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Honors Thesis

An Evaluation of Electrical Conductivity as a Practical Tool in Mastitis Detection at
Andrews University Dairy

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April 2, 2012

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ABSTRACT:

An infection in a cow's udder, also known as mastitis, has been a persistent problem for the U.S. Dairy community. Mastitis not only decreases milk production, but also shortens the productive life of dairy cattle and can be fatal if left untreated. Mastitis presents in both Subclinical and Clinical forms—Clinical is easy to diagnose and treat, whereas Subclinical cases are much harder to detect as they present no physical symptoms, yet can still become clinical in time. At the Andrews University Dairy, part of the milking system includes electrical conductivity (EC) determination which measures the ionic composition of a cow's milk as she is being milked. The milking management software, (AFImilk) checks for increases in EC which may indicate Subclinical mastitis; the system then alerts the milking parlor crew of elevated EC by a visual alarm and records the EC information on the cow's individual record. However, the dairy management team has found that the current EC system offers too many unnecessary or false alarms to be a helpful diagnostic tool, and that it merely promotes the desensitizing of workers to the presence of alarms. The purpose of this study is to determine, based on Dairy records, the practical ability of EC to determine if a cow has mastitis and needs antibiotic treatment. Data on EC was collected from 89 cows at the A.U. Dairy that had experienced at least one episode of Clinical Mastitis in their current lactation. This data was processed using particular statistical parameters to determine false alarm rate, and ultimately, the data was analyzed using Bayes' Theorem to estimate the probability of a cow having mastitis given the presence of an alarm. Analyzing the accuracy and reliability of EC, this study has determined that the management's distrust of EC is well-founded, not misguided. Our results showed that, due to an exceptionally high number of false alarms and unpredicted mastitis events, EC is not a practical tool for detecting clinical mastitis in the milking parlor.

BACKGROUND & SIGNIFICANCE:

Mastitis is a perpetual plague to the U.S. dairy industry, incurring costs that average between 1.7 and 2 billion dollars annually. Mastitis not only decreases milk production, but also shortens the productive life of dairy cattle and can be fatal if left untreated. Literally, mastitis is “inflammation of the mammary glands”. The inflammation is the cow’s immune system response to a bacterial invasion of the udder. It can be caused by any number of pathogens, but the most common offenders are strains of staphylococcus, streptococcus, and coliform bacteria. There are multiple ways these invaders find their way into the cow’s udder, but the vast majority enter through the end of the teat during the milking procedure.

Mastitis most commonly presents itself in one of two forms—a Subclinical or a Clinical infection. A Clinical infection is very readily observable as it is accompanied by a red, swollen, painful and hot udder, abnormal milk (milk that has chunks, blood, or serum in it) and occasionally other systemic complaints (such as a fever) which indicate that the cow is physically ill. Subclinical cases are much more difficult to identify as the cow shows no physical symptoms, but the composition and quantity of the milk she produces may be altered. These values are measured by biological determinants such as Somatic Cell Count (SCC), Milk Yield (MY), and Electrical Conductivity (EC) which are either taken by the automatic milking machine system or by visual evaluation of the milk. Electrical Conductivity, which is the focus of this study, “is a measure of the resistance of a particular material to an electric current” (Nielen et al, 1992). Biologically, if a cow has mastitis, she will most likely have serum or blood in her milk which will be shown by an increase in certain ions (Na^+ , K^+ , and Cl^-). Therefore, if an electrical current is passed through the milk, the presence of these ions will change the passage of the current increasing the conductivity of the charge.

The assumption behind the use of technology such as EC, SCC, and MY, are that a Subclinical infection is “pre-clinical”; in other words, that all Subclinical cases can lead to a Clinical infection. If this were the case, using a system such as EC to determine Subclinical infection would be beneficial as it would allow extra time for diagnosis and possible treatment through the dairy manager.

