. For example, a rise in conductivity can be caused by a longer milking interval, or a drop in milk yield can be caused by changing the feed.
- Following from the above point, the closer the sensor measures towards the cause end of the cause-effect spectrum, the quicker and more effective the management response can be.
- The further along the cause-effect spectrum, the more the infection becomes established, the sicker the cow is and the less likely she will be to self-cure.
- Items on the spectrum that have different biological causes, such as conductivity and SCC, can be correlated, but will never be direct indicators of each other. There will always be false positives and negatives when using one to predict the other. Remembering what the true cause is of what is being measured brings to light the real management value of evaluating that particular piece of data.

'True mastitis' would be difficult to measure and is not really the information most farmers require. Many technologies are being developed to help farmers efficiently diagnose udder health and milk quality on-farm.

Part of the successful application of this technology will be educating the dairy industry about tools such as the mastitis cause-effect spectrum. This education will lead to farmers, their support team and farm consultants being better informed and able to purchase and recommend technology best suited to the needs. Ð