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The value of pathogen information in treating clinical mastitis

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The objective of this study was to determine the economic value of obtaining timely and more accurate clinical mastitis (CM) test results for optimal treatment of cows. Typically CM is first identified when the farmer observes recognisable outward signs. Further information of whether the pathogen causing CM is Gram-positive, Gram-negative or other (including no growth) can be determined by using on-farm culture methods. The most detailed level of information for mastitis diagnostics is obtainable by sending milk samples for culture to an external laboratory. Knowing the exact pathogen permits the treatment method to be specifically targeted to the causation pathogen, resulting in less discarded milk. The disadvantages are the additional waiting time to receive test results, which delays treating cows, and the cost of the culture test. Net returns per year (NR) for various levels of information were estimated using a dynamic programming model. The Value of Information (VOI) was then calculated as the difference in NR using a specific level of information as compared to more detailed information on the CM causative agent. The highest VOI was observed where the farmer assumed the pathogen causing CM was the one with the highest incidence in the herd and no pathogen specific CM information was obtained. The VOI of pathogen specific information, compared with non-optimal treatment of *Staphylococcus aureus* where recurrence and spread occurred due to lack of treatment efficacy, was $20.43 when the same incorrect treatment was applied to recurrent cases, and $30.52 when recurrent cases were assumed to be the next highest incidence pathogen and treated accordingly. This indicates that negative consequences associated with choosing the wrong CM treatment can make additional information cost-effective if pathogen identification is assessed at the generic information level and if the pathogen can spread to other cows if not treated appropriately.

Keywords: Value of information, mastitis, dairy.

Value of information (VOI) studies using techniques from decision science have been conducted across many disciplines, from neuroscience to business management (Repo, 1989; Gavirneni et al. 1999; Behrens et al. 2007). The technique has also been used to examine how people make decisions, extending our understanding of the learning process (Behrens et al. 2007). These studies provide valuations under various amounts of information. Within the field of dairy science, topics addressed have included the economic value of days open for Holstein cows (Holmann et al. 1984), value of pregnancy in dairy cattle (De Vries, 2006), value of various clinical mastitis (CM) treatment rules and decisions (Barkema et al. 2006;

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Pinzon-Sanchez and Ruegg, 2011; Pinzon-Sanchez et al. 2011) and value of culling information in the presence and absence of a milk quota (Kristensen and Thysen, 1991).

In this paper we estimate the value of information in knowing the causation agent of mastitis cases and assess whether obtaining that information is economically justified using a dynamic programming model. Knowing the CM causative agent is important as the production losses associated with CM may depend on the pathogen involved i.e., reduced milk production (Hertl et al. 2014b) and lowered conception (Santos et al. 2004; Hertl et al. 2014a); further, the prognosis (Guterbock et al. 1993; Sol et al. 2000; Schukken et al. 2011), cost of diagnostic testing and treatment are typically directed by the specific agent causing CM.

Typically the farmer observes outward signs in cows indicating they have CM. The signs may include an enlarged and warm udder, a pink/red tinge to the mammary skin, and clots or chunks in the milk. On many farms the choice of drugs for treatment is based on protocols recommended by the herd veterinarian based on clinical severity of the disease and some level of identification of the pathogen involved. If no further testing is performed to identify the exact pathogen causing CM, the cow may be treated with intramammary antibiotics, systemic antibiotics and anti-inflammatory drugs. In many US conventional dairy farms, the choice of supplementary drugs will be dependent on the farmer's and/or herd veterinarian's pattern recognition related to severity of disease, because the specific pathogen causing CM is not known. The drug selected will typically be a broad spectrum antibiotic. While this approach is quick, a disadvantage of treating cows without knowing the exact pathogen involved is that the treatment chosen may not be specific to the causative pathogen, resulting in discarded milk due to treatment, costs incurred due to incorrect treatment, delayed recovery of the cow, and the possibility of increased antimicrobial resistance due to overuse of an antibiotic. If the treatment is unsuccessful, possibly because of an incorrect guess of the causative agent, the next step might be changing to an alternative treatment, or discontinuing treatment. Other actions include 'killing' the quarter, early dry off or culling the cow. Some farmers may choose not to treat at all and discard milk until spontaneous cure occurs (Kessels et al. 2016).