However, it has been shown that the “pre-clinical” nature of Subclinical infections does not always hold fast. Subclinical cases that register as increases in the EC on the automatic milking machines but do not result in a Clinical infection imply that the cow’s immune system resolves the infection on its own. These can be referred to as “Self-cures”. This may appear as a change in EC or high SCC, but the cow never appears physically ill and values return to normal without external aid.

These cases of Subclinical “Self-cures”, while beneficial for the dairy producer as they save time and expense on the treatment of a sick cow, can prove frustrating in the milking parlor as they raise “false alarms” on the automatic milking machines. This can cause confusion by entering into a sort of “boy who cried wolf” scenario; frequent false alarms can desensitize workers to all alarms which can have serious consequences. Also, producers must use caution when administering treatment for an infection. For example, at the Andrews University dairy, a cow may not be treated immediately even if she has abnormal milk but no other symptoms. Antibiotics are only used when it is an absolute necessity—typically when the infection is systemic (fever), MY severely decreases, and other Clinical signs are present. Antibiotics are not given casually for three reasons: producers fear the creation of antibiotic resistant bacteria on their farms; producers do not wish to discard milk that has been treated with antibiotics and therefore lose income; and producers do not wish to unnecessarily treat a cow that will cure itself.

The equipment used for milking and mastitis detection at Andrews University Dairy can be divided into hardware and software. The hardware used is a DeLaval Double Twenty Rapid Exit Parallel Parlor. The cows enter into the parlor in groups of 20 and are enclosed in milking stalls for

the duration of the milking procedure. The cows wear electronic ID on their hind leg which is read by the milking computer system when they enter the milking stall. Then, while the cow is being milked, all of the information about MY and EC for every cow is sent to the herdsman's computer (AFImilk Dairy Management System software). Cows are milked three times daily, and the data collected is stored as the average value of all three milkings. However, within a specific milking, if the change in MY and EC is a certain percentage above the mean of the previous ten days, cows are flagged as potentially being ill. This above-average percentage is determined by the dairy manager who can set the value anywhere between 5-50%. Previous studies have shown that the ability of this percentage to detect Clinical mastitis differs between cows, but shows best results when set between 2-30% (Lukas et al, 2009). The problems arising from this heavy reliance on EC to determine mastitis status are that the automatic milking system can generate high numbers of false alarms, or may neglect to cause an alarm for a cow suffering from Clinical mastitis. These problems are very real and understood by the dairy community, but the overall efficacy of EC outside of strictly experimental situations has yet to be questioned by larger research groups. Many of the previous studies performed, such as those by Fernando (1985), Norberg (2003), Hovinen (2006), Janzekovic (2009), etc. are not practical for the detection of mastitis on a production level—they are far too labor-intensive and expensive to be used on a daily basis by dairy farmers. My study into the practical nature of EC as a tool in detecting Clinical mastitis in the milking parlor is one of the first to emerge.

Bayes' Theorem is a primary factor of my study as it will provide a final analysis of the data I have collected and processed. Bayes' Theorem is based on the idea of conditional probability, that is, the probability of an event occurring given that another event has already occurred. For example, for the events A and B, "the conditional probability of B given A can be found by assuming that event A has occurred and, working under that assumption, calculating the probability that event B will

occur” (Triola). As seen in Figure 1, there are several variables which function to make Bayes’ Theorem a simple yet elegant method of determining conditional probability. The probability of a hypothesis given the data, represented by $P(H | D)$, is also known as the posterior probability. The probability of the hypothesis, represented by $P(H)$, is also known as the prior. The probability of the data given the hypothesis, represented by $P(D | H)$, is also known as the likelihood. This is all normalized by the probability of the data ($P(D)$). The probability of the data is broken down into the sum of $P(H)$ multiplied by $P(D | H)$ and $P(D | NH)$ multiplied by $P(NH)$; $P(D | NH)$ represents the likelihood of the data given the opposite of the hypothesis, and $P(NH)$ represents the probability of the opposite of the hypothesis occurring.

