GENETIC CONTROL OF HEALTH TREATMENT COSTS FOR HOLSTEINS IN 8 HIGH-PERFORMANCE HERDS

A THESIS SUMBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

MICHAEL ROBERT DONNELLY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

ADVISORS LESLIE B. HANSEN AND BRADLEY J. HEINS

JANUARY, 2017

ACKNOWLEDGEMENTS

The completion of my degree program would not have been possible without the support of family, friends, and colleagues. Thank you for being a source of guidance, encouragement, and motivation.

I must thank my primary advisor, Dr. Les Hansen, for his mentorship and guidance throughout this entire process. Your advising will undoubtedly have lasting impacts in my future career endeavors and in my life. In my coursework and research, you encouraged me to strive for the best. My research is something I am proud of and am confident can benefit the greater dairy industry. Your patience and support during my time here was greatly appreciated. Thank you for allowing me to study with you and providing me with so many opportunities.

I also graciously thank my co-advisor, Dr. Brad Heins. Learning SAS and other computing programs would not have been possible without your help. Thank you making time for my project and willingness to offer your expert advice no matter what you were doing. The input and support you have given to me shaped my thesis to the final version I am proud of.

I also extend a very sincere thank you to my graduate school mentor, Amy Loeschke. My research would not have been possible without your commitment to working with the herds and your expertise of handling large data. The time and effort you devoted to helping me succeed in graduate school and develop comprehensive manuscripts of my research was extremely generous, and I am forever thankful. I would also like to thank my officemate, Brittany Shonka-Martin, for support with my coursework and navigating ASReml. The friendship and support from both Amy and Brittany helped get me through the difficult days and I thoroughly enjoyed our time together in the genetics lab.

To all fellow graduate and professional students who have shared in this journey with me, you have made this time an enjoyable experience. A special thank you also goes out to Lindsey Borst, Brett Boyum, and Brenda Reiter: your advice and encouragement throughout my program have been invaluable.

I cannot forget to thank my family, especially my parents. The unconditional love and support you have offered me throughout my program has made this accomplishment possible. I'd also like to give a special thank you to my siblings. You have always been there to help me relax and charge forward with life. Thank you to my grandmother, Elayne, and my godmother, Anne, for being there to talk to. I greatly appreciate your encouragement throughout this process.

Finally, to my grandmother, the late Marcy Rotty. You encouraged me to pursue this degree and any other adventures life has brought my way. I am grateful for the love and support you provided and I wish you could have been here for the completion of this degree. It is to you I dedicate this thesis.

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INTRODUCTION

Historically, selection within the Holstein breed in the US has emphasized increased production alongside conformation traits such as shallower udders, increased body size, and greater dairy form (Rauw et al., 1998; Hansen, 2000; Haile-Mariam and Goddard, 2010). These traits are highly heritable and dairy producers have chosen to optimize production of their cows with the intent of maximizing profit. However, this selection success has been accompanied by a decline in cow health and welfare (Oltenacu and Broom, 2010; Becker et al., 2012), which can negatively impact the profitability of cows. As a result, selection for improved health is of increasing importance to dairy producers. However, health disorders are difficult to evaluate in the US because uniform recording systems for health data are not utilized, inhibiting the genetic evaluation of health traits (Zwald et al., 2004a; Parker Gaddis et al., 2014).

Health Data

A 2007 USDA study reported 93% of US dairy operations with 500 cows or more use some form of a computerized record keeping system for health data. Among these herds, 3 primary software programs are used. The programs are Dairy Comp 305 (Valley Agricultural Software, Tulare, CA), which is used by 35% of herds, followed by PCDART (Dairy Records Management Systems, Raleigh, NC) with 19%, and 15% of herds use DHI Plus (DHI Computing Services Inc., Provo, UT) (USDA, 2007; Wenz and Giebel, 2012).

Many large farms record health data, but health disorders are difficult to analyze because health data lacks consistency and is often incomplete (Parker Gaddis et al., 2014). For example, some software programs offer tremendous flexibility such that the same health disorder may be entered into the system in different ways. Entries into Dairy Comp 305 tend to be recorded in character acronyms up to 4 letters, whereas PCDART follows a character acronym format of up to 7 letters (Zwald et al., 2004a), and Wenz and Giebel (2012) reported 3 to 4 different acronyms were sometimes used within a single farm to record metritis. Zwald et al. (2004a) used data from cooperator herds of the Advantage Progeny Test Program from Alta Genetics (Watertown, WI) to assess the health of dairy cows. They found the 724 herds that recorded mastitis did so using 20 various abbreviations via PCDART.

High-quality health data can contribute to the improvement of management decisions and reduce mortality of cows among herds (Dechow and Goodling, 2008). Cows with a health disorder early in lactation are at an increased risk of a health disorder later in lactation (Parker Gaddis et al., 2012) and knowledge of previous health disorders allows dairy producers to identify cows that may require attention later in lactation. Furthermore, complete and uniform health data can be valuable for minimizing health treatment costs through better identification of health disorders for individual cows as well as for improved culling decisions to remove cows with extensive health disorders from the herd.

The lack of uniformity of recording for health data makes it difficult to summarize health disorders within and between dairy herds. Also, when recording health data, dairy producers may not consistently distinguish the difference between incidence and treatment of health disorders. Parker Gaddis et al. (2012) reported that incidence rates of health disorders in their study were lower than other literature estimates, which could suggest dairy producers are more likely to record only health treatments rather than to record every health diagnosis. Further review of the literature (Lyons et al., 1991; Kelton et al., 1998; Zwald et al., 2004a,b; Koeck et al., 2012; Parker Gaddis et al., 2012) suggests a need for a more comprehensive and uniform approach to recording of health data to enable the data to be used more effectively for day-to-day management decisions and for research.

Several European countries have required recording of all health treatments of dairy cows for over 30 years with health treatments systematically recorded by veterinarians on an individual animal basis (Ruane et al., 1997; Parker Gaddis et al., 2014), which permits the evaluation of health disorders within and between herds. Furthermore, Scandinavian countries have successfully included health data in their total merit index (TMI) (Philipsson and Lindhé, 2003; Abdel-Azim et al., 2005), and this permitted effective selection for fewer health disorders. Outside of Europe, several studies (Lyons et al., 1991; Zwald et al., 2004a,b; Koeck et al., 2012; Neuenschwander et al., 2012) found that utilization of health data for genetic evaluation of common health disorders is possible; however, improving the integrity and uniformity of health data is necessary for genetic evaluation.

Incidence Rates of Health Disorders

Several studies of health data recorded on-farm for incidence rates of common health disorders of dairy cows required extensive scrutiny and editing prior to analysis to ensure reliable and consistent reporting across dairy herds (Koeck et al., 2012). Each of the studies reviewed hereafter have calculated incidence rates of health disorders based on lactations of cows that had at least one incidence of a specific health disorder. Appuhamy et al. (2009) reported mastitis, reproduction disorders (metritis, retained placenta, and cystic ovaries), metabolic disorders (ketosis and displaced abomasum), and lameness incidence rates using health data from 398 commercial dairy herds processed by Dairy Records Management Systems (Raleigh, NC), and found first-parity incidence rates of 9.5%, 17.7%, 6.4%, and 13.3% for mastitis, reproduction disorders, metabolic disorders, and lameness, respectively. In later parities, greater incidence rates of 12.7%, 20.3%, 7.0%, and 17.7% for mastitis, reproduction disorders, metabolic disorders, and lameness were reported (Appuhamy et al, 2009).

First-parity health data of Canadian Holsteins provided by the Canadian Dairy Network from 2007 to 2011 were analyzed by Koeck et al. (2012). Incidence rates were reported for mastitis (12.6%), displaced abomasum (3.7%), ketosis (4.5%), retained placenta (4.6%), metritis (10.8%), cystic ovaries (8.2%), lameness (9.2%), and milk fever (0.20%). In another study, Zwald et al. (2004a) used health data from US dairy herds and reported similar incidence rates for displaced abomasum (3%), cystic ovaries (8%), and lameness (10%) to those reported by Koeck et al. (2012), but greater incidence rates for mastitis (20%), ketosis (10%), and metritis (21%) than the Canadian study (Koeck et al. 2012). Parker Gaddis et al. (2012), also analyzed health records from US dairy herds, but found lower incidence rates than Zwald et al. (2004a) for displaced abomasum (2.2%), cystic ovaries (3.5%), lameness (6.4%), mastitis (12.3%), ketosis (5.2%), and metritis (6.9%).

Appuhamy et al. (2007) analyzed treatment records of 991 Holstein lactations from 2 institutional herds. In that study, ketosis and milk fever were combined for evaluation of metabolic disorders. Across all parities, mastitis had the highest incidence rate of 30.5%, followed by lameness (26%), and then metabolic disorders (12.4%). Becker et al. (2012) analyzed treatment records of Holstein cows at the Northwest Research and Outreach Center (Crookston, MN) of the University of Minnesota from 1983 to 2005. Cows were grouped based on selection for large versus small body size and the incidence rates for health treatments of the large cows was 24.6%, 41.2%, and 23.6% for mastitis, locomotion, and reproduction, respectively. A possible reason for the greater incidence rates reported in studies using institutional herds versus commercial herds is because the health data is more likely to be thoroughly recorded in institutional herds, and institutional herds typically receive frequent support from veterinarians. Furthermore, institutional herds may not be as profit-driven as commercial herds and may be more likely to invest in treatment of a health disorder for a cow, rather than culling a cow for a health disorder.

Incidence rates of health disorders are difficult to compare across research studies because differences exist among recording strategies, health disorder definitions, and diagnosis of health disorders (Harder et al., 2006). Parker Gaddis et al. (2012) summarized incidence rates across 30 research studies, and mastitis, lameness, and metritis occurred most frequently. Mastitis incidence ranged from 1% to 39%, with a mean of 18%. Metritis incidence ranged from 1.8% to 35.5%, with a mean of 12.3%, and lameness incidence ranged 2.5% to 30.4%, with a mean of 9.3%. The large range of incidence rates for health disorders suggests the need for a more systematic and uniform approach of health recording.

Health Disorders by Stage of Lactation

Across the literature (Appuhamy et al., 2009; Harder et al., 2006; Parker Gaddis et al., 2012), a majority of health disorders of cows occurred within the first 30 to 60 days in milk (DIM). Most of the disorders were related to reproduction and metabolism, likely because cows experienced negative energy balance as a consequence of the demand for nutrients to produce milk (Sundrum, 2015). Transition disorders such as displaced abomasum, ketosis, and metritis occurred most commonly during the first 30 DIM (Zwald et al., 2004a; Koeck et al., 2012) and greater than 90% of ketosis cases occurred in the first 30 DIM. For cases of displaced abomasum, Zwald et al. (2004a) reported that 78.5% occurred within the first 30 DIM, but Koeck et al. (2012) reported a higher 30-DIM occurrence rate of 91%. Also, mastitis commonly occurs during the first 30 DIM, and Zwald et al. (2004a) and Koeck et al. (2012) found incidence rates of 23.4% and 35%, respectively during the first 30 DIM.