A more specific treatment approach is to first identify whether the pathogen causing CM is Gram-positive, Gram-negative or 'other' (neither Gram-positive nor Gram-negative). These tests can be conducted on the farm. The advantage is that treatment will be specific to a Gram group of pathogen, even though the exact pathogen is unknown. This reduces the risk of error by having some information relating to the pathogen and might decrease the overall use of antimicrobials, quicken cow recovery and reduce total milk withholding time (Lago et al. 2011a). This approach, however, may still lead to potential misuse of antibiotics due to inappropriate treatment because antibiotics may have various efficacies within a Gram group.

The most specific level of information currently available for mastitis diagnostics is obtainable by sending milk samples to an external laboratory for culture, which identifies the pathogen causing CM, often within 24 h. Knowing the exact pathogen involved permits treatment to be specifically targeted, reducing the risk of selecting an incorrect antibiotic and minimising discarded milk. This, however, requires waiting for results, delaying cow treatment and incurs the cost of sending samples off for culture. One simulation study considered 4 different CM causes and found that waiting for case-specific treatment from the laboratory was not financially beneficial to the farmer (Steeneveld et al. 2011). Most often milk samples were sent to a laboratory for culture (which is what is modelled in the current paper); however, there is now a move toward farms performing pathogen specific culturing on-farm.

The objective of this study was to quantify and compare the VOI of the different methods of deciding on treatment for CM cows based on the identification of CM at different levels of information: (1) outward signs of CM (Generic CM), (2) Gram testing only and (3) pathogen specific culture results.

Materials and methods

Pathogen information available to dairy farmers in treating clinical mastitis

A CM episode can be identified at either the (1) generic level, (2) the Gram specific level (Gram-positive, Gram-negative or other) or (3) the pathogen specific level. At the generic level, there is no knowledge of the exact pathogen causing CM. At the Gram specific level, Gram-positive pathogens considered in this study were *Streptococcus* spp., *Staphylococcus aureus*, and *Staphylococcus* spp.; Gram-negative pathogens were *Escherichia coli* and *Klebsiella* spp.; and other pathogens were the remainder (i.e., other treated, other not treated and negative culture categories). At the pathogen specific level, the CM pathogens were separated into 8 categories: (1) *Staphylococcus* spp., (2) *Staph. aureus*, (3) *Streptococcus* spp., (4) *E. coli*, (5) *Klebsiella* spp., (6) Other treated (these included *Enterobacter, Enterococcus, Citrobacter, Serratia, Pasteurella, Corynebacterium bovis, Corynebacterium* species, *Pseudomonas, Proteus, Gram+ bacillus, Gram- bacillus*, fungus, *Strep.* group 'C', mould and *Nocardia*), (7) Other not treated (these included *Trueperella pyogenes, Mycoplasma, Prototheca* and yeast), and (8) Negative culture, contamination (more than two bacterial species on the culture plate) and no significant organisms. No significant organisms is defined as a culture plate containing more than two different species with no bacterial growth of either *Staph. aureus* or *Strep. agalactiae*; these cases did, however, exhibit clinical signs of mastitis.

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Table 1. Treatment costs (USD) and discarded milk days by pathogens causing clinical mastitis (CM)† by 3 information levels.

Information and treatment for value of information				
Level 1	Level 2	Level 3	Treatment cost	Discarded milk days‡
Generic CM	Gram-positive CM	*Staphylococcus* spp.	12·50	2·5
		Staphylococcus aureus	46·00	9·5
		Streptococcus spp.	28·55	5·0
	Gram-negative CM	*Escherichia coli*	49·20	8·0
		Klebsiella spp.	49·20	8·0
	Other CM	Other treated§	36·85	6·0
		Other not treated¶	13·35	0·15
		Negative culture††	13·35	0·15