FIGURE 1: *Bayes’ Theorem*

$$P(H | D) = \frac{P(D | H)P(H)}{P(D)}$$

$$P(H | D) = \frac{P(D | H)P(H)}{P(D | H)P(H) + (D | NH) P(NH)}$$

Bayes’ Theorem has proved helpful in determining false alarm rates in many different circumstances; in my study, Bayes’ is used to conclude the probability of a cow suffering from Clinical Mastitis given the presence of an Electrical Conductivity alarm.

METHODOLOGY:

The AFImilk Dairy management system at the dairy takes data on EC from each cow as it is milked; each cow is milked three times daily, and the data from all three milkings is averaged into one daily value. EC is typically measured in millisiemens (mS), and then recalculated into reference units by the dairy management software; I used the data in terms of reference units for this study. This program also records the treatment history the cows in the herd—the days they were treated for CM and which quarter of the udder was affected. This is the raw data that I obtained from the dairy. I selected 89 cows from the herd based on the following parameters: 1) the cow had a

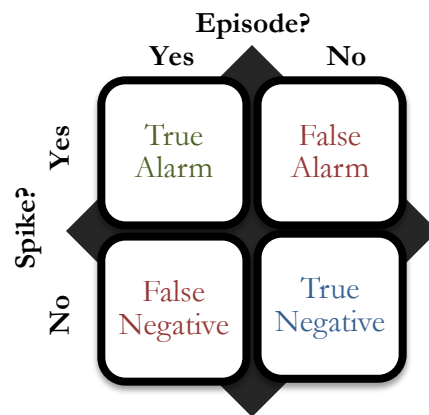
recorded and treated episode of CM in its lactation; and 2) the cow did not have an episode of CM within the first 20 days of milking. The purpose for the first parameter is that it allowed me to determine how well EC predicted actual cases of CM; the purposes for the second parameter are twofold. The biological reason was that, for the first week or so of each lactation, many cows experience unstable SCC and EC values; these values level-out very quickly, and so we decided to avoid the complication of predicting CM with EC values that were guaranteed to be unstable. The statistical reason was to avoid prematurely disrupting the ten-day rolling average I created for each cow. I also collected data on mastitis status from the entire herd from days over a full calendar year (March 2011-March 2012) in order to complete my analysis with Bayes' Theorem (Figure 3). With this data, I simply determined the herd size and the number of cows afflicted with CM for each day, for a total of 155 days. I then calculated the percentage of the herd that had mastitis and averaged these values to determine the probability of any given cow in the herd having mastitis.

With the help of Dr. Jerome Thayer at the Center for Statistical Services on the Andrews University Campus, I used S.P.S.S. to create formulas which would analyze the raw data by isolating it into the categories listed in Figure 2. First, we ordered the data by the cows' ID tag numbers, and then we set the program to only use the first 305 Days in Milk (DIM) for each cow. The traditional lactation length in cows is 305 days, so for the sake of making the data on each cow relatively uniform, we limited the extent of the study to the first 305 DIM of each cow. We also had to remove the first two DIM from each cow from the data set. For some cows, there was missing or incomplete information gathered by the milking machine on the first two DIM, so for the sake of uniformity, we limited the data set to 3-305 DIM.

Then, in order to establish a physiological baseline for each cow, we created a ten-day rolling average of each cow's EC. Ensuring that none of the cows in the study had a recorded case of CM within the first 20 DIM enabled us to create rolling averages without fear of accidentally inflating

each cow's EC baseline. This allowed us to perform the following step with confidence: we tested every EC data point (after the first 10) against the previous 10 days' rolling average to see if it was 20% or greater than the average; if so, then it was marked as a "spike." As mentioned earlier, a study performed by Lukas concluded that this percentage's ability to predict cases of CM varies, but can be effective when set anywhere between 2-30% (Lukas, 2009). I chose the use of 20% because it was the recommended setting for the EC software currently being used by the Andrews University Dairy. Next, I flagged the specific day(s) every cow was treated for CM as recorded by the dairy herd manager in AFImilk.