Koeck et al. (2012) found that lameness disorders were, in general, evenly distributed across lactation, but they were slightly greater during the first 90 DIM; however, this differed from Zwald et al. (2004a), who found slightly greater incidence of lameness in early- (0 to 30 DIM), mid- (151 to 180 DIM) and late- (> 360 DIM) lactation. Both Koeck et al. (2012) and Zwald et al. (2004a) reported incidence of cystic ovaries was highest from 31 to 150 DIM, from the disorder being discovered during palpation at breeding time.

Cost of Health Disorders

Health disorders impact farm profitability by increasing costs due to veterinary services and pharmaceuticals and decreased milk production (Wells et al., 1998). Additionally, cows with mastitis, lameness, or metabolic disorders early in lactation subsequently often have impaired fertility and may acquire additional cost from delayed conception (Weigel, 2004; Guard, 2008). Some treatments for health disorders have tremendous cost; however, dairy producers may have difficulty assigning a cost to specific health disorders, because records may not always encompass the time, the type, and the dosages of pharmaceuticals used for individual health treatments.

Mastitis, reproduction, lameness, and metabolic disorders are among the most expensive health disorders (Wells et al., 1998; Zwald et al., 2004a). Bar et al. (2008) estimated the cost of clinical mastitis in 5 New York dairy herds and found the mean cost of a single case to be $179, which includes lost milk production ($115), treatment cost ($50), and cost associated with increased mortality ($14). When evaluating the treatment of clinical mastitis without accounting for lost production, Ettema and Santos (2004) reported a treatment cost of $50.80. Guard (2008) reported a slightly lower treatment cost of $27 per case of clinical mastitis; however, the total cost was $224 per clinical case when the costs of veterinary attention, labor, decreased milk production, delayed conception, death, and culling were included. Differences in approach to treatment, utilization of discarded milk, and culling policies are possible reasons for differences in treatment cost assigned to mastitis across the studies.

Beside mastitis, Guard (2008) estimated the cost for treatment (veterinary services, pharmaceuticals, and labor fees) of other major health disorders, such as milk fever ($24), retained placenta ($27), ketosis ($25), displaced abomasum ($131), and lameness ($31). Displaced abomasum often has a high treatment cost because it frequently requires surgery. Ettema and Santos (2004) reported a range of $40 to $170 for the treatment of displaced abomasum depending on the treatment method. For health disorders in first parity, Zwald et al. (2004b) estimated the total health cost for cows ranged from $128 to $169. Treatment costs for health disorders vary depending on the expense of pharmaceuticals used for treatment and because some pharmaceuticals do not require milk to be discarded (Guard, 2008).

Heritability of Health Traits

Heritability estimates for health traits from the literature are generally low to moderate. Differences among the estimates are due to differing statistical approaches for analysis as well as the quality of data, the definition of reported health disorders, and sample size (Lin et al., 1989). Heritability estimates from 10 research studies from 1989 to 2012 for mastitis, retained placenta, metritis, cystic ovaries, displaced abomasum, ketosis, and lameness are reviewed in Table 1. The majority of these studies estimated the heritability of health disorders based on incidence from binary recording (0 = absence of health disorder, 1 = presence of health disorder). The most recent study (Appuhamy et al., 2009) using health data of US dairy cows found the heritability of individual health disorders ranged from 0.01 (ketosis) to 0.10 (metritis).

Across all studies reviewed in Table 1, mastitis tended to have the highest heritability estimates. Mastitis is the health disorder most consistently recorded in commercial dairy herds along with displaced abomasum (Zwald et al., 2004a,b), probably because both disorders can have large economic impact. Besides this, displaced abomasum usually requires attention from a veterinarian. Estimates of heritability for lameness were usually low, and Zwald et al. (2004b) hypothesized that the low heritability (0.06) may have resulted from of inconsistent recording of lameness compared to other health disorders. A possible explanation for the inconsistent recording of lameness is some dairy producers may have chosen to cull a cow for lameness rather than provide treatment.

Lyons et al. (1991) combined incidence of abortion, cystic ovaries, retained placenta, uterus infection, number of inseminations, and other reproduction disorders into a reproduction category and found a heritability of 0.02. Dechow et al. (2004) grouped incidence of cystic ovaries, retained placenta, and uterine infection together in a reproduction category, and this also resulted in a heritability of 0.02. Some studies grouped all metabolic and digestive disorders for analysis, and heritability estimates of 0.05 (Gernand et al., 2012) and 0.17 (Lyons et al., 1991) were reported. Inconsistencies among estimates may be due to variability in which health disorders were included in the categories.

Zwald et al. (2004a) pooled all health disorders from the first 50 DIM and reported a heritability of 0.12 for first parity and 0.10 across parities. Similarly, Gernand et al. (2012) analyzed the incidence of at least 1 health disorder of cows throughout a single lactation, and found a lower heritability of 0.04 across parities. Lyons et al. (1991) estimated the heritability (0.07) of the sum of all health incidences in a single lactation. Overall, heritability estimates for health disorders from each of these studies indicates genetic selection should be possible for at least some health disorders. Because of the monetary and animal welfare impacts associated with health disorders of dairy cows, more research using high-quality health data should be conducted in an effort to include health traits in genetic evaluations for US dairy cattle.

Genetic and Phenotypic Correlations between Health Disorders

Lyons et al. (1991) reported a genetic correlation between mammary disorders (mastitis, udder injury, and other udder problems) and digestive disorders of 0.52 and a genetic correlation between mammary and locomotion disorders of 0.82. However, they reported a low and negative genetic correlation (-0.11) between mammary disorders and reproduction disorders. Zwald et al. (2004b) found genetic correlations among health disorders ranged from -0.01 between mastitis and metritis to 0.45 between displaced abomasum and ketosis. Furthermore, Zwald et al. (2004b) found moderate genetic correlations between cystic ovaries and ketosis (0.42) and lameness and mastitis (0.20). Koeck et al. (2012) estimated higher genetic correlations than Zwald et al. (2004b), especially between displaced abomasum and retained placenta (0.64) and between retained placenta and metritis (0.62). The larger genetic correlations of Koeck et al. (2012) may be due to the higher quality of their data from Canadian herds in their analysis, as well as a greater effort by the dairy producers to record health incidences as the study progressed.

The genetic correlations between individual health disorders reported by Zwald et al. (2004b) and Koeck et al. (2012) tend to agree with those of Heringstad et al. (2007), who hypothesized genetic selection against certain health disorders such as mastitis may lead to increased resistance of other health disorders including ketosis and retained placenta for Norwegian Red cows. Zwald et al. (2004b) also concluded the positive genetic correlations between many health disorders may indicate that daughters of certain bulls may be more predisposed to all health disorders compared to daughters of other bulls. Overall, the strong genetic correlations between health disorders often found in these studies suggests a selection index including all health disorders could be effective for the genetic improvement of health of dairy cows.

Phenotypic correlations between health disorders reported by Koeck et al. (2012) ranged from 0.00 (ketosis with cystic ovaries) to 0.27 (ketosis with displaced abomasum). The phenotypic correlation between retained placenta and metritis was 0.14, and all other reported phenotypic correlations were low. The phenotypic correlation of 0.27 between ketosis and displaced abomasum was not surprising because both of these disorders are often a result of negative energy balance after calving, and ketosis has been reported as a risk factor for displaced abomasum (LeBlanc, 2005). Lyons et al. (1991) analyzed reproduction, mammary, digestive, locomotion, and respiratory disorders, and they found the highest phenotypic correlation was between locomotion and digestive disorders (0.12). Perhaps that phenotypic correlation is a result of nutritional factors causing digestive disorders, such as acidosis, which can lead to hoof health disorders (Stone, 2004). Other phenotypic correlations among the aforementioned health disorders were small and ranged from -0.03 to 0.09 for Lyons et al. (1991).

Health Disorders and their Genetic Relationships with Production and Conformation

Rupp and Boichard (1999) reported a genetic correlation of 0.45 between milk production and mastitis, and this was greater than the more modest estimates of 0.15 and 0.18 found by Van Dorp et al. (1998) and Lyons et al. (1991), respectively. Pryce et al. (1997) reported genetic correlations of 0.21 between milk production and mastitis and 0.29 between milk production and hoof health disorders. Van Dorp et al. (1998) also reported genetic correlations between milk production and cystic ovaries (0.23) and between milk production and lameness (0.24). Lyons et al. (1991) estimated genetic correlations between milk production and the health categories of reproduction (-0.27), mammary (0.18), digestive (0.44), locomotion (0.48), and respiratory (0.02) disorders, respectively. Furthermore, Jones et al. (1994) analyzed the difference in health cost of Holstein cows selected for milk production versus a 1964 control line of Holsteins and found cows selected for milk production had greater health cost ($64.71) than the control line ($39.19) for first parity.

The genetic relationships between milk production and some health disorders in the previously mentioned studies document the antagonistic relationship between higher milk production and many health disorders; however, the magnitude of the genetic correlations varied greatly due to statistical approach, sample size, quality of data, or several of these factors combined. Nonetheless, the antagonistic genetic relationships should be taken into account for genetic improvement of dairy cattle. While increased milk production may lead to more income from milk sales, the costs associated with health disorders resulting from the higher milk production should also be considered. Furthermore, Oltenacu and Broom (2010) suggested the impaired health of cows is indicative of a decline in cow welfare, and animal welfare is perceived by the public as an indicator of product quality and, thus, an additional contributor to economic value.

The genetic correlations among conformation and health disorders have been studied less frequently, likely because conformation scores are usually not uniformly recorded for large populations of cows across parities. Rupp and Boichard (1998) reported a moderate negative genetic correlation (-0.46) between mastitis and udder depth, which indicated daughters of bulls with more shallow udders had less mastitis. This makes sense because deeper udders would have more functional problems with milking (Hansen et al., 1999), which in turn could result in mastitis. In contrast, Van Dorp et al (1998) found no genetic correlation (0.00) between udder depth and mastitis. The favorable genetic correlation between udder depth and mastitis of Rupp and Boichard (1998) suggests selection for higher udders should reduce incidence of mastitis, which is important from both a cow health and economic perspective.

Dechow et al. (2004) reported a strong genetic correlation between dairy form and the incidence of any health disorder (0.85), and this suggested daughters of bulls that transmitted greater dairy form were at an increased risk for health disorders. In that study, the magnitude of the genetic correlation between dairy form and health was mostly due to metabolic and digestive disorders, which had a genetic correlation of 0.65 with dairy form. Greater dairy form is associated with lower body condition; therefore, a possible reason for the unfavorable genetic correlation between dairy form and health may be due to cows with low body condition are more likely to experience severe negative energy balance following calving (Dechow et al., 2004). The unfavorable genetic correlation between dairy form and cow health suggests selection for more moderate dairy form may lead to fewer health disorders.