†References are as follows: (Barlow et al. 2013; Lago et al., 2011a, b; Schukken et al. 2011; and Schukken et al. 2013). Further, treatment cost calculations were determined by the cost of drugs for a specific treatment protocol times the number of recommended treatments (on manufacturer's label) or the protocol defined by the farm plus the value of the discarded milk at the current milk price. The cost of drugs was identified by researching three on-line drug sales companies (where prices would be similar for most products). Websites included Animart <http://www.animart.com/store/mastitis-tubes-lactatingtreatments/>
Animal Livestock Supply Inc. <http://www.americanlivestock.com/cattle.html> and Dairy Health USA http://www.pbsanimalhealth.com/category/Dairy/Mastitis-Treatments/D80200.html#cat_top (all accessed 14 March 2013)
‡Applicable as listed when cows are treated with antibiotics/anti-inflammatory treatment
§Included *Enterobacter, Enterococcus, Citrobacter, Serratia, Pasteurella, Corynebacterium bovis, Corynebacterium* species, *Pseudomonas, Proteus, Gram+ bacillus, Gram- bacillus*, fungus, *Strep.* group 'C', mould and *Nocardia*
¶Included *Trueperella pyogenes, Mycoplasma, Prototheca* and yeast
††Negative culture, contamination and no significant organisms

Economic model

The economic model used to assess the value of information has been used previously to study the cost of pathogen specific CM in dairy cows (Cha et al. 2014). An addition to the model made for these analyses was the inclusion of waiting time for pathogen specific CM culture results and Gram CM results. We assumed that the waiting time did not affect cow performance within the month CM was identified, but resulted in the additional cost of discarded milk. Data were collected from 2003/2004 until 2011 from 5 large dairy herds in New York State.

Further description of the data and treatment costs can be found in Cha et al. (2014) and Cha et al. (2016).

Simulating the different levels of pathogen information available to dairy farmers

The economic model used to evaluate the VOI comprises 9 CM states (8 pathogen specific CM states and one healthy state) and the associated production losses and costs due to each pathogen causing CM. The amount of information the farmer has available to make an informed decision is dependent on how much information he or she is willing to pay for; more information generally takes a longer time to obtain at a greater cost. If the farmer does not know the exact pathogen causing CM, the treatment decision cannot depend on the pathogen causing CM, otherwise, we would be assuming the farmer has more information than he/she actually has knowledge. In order to correctly model the information available, we took a non-specific CM approach whenever treatment decisions were not based on pathogen specific CM identification. This meant that all cases of CM were assumed to be caused by only one pathogen in the generic scenario, or caused by one pathogen within each Gram group in the Gram scenario. Therefore, only one optimal decision would be generated by the model for any one state (the generic scenario), and in any one Gram group and state (the Gram scenario). The different levels of information are described below.

Information Level 1: Generic CM. At this information level, the assumption was that no information was available concerning the causation agent. The cost of identifying the CM was \$0, as no test was conducted and there is no time expended waiting for results since the action taken immediately was based on what is observed. Because only one decision can be made i.e., more than one decision would imply pathogen specific knowledge, one pathogen was selected which was assumed to be the pathogen causing CM.

Information Level 2: Gram-positive, Gram-negative, other CM. The cost of identifying the Gram type of the pathogen is \$5 and the time toward identifying the Gram result is 0·5 days. In parallel to information scenario level 1, only one decision can be made within each Gram group (i.e., more than one decision would imply pathogen specific knowledge), so it was necessary to select one pathogen which was the basis of our assumption of which pathogen was causing CM in each Gram group.

Information Level 3: Pathogen specific CM. The cost to treat each type of mastitis causation pathogen and milk discarded as a result of treatment is illustrated in Table 1. The incidence of each type of mastitis is shown in Table 2. The incidence values are based on risk analyses performed on 5 large, high milk producing New York State dairy herds

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Table 2. Distribution of different pathogens causing clinical mastitis (CM) following an optimal replacement policy.