FIGURE 2: *Categories of Data for Electrical Conductivity Spikes and Clinical Mastitis Episodes*



We then set up the program to isolate the data into the categories from Figure 2. A True Alarm is described as any instance where a spike is followed, within ten days, by an episode of CM. A False Alarm is any instance where a spike is not followed by an episode of CM within ten days. A False negative is described as any instance of an episode of CM without a spike within the ten days preceding it—it is an "unpredicted episode". True Negatives are any day that the cow does not have a spike and does not have CM. I then used the percentages gleaned from the False Alarm and True Alarm categories to analyze the data with Bayes' Theorem as shown in Figure 3.

FIGURE 3: Bayes' Theorem Applied to Mastitis and Spikes

$$P(M|S) = \frac{P(S|M)P(M)}{P(S|M)P(M) + P(S|NM)P(NM)}$$

For my study, the definition of variables in the equation is as follows: P(M|S) is the probability of a cow having CM given that she has a spike. P(S|M) is the probability of a cow having a spike given that she has CM, which is the percentage of True Alarms, or “Correct Predicting Spikes” found in the data. P(M) is the probability of a cow having CM, which I determined by averaging the daily percentage of cows in the herd with CM for a full calendar year. P(S|NM) is the probability of a cow having a spike given that she does not have CM, which is the percentage of False Alarms I determined in my analysis. Finally, P(NM) is the probability of a cow not having mastitis; this I calculated by subtracting P(M) from 1.

DATA & RESULTS:

When processing the data, we discovered that our results would yield two different percentages of True Alarms—one depicting the number of correctly predicted episodes of CM and one depicting the number of spikes associated with the correct prediction of an episode of CM. Figure 4 below displays the values determined for each of these categories, along with the total number of episodes and spikes and the number of unpredicted episodes (False Negatives) and False Alarms. Figures 5-7 are example graphs which depict particular instances of each event: False Alarm, True Alarm, and False Negative.

FIGURE 4: Raw Values for Prediction Status of Episodes and Spikes

Episodes (CM)	True Alarm	False Negative	Total
	57	52	109
Spikes (EC)	True Alarm	False Alarm	Total
	77	183	260