Becker et al. (2012) compared health cost of Holsteins selected for small versus large body size, and cows selected for large body size had $21 more health costs for first parity than cows selected for small body size. Also, Hansen et al. (1999) reported that Holstein cows selected for large body size had shorter productive life than Holstein cows selected for small body size. Moreover, Zwald et al. (2004b) found that body size traits of Holsteins had a negative relationship to disease resistance. The antagonistic relationship between body size and health of dairy cows should be considered in the selection plans of individual dairy herds. Larger cows typically have an advantage in the show ring, but larger cows may have more health costs.

Justification and Objectives of Research

Health data from commercial dairy herds is often inconsistently recorded and lacks completeness; therefore, the determination of cost for health disorders and the inclusion of health traits in US genetic evaluations are inhibited. The primary objectives of this study were to assess the health treatment costs of Holstein cows and estimate their genetic parameters from data uniformly recorded in 8 high-performance Minnesota dairy herds.

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Table 1. Heritability estimates of common health disorders among dairy cows

Author	Year	Mastitis	Retained placenta	Metritis	Cystic ovaries	Displaced abomasum	Ketosis	Lameness
Lin et al.	1989	0.19	0.05	0.19	0.12	---	---	---
Lyons et al.	1991	0.14	0.05	0.06[1]	0.05	0.09	0.08	---
Uribe et al.	1995	0.15	---	---	0.17	0.30	0.10	---
Van Dorp et al.	1998	0.04	0.01	0.02	0.02	0.00	0.39	0.16
Dechow et al.[2]	2004	0.02 - 0.06	---	---	0.02 - 0.17	0.08	---	---
Zwald et al.	2004	0.09	---	0.07	0.05	0.15	0.06	0.06
Abdel-Azim et al.	2005	---	---	0.14[1]	0.03	0.09	---	---
Appuhamy et al.[2]	2009	0.10	---	0.04 - 0.10	---	0.03	0.01	---
Neuenschwander et al.[2]	2012	0.01 - 0.05	0.07	0.02 - 0.03	0.05	0.21	0.09	0.04 - 0.05
Koeck et al.	2012	0.02	0.03	0.02	0.03	0.06	0.03	0.01
Gernand et al.	2012	0.06	0.04	---	0.06	---	---	---

[1]Estimates are based on general uterine infection.
[2]Range of estimates reflect different statistical approaches within study.

MANUSCRIPT 1

Health treatment cost of Holsteins in 8 high-performance herds.

INTERPRETIVE SUMMARY

Health treatments of Holsteins were recorded over an 8-year period of time and partitioned into 5 categories (mastitis, reproduction, lameness, metabolic, and miscellaneous). Fixed costs of health treatments were obtained from the veterinary clinics that serviced the 8 herds, and they were assigned to each observation. Health treatment cost of cows was highest during the first 30 days in milk for all parities and means ranged from $22.87 in first parity to $38.50 in fifth parity. The total of health treatment cost during first parity had means that ranged from $23.38 to $74.60 for the 8 herds and usually increased with parity.

MANUSCRIPT 1 ABSTRACT

Health treatments of Holstein cows (n = 2,214) were recorded by the owners of 8 high-performance dairy herds in Minnesota. Cows calved from March 2008 to October 2015, and 14 types of health treatments were uniformly defined across the herds. Specific types of health treatment were subsequently assigned a cost based on the mean veterinary cost obtained from the veterinary clinics that serviced the 8 herds. A fixed labor cost for time ($18/h) associated with specific types of health treatment was determined based on interviews with the herd owners and was added to the veterinary cost. Health treatment cost was partitioned into 5 health categories: mastitis (including mastitis diagnostic test), reproduction (cystic ovary, retained placenta, and metritis), lameness (hoof treatments), metabolic (milk fever, displaced abomasum, ketosis, and digestive), and miscellaneous (respiratory, injury, and other). Lactations of cows were divided into 6 intervals that corresponded with stage of lactation based on days in milk. The first interval of lactation was 30 days in length, followed by 4 intervals of 60 days each, and the final interval started on day 271 and had variable length because it continued to the end of lactation and included the dry period. Health treatment cost was summed within each interval of lactation and subsequently across lactations by parity. Statistical analysis by parity included the fixed effects of herd, interval, and the interaction of herd and interval, with interval regarded as a repeated measure of cows. Means for health treatment cost were highest during the first interval for all 5 parities of cows and ranged from $22.87 for first parity to $38.50 for fifth parity. Reproduction treatment cost was about one-half of total health treatment cost during the first interval for all 5 parities. Metabolic treatment cost for the first interval ranged from $3.92 (in first parity) to $12.34 (in third parity). Compared to other health categories, mastitis treatment cost was evenly distributed across intervals of lactation for all parities. Lameness treatment cost was highest during mid- or late-lactation across parities and reflected the time when cows received routine hoof trimming. Additionally, treatment cost across health categories was summed over intervals of lactation for each cow, and the total health cost of cows varied substantially from herd to herd and means ranged from $23.38 to $74.60 for first parity and usually increased with parity.

Keywords: Health treatment cost, Holstein, transition disorder

INTRODUCTION

Traditionally, selection within the Holstein breed in the US placed major emphasis on production and conformation traits (Hansen, 2000). This approach was accompanied by a decline in cow health and welfare (Oltenacu and Broom, 2010), which negatively impacts the profitability of cows. The impact of health disorders on profitability of cows is difficult to measure, because most health data recorded on farms lack uniformity and are often incomplete. Furthermore, most herd owners do not record the cost of individual health treatments of cows. Determining the full economic impact of heath disorders is complicated because health disorders impact involuntary culling, fertility, and production which, in turn, influence profitability (Zwald et al., 2004; Guard, 2008).

The majority of metabolic and infectious health disorders occur within the first 30 to 60 days of lactation (Harder et al., 2006; Appuhamy et al., 2007; Parker Gaddis et al.,

2012) and may be caused by a depressed immune system and the negative energy balance created by the demand for nutrients to produce milk (Esposito et al., 2014). In a summary of previous studies, Parker Gaddis et al. (2012) reported lactational incidence rates were highest for mastitis, lameness, and metritis, and incidence of mastitis ranged from 1.0% to 39.1% with a mean of 18.0%, metritis ranged from 1.8% to 35.5% with a mean of 12.3%, and lameness ranged from 2.5% to 30.4% with a mean of 9.3%. Differences in recording methods, definition of health disorders, and diagnosis protocols have created variability of results from study to study; therefore, incidence rates of health treatments are difficult to compare across studies (Harder et al., 2006).

Clinical mastitis often results in reduced production (Shim et al., 2004) and metabolic disorders, lameness, and mastitis tend to negatively impact fertility (Weigel, 2004). Ettema and Santos (2004) estimated the cost per case of mastitis was $51, and this included the cost of antibiotic treatment, labor, and 5 d of discarded milk. Guard (2008) estimated a much higher cost of $224 per case of mastitis when lost revenue from reduced milk production, delayed conception, death, and involuntary culling was included. Jones et al. (1994) analyzed the health treatment costs of an experimental herd of Holsteins selected for milk production versus a 1964 control line, and the cows selected for milk production had $28.22 more health treatment cost during first parity than the control line. In that study, 43% ($27.79) of the cost during first parity was attributed to mastitis (Jones et al., 1994).

Reducing the incidence of health disorders of dairy cows is of growing interest to herd owners. To be sure, SCS (as an indicator of mastitis) and productive life (a composite trait including production and functional traits of cows) are two traits that have permitted selection for improved health of cows in the US (García-Ruiz et al., 2016). Improving the integrity and uniformity of health data recorded on farms will provide an opportunity to assess the economic impact of health disorders and allow for selection of reduced health treatment cost (Parker Gaddis et al., 2012, 2014). The objective of this study was to analyze the health treatment cost of Holstein cows from parity 1 to 5 using on-farm data for treatments that were defined uniformly within 8 high-performance Minnesota dairy herds.

MATERIALS AND METHODS

Description of Herds and Cows

Holstein cows in 8 dairy herds throughout Minnesota with very high mean production were enrolled by the University of Minnesota from March to September of 2008 to initiate a long-term study. All herds housed cows in 4- or 6-row freestall facilities and fed cows a TMR. In June 2016, the herds ranged in size from 302 to 1,932 cows with a mean herd size of 981 cows, and the weighted mean production for all cows in the 8 herds was 14,019 kg of milk, 519 kg of fat, and 433 kg of protein.

Each of the 8 herds offered varying numbers of cows and nulliparous heifers for the study. In total 3,550 Holstein females were enrolled, ranging from 266 to 785 females in each herd. Matings were completed by 2 genetic advisors employed by Minnesota Select Sires Co-op, Inc., St. Cloud, MN. Herd owners chose proven AI bulls and were asked to select bulls that ranked among the top 10% for the Net Merit index for Holstein bulls (VanRaden and Cole, 2014). Following the selection of AI bulls, lactating cows were correctively mated for conformation, and all virgin heifers were correctively mated based on their dams' conformation when possible. Also, some virgin heifers and cows were mated to proven AI bulls from the Montbeliarde and Viking Red breeds. All matings of Holstein bulls to Holstein females were provided inbreeding protection.

Data

Lactational Records. Data were lactational health records from Holstein females for parity 1 to 5 for lactations that were initiated from March 2008 to October 2015. Cows with a single lactation that was initiated by an abortion were eliminated from the data. In total, 5,052 cows with 11,862 lactations were available for analysis, and the number of cows and lactations following successive steps of editing are reviewed in Table 1. The lactations beginning with an abortion (for cows with multiple lactations) were removed, and lactations of all cows were required to have the opportunity to reach at least 30 DIM. Furthermore, only lactations of cows that had a first parity commencing after March 2008 were studied. All cows and their dams were required to be sired by an AI bull with a sire code from the National Association of Animal Breeders (Columbia, MO). Additional edits eliminated cows with sires that had only a single daughter and with maternal grandsires that had only a single daughter or granddaughter. The edits that were based on the pedigree of cows were applied to improve the accuracy of sire and maternal grandsire identification. Following all edits, 2,214 cows with 4,979 lactations of variable length for parity 1 to 5 remained for analysis. The distribution of lactations of cows by herd and parity is in Table 2, and data for parity 4 (7%) and parity 5 (3%) were sparse.

Data for Health Treatment and Cost. Health treatments were uniformly defined for 14 individual health disorders across the 8 herds and recorded on-farm with Dairy Comp 305 (Valley Ag Software, Tulare, CA). Monthly backups from Dairy Comp 305 were obtained from the 8 herds, and data were verified for accuracy. The monthly collection and verification of the data prevented the deletion of data by the software and improved the integrity of the data. The health treatments were partitioned into 5 categories: mastitis (**MAST**), reproduction (**REPRO**), lameness (**LAME**), metabolic (**META**), and miscellaneous (**MISC**). The specific health treatments that were assigned to each of the 5 categories are reviewed in Table 3.