Item	CM cases†
Basic scenario (incl. all CM)	35·6
Staphylococcus spp.	1·6
Staphylococcus aureus	1·8
Streptococcus spp.	6·9
Escherichia coli	8·1
Klebsiella spp.	2·2
Other treated cases‡	1·1
Other not treated cases§	1·2
Negative culture cases¶	12·7

†Incidence of CM (cases per 100-cow years)
‡Included *Enterobacter, Enterococcus, Citrobacter, Serratia, Pasteurella, Corynebacterium bovis, Corynebacterium* species, *Pseudomonas, Proteus, Gram+ bacillus, Gram- bacillus*, fungus, *Strep.* group 'C', mould and *Nocardia*
§Included *Trueperella pyogenes, Mycoplasma, Prototheca* and yeast
¶Negative culture, contamination and no significant organisms

(Cha et al. 2016). The treatment may include antibiotics, anti-inflammatories and fluid administration, and the discarded milk was a result of either or both treatments depending on the pathogen involved. There is a $10 culture cost in identifying the specific causation pathogen and the time waiting for culture results is 1 day.

In the case of level 1 and level 2 information, the optimal policy was therefore adjusted to allow for selection of one pathogen (for level 2, one pathogen within each Gram group) in order to fulfil our assumptions which were based on how farmers could make CM treatment decisions. It was anticipated that the overall VOI would differ depending on the pathogens selected to represent each Gram group (level 2) or the pathogen selected to represent all CM (level 1); therefore, several different assumptions were used to show a range of possible effects (see section below on *Evaluating the value of decisions made based on different assumptions* and Table 3).

Evaluating the value of information

The objective function maximised the net present value of the cow under the various scenarios using a constructed dynamic programming model for optimal cow decisions. Net returns were then compared between the various information levels. As milk prices and replacement costs are variable and may play a role in the optimality of CM treatment decisions, scenarios were considered in which milk prices and cow replacement cost varied by 20%. A discount rate of 8% was used in all analyses.

Evaluating the value of decisions made based on different assumptions

Deciding how to treat clinically mastitic cows is dependent on the clinical signs observed, what pathogen is considered to be most likely causing the CM, and the cost of treatment. Other individual cow characteristics which influence the optimal decision include genetic milk yield potential, lactation, stage of lactation, temporary milk yield (day-to-day milk yield) and pregnancy status. The scenarios examined were (1) incidence based decisions and (2) treatment cost based decisions. These scenarios reflect assumptions farmers may make in treating their cows e.g., treating for the highest incidence pathogen, or selecting a more expensive treatment believing this provides greater efficacy. For example, while one farm may tend to treat Gram-positive cases as *Staphylococcus* spp. (level 2, low treatment cost), other farms may tend to treat Gram-positive cases as *Staph. aureus* (level 2, high treatment cost). Therefore, for levels 1 and 2, treatment cost and associated discarded milk days were changed to reflect the pathogen chosen.

Evaluating the effect of incorrect treatment on outcomes

The generic and Gram CM models contain no penalty or change in production outcomes due to treatment with a different regimen than what would be recommended for the actual pathogen infecting the cow. Such a penalty has not been reliably measured in clinical trials and is therefore difficult to parameterise. Only two treatment comparison studies found significant numerical differences in outcome appropriate for implementation in our model to measure the effects of incorrect treatment. First, a non-inferiority study of cephalosporins found that the decrease in the probability of curing Gram-negative CM treated with cephapirin compared with ceftiofur was 0·32 (Schukken et al. 2013). Therefore, a scenario was created in the current study in which the probability of recurring Gram-negative CM cases requiring further treatment was assumed to be 0·32 when the least expensive treatment (cephapirin) was applied to all cases in Information Level 1. Second, a study of *Staph. aureus* transmission dynamics found that treating *Staph. aureus* CM with pirlimycin, as opposed to supportive therapy, increased the probability of cure by 0·78 and decreased the overall incidence by $8{\cdot}5e^{-5}$/quarter-day, which translates to 0·01/cow-month (Barlow et al. 2013). Therefore, a scenario was created in the current study in which the probability of recurring *Staph. aureus* CM cases requiring further treatment was assumed to be 0·78 and the overall probability of all *Staph. aureus* CM was increased additively by 0·01 when only generic CM information was available and supportive therapy was used as the only treatment (the high incidence assumption).