FIGURE 5: Example Electrical Conductivity Graph for Instance of True Alarm

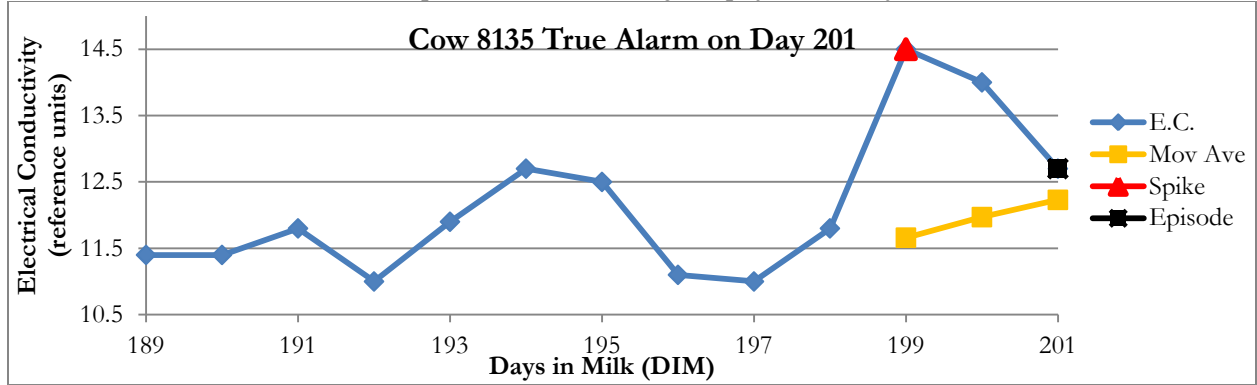


FIGURE 6: Example Electrical Conductivity Graph for Instance of False Alarm

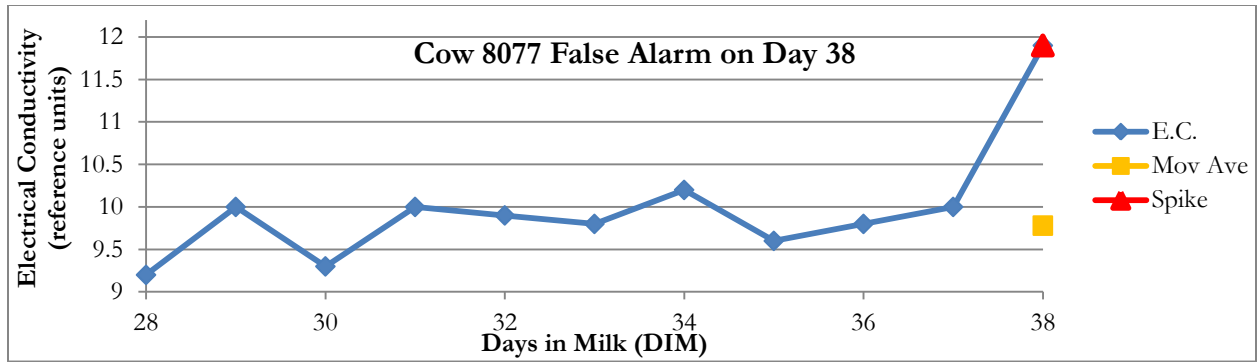


FIGURE 7: Example Electrical Conductivity Graph for Instance of False Negative

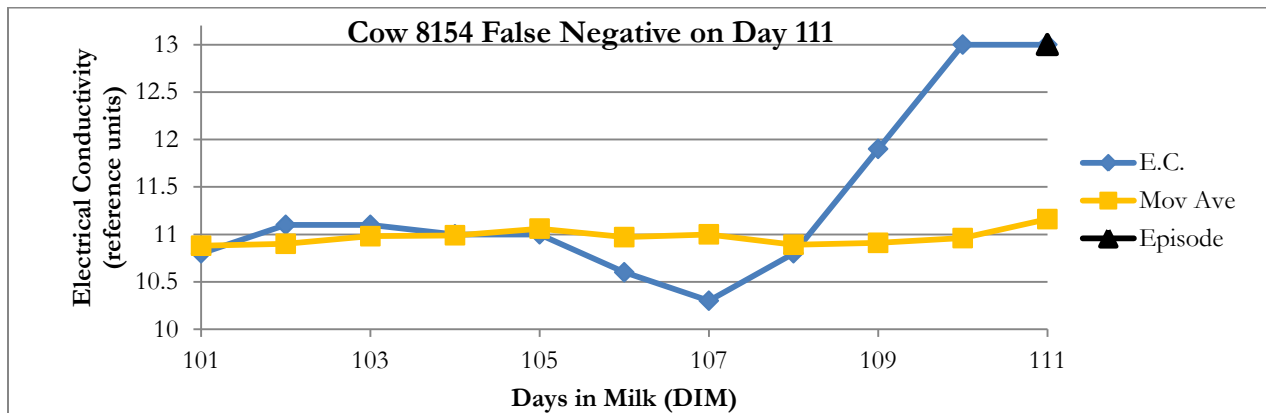


FIGURE 8: Percentages for Prediction Status of Episodes and Spikes

Episodes (CM)	Correct Prediction	Unpredicted
	52.294%	47.706%
Spikes (EC)	Correct Prediction	False Prediction
	29.615%	70.385%

As mentioned in the Methodology section, I determined the probability of a cow having mastitis by averaging the daily percentage of cows afflicted with CM over the course of 155 days. The calculation is as follows: $0.389713/155 = 0.002514$. Therefore, $P(M) = 0.2514\%$. The values belonging to the rest of the variables from my utilization of Bayes' Theorem are: $P(S|M) = 29.615\%$; $P(NM) = 99.7486\%$; and $P(S|NM) = 70.385\%$. The fully worked equation can be seen in Figure 9 below.