Incidence rates of health treatments are commonly reviewed in the literature; however, no previous study has investigated the cost of health treatments from field data in the US. Therefore, this study is unique because it analyzes the cost rather than the incidence of health treatments from field data. A total cost for each specific type of health treatment (Table 4) was determined by summing the respective veterinary cost and the labor cost that was associated with each treatment. Veterinary cost was the mean cost for specific types of health treatment protocols that were obtained from the veterinary clinics that serviced each herd, and this included veterinary labor (when applicable), veterinary supplies, and pharmaceuticals. Farm labor cost was assigned a fixed value of $18/h, and the time assigned to each specific type of treatment was based on an interview with the 8 herd owners. The time assigned to each treatment reflected the time required for animal attendants to restrain the cow and administer the health treatment. For cows with more than 1 treatment of the same type, a new health treatment was triggered for cows when 3 d passed between hoof treatments, when 5 d passed between digestive, ketosis, mastitis, metritis, milk fever, and respiratory treatments, and when 7 d passed between cystic ovary treatments. Only a single treatment for displaced abomasum, retained placenta, and miscellaneous reproduction was permitted per lactation. No restriction on days between treatments was applied to mastitis diagnostic test, injury, or other treatments.

Intervals of Lactation. The time within lactation when health treatment cost occurred was of special interest in this study; therefore, lactations of cows were divided into 6 intervals that corresponded to stage of lactation and were based on DIM. The first interval began at calving and was 30 d in length. The subsequent 4 intervals were each 60 d in length (31 d to 90 d, 91 d to 150 d, 151 d to 210 d, and 211 d to 270 d), and the final interval started at 271 DIM and had variable length because it continued to the end of lactation and included the dry period. Health treatment cost within each health category was summed to obtain an interval cost by health category. Additionally, the health treatment cost across the 5 categories for a lactation of a cow was, in turn, summed within interval to arrive at the total health treatment cost (**TOT**) for that interval. Finally, the TOT for the 6 intervals of lactation were summed to obtain the total lactational health cost (**THC**) of each lactation of a cow. The THC for cows with incomplete lactations was simply the THC from calving to the end of the study (November 2015) without any sort of adjustment.

Statistical Analysis of Health Treatment Cost

Analysis was conducted separately by parity. For analysis of health treatment cost by interval within lactation, dependent variables were the cost of each of health category as well as TOT. Independent variables were the fixed effects of herd, interval, and the interaction of herd and interval, with interval regarded as a repeated measure for cows. An attempt was made during preliminary analysis to fit the fixed effects of year and season of calving; however, they did not significantly account for variation. A separate analysis assessed the THC of cows (dependent variable), and the independent variables were herd as a fixed effect and cow as a random variable. The MIXED procedure of SAS 9.3 (SAS Institute, 2011) was used to conduct the ANOVA and to obtain least squares solutions. Both of the analyses were, again, conducted separately by parity. A multi-parity model was considered but may have resulted in biased solutions, because cows with high health treatment cost typically leave herds more quickly than cows with low health treatment cost.

RESULTS AND DISCUSSION

Significance of Effects from Analysis of Intervals

For the analysis of health treatment cost by interval within lactation, the fixed effects of herd, interval, and the interaction of herd and interval were all highly significant ($P < 0.01$) during first parity for each category of health treatment cost, as well as TOT. For second parity, the fixed effects of herd, interval, and the interaction of herd and interval were again significant ($P < 0.05$) for each category of health treatment cost and TOT, except not significant ($P = 0.59$) for the interaction of herd and interval for META cost. For parities 3 to 5, the fixed effect of herd was significant ($P < 0.05$) for each category of health treatment cost, except herd was not significant ($P = 0.11$) for REPRO cost in parity 5. Interval was significant ($P < 0.05$) for each category of health treatment cost and TOT for third parity, but only for REPRO cost, LAME cost, and TOT in fourth parity and only for REPRO cost and TOT in fifth parity. The interaction of herd and interval for third parity was highly significant ($P < 0.01$) for REPRO cost, LAME cost, MISC cost, and TOT but was not significant for MAST and META costs. For fourth and fifth parity the interaction of herd and interval was significant ($P < 0.05$) only for REPRO cost.

Health Treatment Cost for Intervals within First Parity

Least squares means of health treatment cost by category for the 6 lactation intervals of first parity are in Table 5, which also provides the percentage of each category's contribution to TOT. The TOT was significantly higher ($P < 0.05$) during the first interval at $22.87 than all other intervals, and cows accrued the most cost for REPRO, META, and MISC during this interval. The high cost for REPRO and META during the first interval was expected, because these categories are primarily comprised of treatments for metritis, retained placenta, displaced abomasum, and ketosis, and these health disorders most commonly occur near calving (Zwald et al., 2004; Koeck et al., 2012).

The REPRO cost during the first interval was mostly metritis treatments that, when analyzed separately from other REPRO costs, accrued a mean cost of $9.06. Health treatment cost for META during the first interval was mostly because of displaced abomasum with a mean cost of $3.02. In general, REPRO and META costs during the first interval of first parity may have been the result of health disorders from the negative energy balance that often occurs postpartum (Sundrum, 2015). Beyond the first interval, REPRO cost mainly resulted from treatment for cystic ovaries, mostly during the third interval, when this health disorder was uncovered via palpation or ultrasound. The META cost for later intervals was mostly for digestive treatment.

The high MISC cost during the first interval of first parity is because almost one-half of the MISC cost was attributed to treatment for elevated temperatures without a specific health disorder being diagnosed. The treatment of elevated temperature was mostly due to the herd health practices of one herd owner. About one-third of MISC cost in later intervals of first parity was for elevated temperatures. Other MISC cost during first parity after the first interval was evenly split between respiratory and injury treatments.

The MAST cost was highest for interval 1 and interval 6 during first parity but was evenly distributed across intervals 2 to 5. The higher MAST cost during the first interval is agreement with Appuhamy et al. (2007), who reported a higher incidence of mastitis during the first month of lactation than any other time. A possible reason for the elevated MAST cost during the first interval may have been the decreased immune response to infection cows often experience during the transition period (LeBlanc, 2010). Additionally, Green et al. (2007) indicated poor hygiene causes mastitis during early lactation and, perhaps, the high MAST cost for the first interval in this study was due to exposure to mastitis-causing pathogens in the heifer rearing or calving facilities. Furthermore, the SCC of cows usually increases later in lactation (de Haas et al., 2002), and this may explain the high MAST cost near the end of lactation in interval 6.

The LAME cost was significantly higher ($P < 0.05$) for intervals 3 and 6 of first parity and reflected the timing of routine hoof trimming and the resulting treatment for hoof health disorders. The LAME cost during intervals 3 and 6 in this study is in disagreement with Koeck et al. (2012), who reported lameness incidences are evenly distributed throughout lactation with slightly higher incidence during early lactation.

Health Treatment Cost for Intervals during Later Parities

Tables 6 to 9 provide the least squares means of health treatment cost by category for the lactation intervals of parities 2, 3, 4, and 5, as well as the percentage of each category's contribution to TOT. For each parity, TOT was significantly higher during the first interval and ranged from $24.69 in second parity to $38.50 in fifth parity. Across parities 2 to 5 the distribution of treatment cost for each health category except MAST was similar for individual intervals. Also, standard errors of treatment cost for each health category as well as TOT increased with parity because fewer cows contributed data for later parities.

The REPRO cost was significantly higher ($P < 0.05$) during the first interval than other intervals for parity 2 to 5. The high REPRO cost during first interval was expected because cows experience transition disorders during this period of time (LeBlanc, 2010). The especially high REPRO cost during the first interval of fifth parity was mainly from metritis treatments which, when evaluated separately, had a mean cost of $16.87. Most of the REPRO cost after first interval was from treatment for cystic ovaries and, in some instances, from additional treatment for metritis. Metritis may require multiple treatments and also may occur at various times during lactation from injury to the reproductive tract or from nutritional deficiencies (Hutchinson, 2008).

The META cost was significantly higher ($P < 0.05$) during the first interval for parities 2, 3, and 4, as it was for first parity, and may have been due to negative energy balance after calving (Esposito et al., 2014). However, META cost for fifth parity was evenly distributed across intervals. For third parity, specifically, the high META cost of $12.34 during the first interval was for displaced abomasum, which accrued a mean cost of $8.91 (72% of META cost) for the first interval. Surgery for displaced abomasum during a previous lactation perhaps explains the numerically lower displaced abomasum and META cost in fourth and fifth parities. The META cost after first interval for later parities was overwhelmingly due to treatment for digestive disorders.

The distribution of MAST cost across the intervals for later parities was different from first parity. For later parities, the proportion of MAST cost during intervals 2 to 5 was higher than it was in first parity because, in first parity, MAST cost was numerically highest for interval 1 and for interval 6. The difference in distribution of MAST cost across intervals for later parities perhaps resulted from preventative treatment for mastitis at dry-off during the previous lactation and better management during the pre-fresh period for cows than for springing heifers.

Similar to first parity results, the LAME cost for parities 2 to 5 was typically greatest during interval 3 and interval 6. The LAME cost during intervals 3 and 6 reflected the timing of routine hoof trimming that often resulted in hoof treatment, with treatment for hoof ulcers accounting for the majority of the LAME cost. Other than during interval 3 and interval 6, LAME cost was usually from treatment for infectious pododermatitis.

Total Health Treatment Cost by Herd and Parity

The results from the analysis of THC by herd and parity are in Table 10, and standard errors for estimates of THC increased with parity because the number of cows declined with parity. The weighted least squares means of THC of cows based on the number of cows in each herd were $54.73, $75.56, $94.43, $100.97, and $122.29 for first to fifth parity, respectively. No previous research has analyzed health treatment costs from commercial dairy herds; however, Becker et al. (2012) analyzed THC of cows in an institutional herd of Holsteins and reported a mean THC for first parity of $41.41 and $62.41 for cows selected for small and large body size, respectively. The estimates of mean THC from that study are comparable to THC for first parity of herds in this study that ranged from $23.38 to $74.60.

The mean THC was variable across herds in this study and tended to numerically increase from first to third parity for all herds except herd B, which had numerically lower REPRO cost in second and third parity than in first parity. The difference in THC between herds is probably a reflection of alternative approaches for addressing the health disorders of cows. Herd owners who more closely monitor fresh cows for transition disorders are more likely to detect health disorders, and as a result, may provide treatment. Herd C had the highest THC, numerically, for parities other than for first parity, and herd C was more aggressive in treating low-grade disease cases than the other herds. Herd H tended to have low THC for all 5 parities, and we suspect this was a reflection of its excellent attention to nutritional requirements and preventative care.