In both of these cases, the probability of recurrent infection was incorporated into the cost of treatment and the number of discarded milk days using the formula: $new\ impact = impact + P(recurrence) \times (extra\ \ impact)$, where *impact* refers to either the cost or the days milk was discarded, $P(recurrence)$ is the probability of recurrent infection requiring further treatment, and the *extra impact* was determined by the method used to choose a second treatment. Two methods were considered for choosing a

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Table 3. Pathogen(s) chosen to represent clinical mastitis in all levels, based on various assumptions of cost and incidence.

			Assumptions			
			Cost-based decisions		Incidence-based decisions	
Information level	Waiting time for results (days)	Culture cost	Most expensive	Least expensive	Highest incidence	Lowest incidence
Generic level	0	$0	*Escherichia coli*	*Staphylococcus* spp.	Negative culture†	Other treated‡
Gram level						
Gram-positive	0·5	$5	*Staphylococcus aureus*	*Staphylococcus* spp.	*Streptococcus* spp.	*Staphylococcus* spp.
Gram-negative			*E. coli*	*Klebsiella* spp.	*E. coli*	*Klebsiella* spp.
Other			Other treated	Negative culture	Negative culture	Other treated
Pathogen specific level	1	$10	NA	NA	NA	NA

†Negative culture, contamination and no significant organisms.
‡Included *Enterobacter, Enterococcus, Citrobacter, Serratia, Pasteurella, Corynebacterium bovis, Corynebacterium* species, *Pseudomonas, Proteus, Gram+ bacillus, Gram- bacillus*, fungus, *Strep.* group 'C', mould and *Nocardia*.

Table 4. Adjusted input values and assumptions to explore the impact of incorrect treatment of *Staph. aureus* and Gram-negative clinical mastitis.

		Extend current treatment		New treatment, same assumption	
Pathogen	Assumption (generic level)	Treatment cost ($)	Discarded milk days	Treatment cost ($)	Discarded milk days
Staph. aureus	Highest incidence	23·76	0·27	51·73	6·39
Gram-negative (*E. coli, Klebsiella*)	Least expensive	16·50	3·30	16·77	2·55

second treatment: extending the current treatment and choosing the next treatment under the treatment assumption (i.e., treat the next highest incidence pathogen). In this economic framework, a decision can be made at every time step in the dynamic programme which is 1 month. For each method outlined above, an adjusted treatment cost was calculated. This adjusted treatment cost combines two treatments. We assumed that the two treatments for each method could be performed in 1 month. The adjusted treatment costs and number of discarded milk days for each scenario and treatment method are outlined in Table 4.

Results and discussion

To the authors' knowledge no study thus far has compared the value of different levels of information in deciding how to treat cows with CM at the individual cow level. Following modifications to our pathogen specific CM model, we evaluated the value of treatment decisions based on employing different methods of identifying CM cows on farm. While other studies have examined the value of different treatment decisions (Pinzon-Sanchez and Ruegg, 2011; Pinzon-Sanchez et al. 2011), we have not found any studies that have examined the value of information attained which influences the treatment decision adopted.

The results of the VOI analysis are shown in Tables 5 and 6. For each scenario in Table 5 the ranges of NRs and VOI (the difference in net returns per year with more information) are shown as the upper and lower limit of each scenario. In the case of cost-based decisions, the NR for each scenario is calculated based on assuming the treatment taken is the most or least expensive and in the case of the incidence-based decisions, the NR for each scenario is calculated based on assuming the pathogen in question is the one with the greatest or smallest incidence in the generic or Gram group.

Because our data were generated by farmers who were given our pathogen specific test results, and thus made decisions with that level of information, partial treatment effect has already been incorporated. Assuming that the treatment these farmers selected was correct for the majority of cases, this means that if we could include the detrimental production effects (i.e., milk loss, reduced conception, risk of mortality) of incorrectly treating CM, the NR we observed would not be as great as for the generic and Gram CM levels of information. In this respect, our results are conservative and have a bias toward favoring the generic and Gram CM levels of information. If the parameter estimates for incorrect treatment were available for inclusion, we would expect a greater gap between the pathogen specific and generic/Gram

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Table 5. Results from an economic model for clinical mastitis treatment, by different levels of information for each assumption.