FIGURE 9: Bayes' Theorem on The Probability of a Cow Having Mastitis Given The Presence of a Spike

$$P(M|S) = \frac{P(S|M)P(M)}{P(S|M)P(M) + P(S|NM)P(NM)}$$

$$P(M|S) = \frac{(0.29615)(0.002514)}{(0.29615)(0.002514) + (0.70385)(0.997486)}$$

$$P(M|S) = 0.001059 = 0.1059\%$$

This essentially indicates that, for all of the cows in the dairy (not just the healthy cows or the cows in the hospital) if an alarm goes off, the cow has a 0.1059% chance of coming down with CM.

DISCUSSION:

From a practical standpoint, ten days between a spike and an episode of CM is an unrealistically long time for a producer to monitor a cow for mastitis; however, according to one of the sources I read, EC can increase due to Subclinical mastitis between three to forty-nine days in

advance (Lukas et al, 2009). This study also concluded that, “significant changes in milk yield and electrical conductivity can be observed as early as 10 days before diagnosis of an adverse health event” (Lukas et al, 2009). In hindsight, a more realistic evaluation of EC’s practicality in predicting CM would have used two to four days between a spike and an episode, as used by Milner et al in their 1996 study.

The use of 20% as the value by which a spike is determined is somewhat ambiguous—it is simple enough to change the percentage and end up with widely different results. However, I feel that the tolerance of 20% was realistic and practical for this study—when lowered to 15%, the percentage of correctly predicted cases rose to almost 60%, but the percentage of false alarms also jumped to approximately 75%. From a production standpoint, if increasing the tolerance means lowering the false alarm rate while also lowering the number of correctly predicted cases, and decreasing the tolerance means increasing the number of correctly predicted cases while also increasing the false alarm rate, then EC is not a practical method of determining mastitis status. There is no tolerance which will magically make EC a fantastic predictor of CM without having an exceptionally large number of false alarms. As mentioned by Steeneveld et al, “The sensitivity and specificity of these models...remain too low to substantially reduce the number of false positive alerts and at the same time retain a sufficient detection of true cases”(2010). The option of increasing the specificity and sensitivity by increasing the amount of requirements needed in order to create an alarm was not available as I was solely using previous records from the A. U. Dairy and the data that was available to me was limited.

This study is relatively simplistic when compared with the procedures utilized by Norberg (2003) and Steeneveld (2010) which include such factors as SCC, MY, dystocia status, quarter affected, external temperature, barometric pressure, and individual udder visual evaluation. Despite the fact that this study lacked the excess of variables present in other studies, I think that this study

accurately mimics the information that is present to workers in the milking parlor, and therefore I think that it is a more realistic evaluation of the practicality of EC. There is no doubt that there is a correlation between EC and mastitis (Zecconi, 2004), however, on a day-to-day basis for practical herd management, the A.U. Dairy would benefit from using visual evaluation of the udder combined with SCC and California Mastitis Tests as necessary rather than depend on EC. EC is promising, but until the issues of sensitivity and specificity are worked out, careful visual inspection of the udder and milk will be the best mechanism for indicating CM.

CONCLUSION:

According to the Bayes' Theorem calculation, the probability of a cow being infected with Clinical Mastitis given that an EC alarm was raised is only 0.1059%. Due to this exceedingly low probability, I would seriously recommend that the management at the dairy turn off or disregard any alarms pertaining to Electrical Conductivity; Electrical Conductivity is not a practical indicator of Clinical Mastitis in the milking parlor at this time.

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