CONCLUSIONS

This study was the first to document the cost of health treatments using field data from commercial dairies. Because the data were of high quality, we were able to determine the stage of lactation in which health treatment cost was incurred for 5 categories of health treatment and TOT. The highest mean TOT was during the first 30 DIM (interval 1) for all 5 parities and was mainly due to REPRO and META costs. Mean MAST cost was highest during interval 1 and interval 6 during first parity but was more evenly distributed across intervals for later parities. The REPRO cost was numerically greatest among the 5 categories for first-parity cows, but in later parities MAST cost was generally the highest health treatment cost for cows in the 8 herds. Therefore, minimizing REPRO and MAST costs should be a priority of dairy producers to enhance profitability.

Weighted herd means of THC ranged from $54.73 in first parity to $122.29 in fifth parity, but THC varied substantially between herds. This may be a reflection of the divergent management strategies and environments of the 8 herds. Considerable variation existed for THC of the 8 herds, but health treatment cost was substantial for the majority of the herds. Reducing the THC of cows in all herds will provide economic benefit to dairy producers and, perhaps more importantly, will improve cow welfare.

Our approach of applying veterinary cost and labor cost to individual health treatments permitted the elucidation of the economic effects of alternative health disorders. Also, the method used in this study to supplement incidence of health disorders with their cost may provide dairy producers the opportunity to better utilize health data for day-to-day management decisions. Furthermore, resulting data may also permit researchers to investigate genetic selection for lower health cost of dairy cows. The integrity and uniformity of health data in this study may permit an enhancement of genetic variation between daughters of sires for health disorders and, perhaps, to expose the genetic control of health traits.

ACKNOWLEDGEMENTS

The authors are exceedingly grateful to the owners/managers of the 8 herds for their participation in this study. The authors also wish to thank Minnesota Select Sires Co-op, Inc. for its contribution of mating individual heifers and cows. Funding for this project was provided by Coopex Montbeliarde, Roulans, France; Viking Genetics, Randers, Denmark; Creative Genetics of California, Oakdale, CA; Select Sires, Inc., Plain City, OH; and Minnesota Select Sires Co-op, Inc., St. Cloud, MN.

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Table 1. Cows and records remaining after each step of data editing

Edit	Cows	Records
Cows with parities 1 to 5	5,052	11,862
Individual lactations initiated by an abortion	5,052	11,454
Lacked the opportunity to reach 30 DIM	5,024	11,354
Cows without first parity	3,224	7,595
Cows without an AI sire and cows whose AI sire had a single daughter	2,849	6,674
Cows whose AI maternal grandsire had a single daughter or granddaughter	2,214	4,979

Table 2. Distribution of cows by herd and parity

	Parity				
Herd	1	2	3	4	5
A	394	246	125	51	17
B	227	157	100	44	9
C	427	299	181	88	43
D	402	279	150	74	29
E	179	117	59	15	6
F	152	105	48	17	5
G	250	159	66	31	8
H	183	125	71	30	11
Total	2,214	1,487	800	350	128
Percentage by parity (%)	44	30	16	7	3

Table 3. Specific health treatments included in the health categories

Category	Abbreviation	Treatment
Mastitis	MAST	Mastitis Mastitis diagnostic test[1]
Lameness	LAME	Hoof treatment[2]
Reproduction	REPRO	Cystic ovaries Retained placenta Metritis Miscellaneous reproduction[3]
Metabolic	META	Milk fever Displaced abomasum Ketosis Digestive[4]
Miscellaneous	MISC	Respiratory Injury Other treatments

[1] Mastitis diagnostic test included milk culture and California Mastitis Test (Immucell, Portland, ME).
[2] Hoof treatment included dermatitis, infectious pododermatitis, foot ulcer, and other hoof treatments.
[3] Miscellaneous reproduction included abortion treatments, caesarean section, pyometria, uterine disorders (adhesion, mass, prolapse, and torsion), and mummified calf.
[4] Digestive included clostridium, traumatic reticuloperitonitis, hemorrhagic bowel syndrome, peritonitis, twisted cecum, lack of appetite, or any other digestive treatment.

Table 4. Total cost assigned to individual health treatments

Type of treatment	Veterinary cost[1]	Labor cost[2]	Total
	------------------------($)------------------------		
Mastitis diagnostic test	8	3	11
Cystic ovaries	14	2	16
Digestive	34	10	44
Displaced abomasum	256	19	275
Hoof treatment	21	9	30
Injury	3	23	26
Ketosis	24	9	33
Mastitis	22	6	28
Metritis	112	5	117
Milk fever	21	17	38
Miscellaneous reproduction	170	19	189
Other	25	6	31
Respiratory	67	10	77
Retained placenta	75	5	80

[1] Veterinary cost was obtained from the veterinary clinics that serviced the 8 herds.
[2] Fixed labor cost ($18/h) across the 8 herds.

Table 5. Least squares means, standard errors, and percentage of total cost (TOT) by category[1] of health cost for 6 intervals of lactation of first parity

	Health Category																	
	MAST			REPRO			LAME			META			MISC			TOT		
Interval (days in milk)	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
	----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----		
1 (0 to 30 d)	2.78^{a}	0.21	12	11.78^{a}	0.47	52	0.84^{d}	0.19	4	3.92^{a}	0.38	17	3.56^{a}	0.23	16	22.87^{a}	0.74	100
2 (31 to 90 d)	1.55^{c}	0.21	28	0.65^{b}	0.48	11	1.39^{c}	0.19	25	0.89^{b}	0.39	16	1.15^{b}	0.23	20	5.63^{cd}	0.76	100
3 (91 to 150 d)	1.97^{bc}	0.21	26	1.36^{b}	0.49	18	2.93^{b}	0.20	39	0.39^{b}	0.40	5	0.84^{bc}	0.24	11	7.48^{c}	0.78	100
4 (151 to 210 d)	1.71^{bc}	0.22	40	0.35^{b}	0.50	8	1.46^{c}	0.20	34	0.47^{b}	0.40	11	0.30^{c}	0.24	7	4.30^{d}	0.79	100
5 (211 to 270 d)	1.49^{c}	0.22	27	0.28^{b}	0.50	5	1.72^{c}	0.20	31	0.58^{b}	0.41	10	1.48^{b}	0.25	27	5.55^{cd}	0.80	100
6 (271 d to end)	2.22^{ab}	0.22	22	0.22^{b}	0.50	2	5.84^{a}	0.20	57	0.79^{b}	0.41	8	1.52^{b}	0.25	11	10.23^{b}	0.80	100

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.

[a–d] Superscripts denote significant differences ($P < 0.05$) within each health category (column).

Table 6. Least squares means, standard errors, and percentage of total cost (TOT) by category[1] of health cost for 6 intervals of lactation for second parity

Interval (days in milk)	Health Category																	
	MAST			REPRO			LAME			META			MISC			TOT		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
	----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----		
1 (0 to 30 d)	1.80^{c}	0.33	7	12.81^{a}	0.63	52	1.18^{d}	0.27	5	5.85^{a}	0.52	24	3.04^{a}	0.29	12	24.69^{a}	1.03	100
2 (31 to 90 d)	3.09^{b}	0.34	35	0.52^{bc}	0.64	6	2.02^{c}	0.27	22	1.94^{b}	0.54	22	1.39^{b}	0.30	16	8.96^{c}	1.06	100
3 (91 to 150 d)	4.41^{a}	0.35	32	1.98^{b}	0.66	14	4.30^{b}	0.28	32	1.72^{b}	0.55	13	1.24^{b}	0.31	9	13.65^{b}	1.09	100
4 (151 to 210 d)	4.21^{a}	0.36	41	1.17^{bc}	0.68	11	2.52^{c}	0.29	25	1.38^{b}	0.56	14	0.91^{b}	0.31	9	10.17^{c}	0.11	100
5 (211 to 270 d)	3.43^{ab}	0.37	44	0.16^{bc}	0.69	2	2.24^{c}	0.29	29	0.85^{b}	0.57	11	1.04^{b}	0.32	13	7.72^{c}	1.13	100
6 (271 d to end)	3.03^{b}	0.37	28	0.03^{c}	0.69	0	6.11^{a}	0.29	56	0.64^{b}	0.58	6	1.06^{b}	0.32	10	10.86^{bc}	1.14	100

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.
[a–d] Superscripts denote significant differences ($P < 0.05$) within each health category (column).

Table 7. Least squares means, standard errors, and percentage of total cost (TOT) by category[1] of health cost for 6 intervals of lactation of third parity

Interval (days in milk)	MAST			REPRO			LAME			META			MISC			TOT		
	$\overline{X}$	SE	%	$\overline{X}$	SE	%	$\overline{X}$	SE	%	$\overline{X}$	SE	%	$\overline{X}$	SE	%	$\overline{X}$	SE	%
	----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----		
1 (0 to 30 d)	2.65[b]	0.53	8	13.36[a]	0.91	41	1.56[c]	0.41	5	12.34[a]	1.09	38	2.88[a]	0.46	9	32.79[a]	1.72	100
2 (31 to 90 d)	5.49[a]	0.56	49	0.41[b]	0.96	4	2.36[bc]	0.43	21	1.83[b]	1.15	16	1.05[b]	0.48	9	11.14[bc]	1.82	100
3 (91 to 150 d)	5.27[a]	0.60	32	1.53[b]	1.02	9	5.18[a]	0.46	32	2.66[b]	1.22	16	1.65[ab]	0.51	10	16.28[b]	1.93	100
4 (151 to 210 d)	4.81[a]	0.61	36	0.70[b]	1.04	5	2.86[b]	0.47	22	2.61[b]	1.25	20	2.32[ab]	0.52	17	13.31[bc]	1.97	100
5 (211 to 270 d)	4.09[ab]	0.63	46	0.29[b]	1.07	3	1.96[bc]	0.48	22	1.68[b]	1.28	19	0.89[b]	0.54	10	8.92[c]	2.03	100
6 (271 d to end)	2.84[b]	0.63	22	0.47[b]	1.07	4	6.38[a]	0.48	49	1.90[b]	1.29	15	1.30[b]	0.54	10	12.89[bc]	2.04	100

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.
[a–c] Superscripts denote significant differences ($P < 0.05$) within each health category (column).

Table 8. Least squares means, standard errors, and percentage of total cost (TOT) by category[1] of health cost for 6 intervals of lactation of fourth parity

	Health Category																	
	MAST			REPRO			LAME			META			MISC			TOT		
Interval (days in milk)	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
	----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----		
1 (0 to 30 d)	3.59^{b}	1.06	12	11.25^{a}	1.56	38	3.00^{b}	0.77	10	8.26^{a}	1.70	28	3.14^{a}	0.67	11	29.25^{a}	2.94	100
2 (31 to 90 d)	5.22^{ab}	1.14	33	2.41^{b}	1.67	15	3.74^{b}	0.82	24	3.04^{b}	1.82	19	1.19^{b}	0.72	8	15.60^{b}	3.16	100
3 (91 to 150 d)	7.05^{a}	1.25	32	3.41^{b}	1.84	16	7.38^{a}	0.90	34	2.74^{b}	2.00	13	1.21^{ab}	0.79	6	21.79^{ab}	3.46	100
4 (151 to 210 d)	6.07^{ab}	1.30	48	0.00^{b}	1.91	0	3.38^{b}	0.94	27	2.23^{b}	2.08	17	1.08^{ab}	0.82	8	12.76^{b}	3.60	100
5 (211 to 270 d)	4.93^{ab}	1.34	40	0.09^{b}	1.96	1	3.55^{b}	0.97	29	2.43^{b}	2.14	20	1.35^{ab}	0.85	11	12.35^{b}	3.71	100
6 (271 d to end)	3.54^{ab}	1.36	28	0.00^{b}	2.00	0	6.56^{a}	0.98	52	1.39^{b}	2.18	11	1.04^{ab}	0.86	8	12.52^{b}	3.77	100

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.
[a–b] Superscripts denote significant differences ($P < 0.05$) within each health category (column).