		Assumptions							
		Cost-based decisions				Incidence-based decisions			
		Most expensive		Least expensive		Highest incidence		Lowest incidence	
Scenario	Information level†	NR‡	VOI§	NR	VOI	NR	VOI	NR	VOI
Base	Pathogen specific	507	12	507	−6	507	−3	507	3
	Gram	495	1	513	−6	509	−16	503	1
	Generic	493	NA	519	NA	526	NA	502	NA
Milk price increases 20%	Pathogen specific	1245	14	1245	−7	1245	−3	1245	4
	Gram	1231	1	1252	−5	1248	−19	1241	2
	Generic	1230	NA	1258	NA	1266	NA	1239	NA
Milk price decreases 20%	Pathogen specific	−224	10	−224	−6	−224	−2	−224	2
	Gram	−234	1	−218	−6	−222	−14	−227	1
	Generic	−235	NA	−213	NA	−208	NA	−227	NA
Replacement cost increases 20%	Pathogen specific	429	12	429	−7	429	−3	429	3
	Gram	417	1	436	−6	432	−17	426	1
	Generic	416	NA	442	NA	448	NA	425	NA
Replacement cost decreases 20%	Pathogen specific	590	12	590	−6	590	−2	590	3
	Gram	579	1	596	−5	593	−16	587	1
	Generic	578	NA	602	NA	608	NA	586	NA

†Level of information known
‡Net returns per year
§VOI (value of information) is calculated as the difference between the NR at a particular level and the NR at the next lowest level. Values rounded to nearest US $

Table 6. Results from an economic model for clinical mastitis treatment, allowing for differential effects due to targeted vs. generalised treatment.

	Extend treatment‡		New treatment§	
Information level†	NR¶	VOI††	NR	VOI
Pathogen specific	507	NA	507	NA
Gram-negative‡‡	516	9	516	10
Staph. aureus§§	486	−20	476	−31

‡Extending the current treatment
§Choosing the next treatment under the treatment assumption of treating the next highest incidence pathogen
†Level of information known about the causative pathogen
¶Net returns per year
††VOI (value of information) is calculated as the difference between the NR at the level with treatment effects and the NR at the next pathogen specific level. For example, VOI (Gram-negative) = NR (Gram-negative)−NR (pathogen specific). Values are rounded to nearest US $
‡‡It was assumed that Gram-negative pathogens would have an increased recurrence rate after treatment at the generic level, such that 32% of cases would require further treatment (Schukken et al. 2013)
§§It was assumed that *Staph. aureus* would have an increased recurrence rate after treatment, such that 78% of cases would require further treatment, and that the overall incidence of *Staph. aureus* would be increased at the generic level (Barlow et al. 2013)

specific levels of information, with results favoring the pathogen specific level of information.

The primary finding, that VOI is greatest when identifying CM at the generic level and treating based on the highest incidence pathogen, might be contradicted if incorrect treatment of the pathogen produces less efficacious results. While there are limited data supporting any decrease in efficacy for incorrect treatment, this study found that simply increasing the days of incorrect treatment or adding the possibility of 2 treatments being applied (representing common responses to a treatment failure) resulted in greater NR in both instances, compared with the pathogen specific CM level of information in the case of incorrectly treating Gram-negative pathogens. However, *Staph. aureus* treatment failure, which included an increase in incidence due to its contagious nature, generated a smaller NR than the pathogen specific CM level of information. The VOI of pathogen specific information, compared with non-optimal treatment of *Staph. aureus* where recurrence and spread occurred due to lack of treatment efficacy, was

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$20.43 when the same incorrect treatment was applied to recurrent cases, and $30.52 when recurrent cases were assumed to be the next highest incidence pathogen and treated accordingly.