Table 9. Least squares means, standard errors, and percentage of total cost (TOT) by category[1] of health cost for 6 intervals of lactation of fifth parity

	Health Category																	
	MAST			REPRO			LAME			META			MISC			TOT		
Interval (days in milk)	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
	----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----			----- ($) -----		
1 (0 to 30 d)	5.47[a]	1.59	14	20.70[a]	2.90	54	1.70[b]	1.08	4	8.16[a]	2.71	21	2.47[a]	1.38	6	38.50[a]	4.97	100
2 (31 to 90 d)	4.59[a]	1.82	31	2.19[b]	3.32	15	2.31[b]	1.24	16	3.91[a]	3.10	27	1.71[a]	1.59	12	14.72[b]	5.69	100
3 (91 to 150 d)	6.13[a]	1.90	34	4.57[b]	3.47	25	3.63[ab]	1.30	20	2.10[a]	3.23	12	1.80[a]	1.65	10	18.23[b]	5.94	100
4 (151 to 210 d)	3.82[a]	1.95	33	0.00[b]	3.57	0	2.67[ab]	1.33	23	2.64[a]	3.33	23	2.44[a]	1.70	21	11.58[b]	6.11	100
5 (211 to 270 d)	2.27[a]	2.00	39	0.00[b]	3.67	0	0.92[b]	1.37	16	1.06[a]	3.42	18	1.64[a]	1.75	28	5.90[b]	6.28	100
6 (271 d to end)	4.98[a]	2.02	33	0.18[b]	3.69	1	6.03[a]	1.38	41	3.14[a]	3.44	21	0.55[a]	1.76	4	14.88[b]	6.32	100

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.
[a–b] Superscripts denote significant differences ($P < 0.05$) within each health category (column).

Table 10. Least squares means for total health costs (THC) by herd and parity

	Parity									
	1		2		3		4		5	
Herd	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
	-------- $ --------		-------- $ --------		-------- $ --------		-------- $ --------		-------- $ --------	
A	74.60[a]	4.11	98.81[a]	5.99	118.50[ab]	9.18	100.04[bc]	16.51	129.18[ab]	25.22
B	64.60[ab]	4.07	50.07[d]	5.62	58.92[cde]	8.38	61.82[cd]	13.70	37.83[c]	19.31
C	53.13[c]	3.95	107.61[a]	5.43	140.34[a]	7.63	176.52[a]	12.57	170.09[a]	15.86
D	59.57[bc]	6.10	75.90[bc]	8.69	87.29[bc]	13.36	90.00[bcd]	30.44	156.17[a]	42.45
E	49.76[c]	5.41	68.47[c]	7.50	72.69[cd]	10.26	58.64[cd]	17.77	30.67[c]	34.66
F	64.81[abc]	6.03	92.70[ab]	8.40	117.90[ab]	12.18	114.53[b]	21.52	123.45[ab]	31.35
G	29.79[d]	5.16	36.11[de]	7.45	43.55[de]	12.63	59.61[bcd]	21.17	23.88[c]	36.76
H	23.38[d]	6.62	26.86[e]	9.17	27.02[e]	14.81	21.59[d]	28.59	25.60[bc]	46.50

[a–e] Superscripts denote significant differences ($P < 0.05$) between herds within each parity (column).

MANUSCRIPT 2

Genetic control of health treatment cost and the correlation of health treatment cost with production and conformation of US Holstein cows.

INTERPRETIVE SUMMARY

Health treatments of Holsteins were obtained from producer-recorded health records of 8 herds and assigned a fixed cost for veterinary expense and labor. Heritability was estimated for the health treatment cost within 5 health treatment categories. The estimates of heritability were 0.13, 0.04, 0.10, 0.12, and 0.04 for the mastitis, reproduction, lameness, metabolic, and miscellaneous categories, respectively, for first parity. The estimates of heritability for total health treatment cost were 0.25 for first, 0.16 for second, and 0.17 for third parity. Large genetic correlations were found for total health treatment cost with milk production (0.44) and somatic cell score (0.93).

MANUSCRIPT 2 ABSTRACT

Genetic parameters of health treatment cost were estimated for first (n = 2,214), second (n = 1,487), and third (n = 800) parities of US Holstein cows. The health treatments were uniformly defined and consistently recorded by 8 high-performance dairy herds in Minnesota from 2008 to 2015. A fixed treatment cost was assigned to 14 types of health treatments, and the cost included the mean veterinary expense obtained from the veterinary clinics that serviced the 8 herds, from pharmaceuticals, and from labor cost. Farm labor cost was $18/h, and the time incurred for each type of health treatment was determined from interviews with the herd owners. The 14 types of health treatment costs were grouped into 5 categories: mastitis (including mastitis diagnostic test), reproduction (cystic ovary, retained placenta, and metritis), lameness (hoof treatments), metabolic (milk fever, displaced abomasum, ketosis, and digestive), and miscellaneous (respiratory, injury, and other). Health treatment costs for each cow were summed by category within lactation and also across categories within lactation. The estimates of heritability for health treatment cost were 0.13, 0.04, 0.10, 0.12, and 0.04 for the mastitis, reproduction, lameness, metabolic, and miscellaneous categories, respectively, for first parity. Genetic correlations between categories of health treatment cost for first parity were greatest for mastitis and reproduction ($r = 0.85 \pm 0.20$); however, phenotypic correlations between all categories were small ($r < 0.16$). Total health treatment cost had a large genetic correlation with 305-d milk production (0.44 ± 0.18) and somatic cell score (0.93 ± 0.13) for first parity. Also, the genetic correlation (-0.60 ± 0.16) between total health treatment cost and udder depth for first parity indicated a genetic relationship exists between shallow udders and less total health treatment cost.

Total health treatment cost across categories had a heritability estimate of 0.25 ± 0.07 for first parity, 0.16 ± 0.06 for second parity, and 0.17 ± 0.11 for third parity. Consequently, genetic selection for reduced health treatment cost should be possible by using producer-recorded health treatment records supplemented with treatment costs.

Keywords: Health treatment cost, Holstein, wellness trait, transition disorder

INTRODUCTION

The long-term genetic improvement of production and conformation traits in the Holstein breed has negatively affected the health and welfare of dairy cows (Oltenacu and Broom, 2010), and the decreased health of cows usually reduces profitability. The total economic cost of health disorders are often not considered by dairy producers, but those costs may substantially erode profit per cow for diseased animals. For example, Guard (2008) reported the total cost of a displaced abomasum was $494 and the cost of each case of lameness was $469. Also, health disorders impact the profitability of cows through greater involuntary culling, loss of cull cow income from death, decreased milk production, and greater milk withholding (Zwald et al., 2004a). Furthermore, the impaired health of cows leads to reduced fertility (Weigel, 2004), and each additional day open (d from calving to conception) results in a reduction of $2.75 in profit (VanRaden and Cole, 2014). Consequently, selection for cow health is of growing interest to dairy producers.

Direct selection against health disorders has been successful in Scandinavian countries for more than 30 yr (Philipsson and Lindhé, 2003), because only veterinarians are permitted to treat health disorders and they uniformly record all health treatments for cows in a national database. Also, since the 2000s, several European countries including Austria and Germany, have instructed producers to keep accurate and complete records of health treatments, which has proven valuable for the genetic evaluation of some health disorders (Pryce et al., 2016). However, in many countries (including the US), the recording of health treatments is voluntary, and producer-recorded health data are often variable and incomplete. Low-quality data for health treatments may lack utility for both herd management and for genetic evaluation. However, several North American studies have documented the feasibility of using producer-recorded health data to genetically improve the health of dairy cows (Zwald et al., 2004a; Koeck et al., 2012; Neuenschwander et al., 2012; Parker Gaddis et al., 2014).

Estimates of heritability for health traits of dairy cows have generally been low; however, the highest estimates have been reported for the health disorders that are most frequently recorded due to either their high cost or their ease of recording (Zwald et al., 2004a; Appuhamy et al., 2009; Neuenschwander et al., 2012). For example, the estimates of heritability for displaced abomasum (from 0.03 to 0.21) and mastitis (from 0.01 to 0.09) make these particular disorders attractive candidates for genetic selection. Despite the typically low estimates of heritability, significant genetic correlations between health disorders have been reported (Koeck et al., 2012; Parker Gaddis et al., 2014; Vukasinovic et al., 2017), including 0.44 for displaced abomasum with metritis (Koeck et al., 2012) and 0.56 for retained placenta with metritis (Parker Gaddis et al., 2014). Furthermore, Rupp and Boichard (1999) found an antagonistic genetic correlation (0.45) between milk production and clinical mastitis. Mounting evidence suggests selection for greater body size and lower body condition of Holstein cows has been detrimental to health of cows. In particular, a long-term selection study on body size reported large Holstein cows had 30% greater cost of health care than small cows (Becker et al., 2012). Furthermore, Dechow et al. (2004) found that dairy form, as a measure of angularity, was highly correlated (0.85) with a composite of all health disorders from national US data.

Health disorders have not been included in official genetic evaluation in the US because traits with low incidence rates and recorded in a binary fashion present challenges for effective selection (Zwald et al., 2004a). Moreover, Neuenschwander et al. (2012) and Parker Gaddis et al. (2012) suggested producer-recorded health data require large numbers of cows over multiple years in order to detect reliable differences between sires within breeds. The objective of this study was to estimate genetic parameters of health treatment cost (as opposed to binary incidence rates) of Holstein cows from producer-recorded health treatments that were uniformly defined and consistently recorded in 8 herds over an 8-yr period of time.

MATERIALS AND METHODS

Experimental Design

A long-term study of Holstein cows in 8 high-performance herds in Minnesota was initiated by the University of Minnesota in 2008. In June 2016, the weighted mean production for all cows in the 8 herds was 14,019 kg of milk, 519 kg of fat, 433 kg of protein, and the herds ranged in size from 302 to 1,932 cows with a mean herd size of 981 cows; however, some cows in the herds were not Holstein. All cows in each of the 8 herds were housed in a 4- or 6-row freestall facility and fed a TMR during lactation.

Cows were mated to only proven AI bulls with very high rank for Net Merit (VanRaden and Cole, 2014), and the bulls were chosen by the herd owners in consultation with 2 genetic advisors employed by Minnesota Select Sires Co-op, Inc., St. Cloud, MN. Herd owners were asked to select proven AI bulls that ranked among the top 10% of available bulls for the Net Merit index within the Holstein breed. Also, some of the pure Holstein heifers and cows were mated to proven AI bulls from the Montbeliarde and Viking Red breeds, but those progeny were not included in this study. Following selection of AI bulls, cows were correctively mated by the 2 genetic advisors for conformation and heifers were correctively mated, when possible, using the conformation scores of their dam. Also, inbreeding protection was provided for matings of Holstein AI bulls to Holstein cows and heifers.

Experimental Units

Only the first 3 lactations of 4,894 Holstein cows across the 8 herds were considered for the study. Cows initiated a first lactation from March 2008 to October 2015 and were required to calve for a first time during this time span in order to contribute data for second and third parity. Data for this study included 287 cows that had not completed first, 218 cows that had not completed second, and 109 cows that had not completed third lactation by the end of the study (November, 2015). Lactations of cows commenced with an abortion (n = 267) were removed from the analysis. Also, the lactations of cows that calved during the final month of the study (n = 77) did not have the opportunity to accumulate 30 d of health treatment cost and were removed from the data.

All cows and their dams were required to be sired by a Holstein AI bull that had a sire code assigned by the National Association of Animal Breeders (Columbia, MO). Additional edits eliminated cows with sires that had only a single daughter and with maternal grandsires that had only a single daughter or granddaughter. The edits that were based on pedigree of cows were applied to improve the accuracy of sire and maternal grandsire identification. Following all edits, 2,214 cows sired by 260 AI bulls remained for analysis and a total of 4,501 lactations were analyzed. The distribution of cows by herd and parity is in Table 1.

Trait Descriptions

Health Treatments. The treatment of 14 individual health disorders (Table 2) were uniformly defined and consistently recorded across the 8 herds with Dairy Comp 305 (Valley Ag Software, Tulare, CA). To distinguish between multiple treatments of the same illness event during the lactation of each cow, a new health treatment observation was assigned only if 3 or more days elapsed between hoof treatments, if 5 or more days elapsed between digestive, ketosis, mastitis, metritis, milk fever, and respiratory treatments, or if 7 or more days elapsed between cystic ovary treatments. Only a single treatment observation was permitted per lactation of a cow for displaced abomasum, retained placenta, and miscellaneous reproduction. No restriction on days between treatments was applied to mastitis diagnostic test, injury, or other treatments; however, only 1 treatment per day was permitted. The health treatments were assigned to 1 of 5 categories: mastitis (**MAST**), reproduction (**REPRO**), lameness (**LAME**), metabolic (**META**), and miscellaneous (**MISC**), which are itemized in Table 2.

A fixed cost was calculated for each of the 14 types of health treatments, and cost was the sum of veterinary expense, pharmaceuticals, and labor cost associated with each specific type of treatment. Veterinary expenses and pharmaceutical costs were the mean costs for each treatment reported by the veterinarians that serviced the 8 herds. Labor cost included the time required by herd owners for segregation, restraint, and therapy and was assigned a value of $18/h. The hourly rate and the time attributed to each type of health treatment was the mean rate and time reported during interviews of the 8 herd owners.

The observations for health treatment cost of each cow were summed within each of the 5 health categories by parity (including the subsequent dry period) to obtain a lactational cost for MAST, REPRO, LAME, META, and MISC. Likewise, the costs of 4 specific health treatments (displaced abomasum, ketosis, metritis, and retained placenta) were summed by treatment type and by parity for each cow. Finally, health treatment cost across all 14 treatment types was summed to obtain the total health cost (**THC**) by parity for individual cows. For cows that left the herd during lactation, THC was simply the sum of health costs from calving until the day of disposal and no adjustment was made for DIM at disposal. Likewise, for cows with records in progress at the end of the study (n = 614), THC for that parity was the sum of health costs incurred from calving until the end of the study.

Production and SCS. Best Prediction (Cole and VanRaden, 2009), which is routinely used for genetic evaluation in the US, was applied to individual test-day observations to calculate the actual 305-d milk, fat, and protein production (not mature equivalent production) as well as SCS of cows for their first 3 lactations. Five of the 8 herds had monthly test-day observations, and the other 3 herds had test-day observations at least 8 times per yr. Test-days were required to be at least 4 DIM and milk weights were required to be greater than 2.27 kg, fat percentage was required to be at least 1.0% but no greater than 9.9%, and protein percentage was required to be at least 1.0% but no greater than 6.0%. Best Prediction adjusted records for age at first calving and projected records to 305 d for records less than 305 d. Some cows left herds prior to a first test day; therefore, a total of 2,155 first parity, 1,466 second parity, and 757 third parity records were available for analysis.

Conformation. Conformation of cows was scored once during first lactation by 1 of 2 evaluators employed by Minnesota Select Sires Co-op, Inc., St. Cloud, MN. Three conformation traits (stature, dairy form, and udder depth) were analyzed for this study and were subjectively scored on a 1-to-9 linear scale with a score of 5 representing the biological mid-point for each trait (Select Sires, Inc., Plain City, OH). Most cows were scored in early lactation (32 ± 0.3 DIM). Stature was scored, but not measured, at the withers and each unit on the 1 to 9 scale represented approximately 2.54 cm of height. Cows with a score of 1 were less than 130 cm and cows with a score of 9 were greater than 150 cm. For dairy form, a score of 1 represented heavy, coarse-boned cows that lacked openness of rib, whereas 9 represented clean, open-ribbed, long-necked cows. Udder depth described the position of the udder floor relative to the hocks and each unit on the 1 to 9 scale represented approximately 2.54 cm. Cows with a score of 1 had udder depth at least 5 cm below the point of the hock, and cows with a score of 9 had udder depth at least 15 cm above the point of the hock. Some cows either left the herds prior to scoring or were not scored; therefore, conformation was analyzed for 2,090 first-parity cows.

Genetic Analysis

Linear animal models ignoring the pedigree for maternal granddams of cows were fitted using restricted maximum likelihood (ASReml; Gilmour et al., 2015). Pedigrees of the Holstein cows were provided by the Council on Dairy Cattle Breeding (Bowie, MD); however, only relationships among sires and maternal grandsires of cows were used for analysis. All models included the fixed effect of herd and cow nested within herd was a random variable. A preliminary analysis examined the fixed effects of year and season of calving; however, neither effect significantly accounted for variation of the dependent variables.

Three distinct statistical models were used for analysis. First, a univariate linear model was fitted to obtain least squares means, estimates of heritability, and standard errors for health treatment cost for each of the 5 health treatment categories, THC, the 4 specific health treatment costs, and the 3 conformation traits for only first parity. The second was a bivariate linear model, which was fitted to obtain pairwise genetic and phenotypic correlations between the 5 categories of health treatment cost, THC, 4 specific health treatment costs, 305-d production, and conformation for only first parity. Correlations were obtained in a pairwise manner because convergence of a multitrait model including all dependent variables simultaneously was not feasible with ASReml. Lastly, a multivariate linear model was fitted to obtain least squares means, estimates of heritability, and standard errors for THC, 305-d production, and SCS during first, second, and third parity. For this model, each of the dependent variables were analyzed separately and each of the 3 parities were defined as 3 distinct traits in the multivariate model.

RESULTS AND DISCUSSION

Least Squares Means

The mean cost for 5 categories of health treatment, THC, and mean cost for 4 specific health treatments (Table 3) were generated by the univariate analysis that included only a single parity for Holstein cows. The REPRO had the highest percentage contribution (28%) to THC and a first-parity cost of $15.28. The cost of REPRO mostly reflected treatment cost for metritis, which had a cost of $9.95. Also, LAME (23%) and MAST (20%) contributed greatly to THC with cost of $12.89 and $10.88, respectively. Donnelly et al. (2017) analyzed the costs of health treatments subdivided by 6 intervals of lactation and found the treatment costs for REPRO, META, and MISC were more concentrated during early lactation, while treatment costs for MAST and LAME were distributed throughout first lactation. In that study, 41% of THC during first parity occurred during the first 30 d of lactation.

The means for the 3 conformation traits for first parity conformed to expectation for young Holstein cows in early lactation (Table 3). The score of 5.6 for stature (on a 9-point scale) converts to approximately 141 cm of stature at the withers (Select Sires, Inc., Plain City, OH). For dairy form, the least squares mean of 5.4 indicated these first-parity cows in early lactation were slightly more angular than the biological midpoint for dairy form. First-parity cows in this study had mean udder depth of 6.7, which indicated that the average cow had an udder floor approximately 9 cm above the point of hock. Shallow udders for first-parity Holsteins were also reported in a French study by Rupp and Boichard (1999) and were also scored on a similar 9-point scale with an average score of 6.3 for udder depth.

The multivariate analysis was used to fit means for THC across the first 3 parities (Table 4), and the mean THC for first parity from that analysis differed by only $2.73 from the univariate analysis. The least squares means for THC from the multivariate analysis increased with parity (Table 4) and ranged from $57.91 for first parity to $87.95 for third parity. The THC observed for first parity in this study may not seem expensive on a per-cow basis; however, the average herd in this study calved 444 first-parity cows during 2015, which amounts to at least $25,000 annually in THC. Furthermore, the 8 herds had more multiparous than primiparous cows; therefore, the economic impact of THC for these 8 herds was substantial and may greatly impact profitability.

The least squares means for production traits for parities 1 to 3 (Table 4) were also calculated from the multivariate analysis, and the means fit expectations for the high performance of these 8 herds. The least squares means for milk, fat, protein, and fat plus protein production increased with parity, and the milk production of cows in this study was far superior to the average fluid milk production (10,157 kg) of cows enrolled in milk recording across the US during 2015 (US Department of Agriculture, 2016). Furthermore, the means of SCS were similar to the average SCS for first (2.2), second (2.4), and third and greater (3.0) parity of US Holstein herds enrolled in milk recording (Dairy Records Management System, 2016).

Estimates of Heritability for Health Treatment Cost in First Parity

Heritability was estimated for the 5 categories of health treatment cost and also for THC with a univariate analysis that only considered first parity of cows and is in

Table 5. The estimate of heritability (0.13) for cost of MAST was higher than the estimates of heritability of 0.06 and 0.09 reported by Gernand et al. (2012) and Zwald et al. (2004a), respectively. The estimate of heritability for cost of MAST in this study supports the suggestion of Nash et al. (2000) and Zwald et al. (2004a) to include both mastitis and SCS in a selection index to improve the effectiveness of selection for mastitis resistance.