This indicates that negative consequences associated with choosing the wrong CM treatment can make more information cost-effective, but only if the response to treatment failure is assessed at the generic information level and if the pathogen can spread to other cows if not treated appropriately. The treatment cost for the *Staph. aureus* treatment failure scenarios is greater than for the *E. coli* treatment failure scenarios, and this is reflected in the much lower NR for the *Staph. aureus* treatment failure scenarios. The probability of cure has been found repeatedly to be associated with the duration of treatment, but Barkema et al. (2006) found that longer treatment was not necessarily financially justified due to the loss of milk income during withdrawal. However, in a comparison of on-farm culture-determined Gram-level treatment with generic treatment (Information Levels 1 and 2), Lago et al. (2011b) found that culture did not improve recurrence, removal from the herd, milk production, or SCC, and there was no difference in bacteriological cure or treatment failure (Lago et al. 2011a). Due to these contradictory findings and the lack of concrete evidence regarding the efficacy of CM treatment, further study of the effects of different treatments on a variety of pathogens could be justified in order to determine if the cost of CM culture is truly not warranted under reasonable treatment assumptions.

Different analytical approaches have been previously used to estimate the economic impact of different treatments. In the study by Pinzon-Sanchez et al. (2011), a decision tree was developed to evaluate the economic impact of different durations of intramammary treatment for a first case of mild or moderate CM. The decisions included on-farm culture and different treatment strategies and distributions of Gram-positive, Gram-negative and no growth, bacteriological cure and recurrence. That study also included economic and production losses due to mastitis, and found that generally, the optimal economic strategy was to treat Gram-positive pathogens for 2 days and avoid using antimicrobials for Gram-negative pathogens or where no pathogen was found. Those results cannot be compared directly to our results because we included cow level characteristics, i.e., permanent milk yield potential, lactation, stage of lactation, pregnancy status and temporary milk yield, which factor into the optimal decision recommended by the model. Information about the aetiology of CM, history of clinical and subclinical mastitis, and parity were found to be useful when making strategic treatment decisions (Pinzon-Sanchez and Ruegg, 2011). From a study by Barkema et al. (2006), the most important treatment factor affecting cure was treatment duration.

Our selection of scenarios was not exhaustive, but we believe that we captured the behaviour of most farmers. We did not model the behaviour of farmers who do not use a routine procedure for CM treatment, as random behaviour cannot be captured in our modelling system. Differentiation of treatment at the generic level would be possible by inclusion of symptomatic information on CM. This would require incorporation of symptoms as part of the state space. Alternatively, by specifying the likelihood of certain symptoms given the true pathogen specific state, it may be possible to use random strategies to evaluate the VOI. Alternative treatment scenarios examined in future may include absence of treatment and discarding of milk until spontaneous cure occurs.

The primary finding is that if the farmer selects treatments for generic or Gram specific CM by selecting the least expensive treatment or treating the most likely pathogen, more information is not justified. This agrees with the findings of Steeneveld et al. (2011), who used a Monte Carlo simulation model to study the cost of CM treatment. Many of the input parameters they used were similar to those used in the model presented above. Their model considered 6 treatment regimens and explicitly modelled the probability of both bacteriologic and clinical cure and the cost of follow-up treatment and recurrent cases. The pathogens studied however, were limited to *Strep. uberis* and *Strep. dysgalactiae, Staph. aureus* and *E. coli*.

Our model did not consider the value of preventing or delaying the development of antimicrobial resistance. Lago et al. (2011b) found that on-farm culture (corresponding to Information Level 2 in this study) greatly decreased the amount of antibiotics used in treating CM. There are also external impacts on other farms and species, including humans. The public health risk associated with increased antimicrobial resistance in the microbiome is not quantifiable in our model, but under the precautionary principle, such a situation would call for use of Information Level 3 (pathogen-specific culture) regardless of cost differences. This model also did not explicitly consider animal welfare, outside of the assumption that cows with CM would be treated or culled.

Conclusion

If the farmer selects treatments for generic or Gram specific CM by choosing the least expensive treatment or treating the most likely pathogen, more information is not justified. On the other hand, if the farmer selects treatment for generic or Gram specific CM by choosing the most expensive treatment or treating the least likely pathogen, then more information is justified. Negative consequences associated with choosing the wrong CM treatment increases the VOI if the response to treatment failure is assessed at the generic information level and if the pathogen can spread to other cows if not treated appropriately. Depending on individual farms, the distribution of incidences may differ. Our results are particularly applicable to large, high milk producing dairy herds in NY State with low SCC and management practices with a focus on reducing SCC and improving milk quality.

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