The estimate of heritability (0.04) for cost of REPRO in first parity (Table 5) was low and not significantly different from zero. Previous studies have reported similarly low estimates of heritability (0.02) for the incidence of reproduction disorders across parities (Lyons et al., 1991; Dechow et al., 2004). The health treatment cost for metritis and retained placenta (Table 6) had estimates of heritability of 0.02 and 0.12, respectively, and both of these individual health treatment costs were included for the cost of REPRO. The estimate of heritability of metritis cost in this study was similar to the estimates of heritability (0.01 to 0.04) from 3 other reports (Van Dorp et al., 1998 and Koeck et al., 2012, Parker Gaddis et al., 2014). However, the estimate of heritability (0.12) for cost of retained placenta in this study was smaller than the heritability (0.22) reported by Parker Gaddis et al. (2014), but larger than the estimate of heritability (0.07) recently reported by Vukasinovic et al. (2017) from a large, producer-recorded data file in the US. A possible explanation for the different estimates of heritability for retained placenta across studies may be due to differences in the clear distinction of treatment for retained placenta and treatment for metritis, because treatments for these two reproductive disorders are sometimes recorded as a single disorder. The estimates of heritability in this study suggest the cost of retained placenta is a superior selection criterion to the categorical cost of all REPRO treatments because large variation existed for the cost of metritis and other costs of specific health treatments summed within REPRO.

The estimate of heritability of 0.10 for cost of LAME in this study (Table 5) is within the range of estimates (0.02 to 0.23) for incidence of specific types of hoof health disorders for Holstein cows in Nordic countries (Häggman and Juga, 2013; Ødegård et al., 2013). Hoof health data recorded by professional hoof trimmers in Nordic countries was the foundation for the development of a hoof health selection index, which was integrated into the Nordic total merit index in 2011 (Johansson et al., 2011). Genetic evaluation of hoof health disorders using data recorded by hoof trimmers has also been explored in other regions of the world including Canada (Chapinal et al., 2013), Spain (Pérez-Cabal and Charfeddine, 2015), and the Netherlands (van der Linde et al., 2010). The estimate for cost of LAME in this study suggests selection for reduced cost of lameness of dairy cattle is possible when treatments for LAME are routinely recorded. Selection for reduced lameness may increase the profitability of cows; however, the consequential improvement of welfare of cows may be even more valuable into the future.

The cost of META had an estimate of heritability of 0.12 for first parity (Table 5), which was higher than the estimate of 0.05 reported by Gernand et al. (2012), but lower than the estimate of 0.17 from Lyons et al. (1991) for incidence of metabolic disorders. Displaced abomasum accounted for 61% of the cost of META (Table 3) and had an estimate of heritability of 0.12 (Table 5) for first parity. The heritability of displaced abomasum cost in the present study was in agreement with the estimate of heritability

(0.12) for incidence of displaced abomasum reported by Parker Gaddis et al. (2014), but higher than estimates of 0.08 and 0.09 reported for incidence of displaced abomasum by Dechow et al. (2004) and Abdel-Azim et al. (2005), respectively. Ketosis also contributed to cost of META cost in this study, and ketosis had an estimate of heritability of 0.18 when evaluated as a specific health treatment (Table 6). Our estimate of heritability (0.18) for ketosis cost was greater than the estimates ranging from 0.01 and 0.14 for incidence of ketosis in Holstein cows reported by the 10 studies reviewed by Pryce et al. (2016). Donnelly et al. (2017) described the substantial treatment costs for specific health disorders (especially displaced abomasum) included in META for this study; however, the incidence of treatments for META is apparently low because the cost of META was only 15% of THC (Table 3). Therefore, selection against META cost may substantially reduce health costs even though a small percentage of cows have metabolic disorders because of the high cost associated with each treatment of META.

The low estimate of heritability (0.04) for MISC cost for first parity was not significantly different from zero. Reports of heritability for respiratory disorders are sparse in the literature; however, Lyons et al. (1991) estimated heritability of 0.01 for respiratory disorders. Few injured cows experience treatment because most cows either recover without intervention or exit the herd without treatment when an injury is catastrophic. Therefore, results from this study suggested treatments for injury were highly dependent on environmental factors. Therefore, the low heritability (0.04) for cost of MISC in this study was anticipated because of the lack of uniform treatment types within the MISC category.

This study summed the cost of all disorders for a lactation, which permitted a comprehensive consideration of the genetic control of health disorders, and this is contrary to a majority of studies that used field data to estimate genetic parameters for incidence of health treatments recorded in a binary manner (Harder et al., 2006; Koeck et al., 2012; Parker Gaddis et al., 2014; Vukasinovic et al., 2017). Previous research with incidence data typically gave estimates of heritability for health disorders that were less than 0.10; however, the estimate of heritability (0.27) for THC from this study was moderate for first parity (Table 5), despite the lower estimates for each of the 5 treatment categories. The higher estimate of heritability (0.27) found in this study compared with previous research likely resulted from greater variation for THC between cows. Variation in THC in this study may have resulted from the assignment of variable costs for 14 specific health treatments, from permitting treatment incidence of some disorders to be recorded more than once per lactation, or from both. Apparently, sires that transmitted genes to their daughters that resulted in greater cost of health disorders were more readily exposed when cost of treatments were combined compared to analyses in which incidence of health treatments were combined. Few studies have summed incidence or cost of health treatments within a lactation; however, Lyons et al. (1991) estimated a heritability of 0.03 for the sum of all health incidences weighted by their costs and pooled across lactations.

Estimates of Heritability for Conformation

The heritability estimate (0.42 ± 0.08) for stature was the highest of the 3 conformation traits, and this was expected because previous studies also reported stature had the highest heritability among commonly reported conformation traits (DeGroot et al., 2002; Dechow et al., 2003). The estimate of heritability for dairy form and udder depth for first parity was 0.28 ± 0.06 and 0.32 ± 0.07, respectively. Dechow et al. (2003) reported estimates of heritability of 0.37 for stature and 0.24 for dairy form, which are similar to the estimates in this study. However, Van Dorp et al. (1998) found a much lower estimate of heritability for udder depth (0.19). Nonetheless, the heritability estimates from this study are in general agreement with those published by Holstein Association USA (2016), which were 0.42, 0.29, and 0.28 for stature, dairy form, and udder depth, respectively.

Genetic and Phenotypic Correlations for First Parity

Health Categories and THC. Positive genetic correlations were found among all combinations of the 5 categories of health treatment costs for first-parity cows (Table 5). Clearly, genetic predisposition for health treatment cost in one category was accompanied by greater likelihood of health treatment cost in other categories. The genetic correlation (0.85) between the costs of MAST and REPRO was particularly large, and the estimate from this study was greater than the genetic correlations between mastitis and specific types of reproduction disorders reported by Koeck et al. (2012) and Parker Gaddis et al. (2014). The genetic correlation (0.73) between the costs of REPRO and META was also substantial and greater than estimates of genetic correlation (-0.21 to 0.42) between the incidence of similar types of health disorders reported by Zwald et al. (2004b), Koeck et al. (2012), and Parker Gaddis et al (2014).

Genetic correlations between THC and health treatment cost for each of the 5 categories (Table 5) were all highly positive and ranged from 0.65 (THC with LAME) to 0.92 (THC with MAST). The correlations of THC with the cost of REPRO (r = 0.91) and THC with the cost of MISC (r = 0.72) were not different from unity for first parity because the SE for both correlations were large; therefore, we believe selection for THC may be more effective for lowering the cost of REPRO and MISC than direct selection for only cost of REPRO and MISC, which both had low and non-significant estimates of heritability.

The phenotypic correlations among the 5 categories of health treatment cost were much smaller than the genetic correlations and ranged from −0.05 (MISC with LAME) to 0.16 (MISC with META). Phenotypically, cows with more META cost were more prone to higher costs of REPRO (r = 0.14) and MISC (r = 0.16). Metabolic disorders, especially ketosis, have been associated with an increase of other infectious diseases and impaired reproduction in other reports (Reist et al. 2003; Walsh et al., 2007); therefore, the significant phenotypic relationship between the costs of REPRO and META in this study was not surprising. Among commercial herds in New York, cows with retained placenta had increased risk of developing mastitis (Schukken et al., 1988). However, our study found no phenotypic correlation (0.00) between the costs of REPRO and MAST for first parity. Phenotypic correlations between THC and the health treatment cost of the 5 categories ranged from 0.27 (LAME) to 0.66 (REPRO). Costs of REPRO and META had the largest phenotypic correlations (0.66 and 0.63, respectively) with THC. The individual treatments with highest cost were found within these 2 categories (Donnelly et al., 2017), which may partially explain their strong phenotypic correlation with the total costs of health treatment for first-parity cows. Furthermore, a moderate phenotypic correlation (0.34) existed between THC and the cost of MAST, which confirmed the result of Hansen et al. (2002), who reported cows with mastitis are more likely to experience other health disorders.

Four Specific Health Treatments. For first parity, the costs of displaced abomasum and ketosis had a genetic correlation (0.97) near unity (Table 6), which indicated genes influencing treatment for displaced abomasum were likely the same genes influencing treatment of ketosis. Similarly, the genes associated with treatment costs of retained placenta and ketosis (r = 0.88) may be mostly the same. Also, the genetic correlation (0.79) for costs of metritis and displaced abomasum was likely the explanation for the large genetic correlation (0.73) between the categorical costs of REPRO and META (Table 5).

Four of the 5 phenotypic correlations estimated among the costs for the specific health treatments (Table 6) were significantly greater than zero. Apparently, some cows treated for a first health disorder postpartum experienced a second (or multiple) health disorders postpartum. The phenotypic correlation (0.24) for ketosis and displaced abomasum is comparable to the correlation of 0.27 among the same 2 traits for Holstein cows in a study of Canadian commercial herds (Koeck et al., 2012). A study by LeBlanc et al. (2005) reported postpartum negative energy balance may lead to a metabolic disorder, such as ketosis, which is a risk factor for displaced abomasum. The low phenotypic correlations between the cost of specific health treatments in this study agree closely with the correlations between incidences of health disorders from other studies (Van Dorp et al., 1998; Koeck et al., 2012), and this is likely because treatments of retained placenta and displaced abomasum occurred once per lactation and none of these traits were grouped with other disorders for analysis.

THC and Production Traits. The genetic correlation (0.44) of THC with 305-d milk production was especially unfavorable (Table 7) and provided evidence that the simultaneous selection for lower health cost in conjunction with selection for milk production is very important. Lyons et al. (1991) reported a smaller genetic correlation (0.29) between milk production and the sum of all health incidences. In the current study, fat, protein, and fat plus protein production also had unfavorable genetic correlations with THC, but they were smaller and not significantly different from zero. Perhaps, selection for the solids constituents in milk is not as detrimental to cow health as the historical selection for fluid milk. The genetic correlation (0.93) of THC with SCS was large, and Täubert et al. (2013) reported a large genetic correlation (0.76) of SCS with incidence of mastitis. More than likely, the dramatic genetic trend for reduced SCS in the US since 2001 (Council on Dairy Cattle Breeding, 2016) has reduced THC of the Holstein breed during the last 15 yr.

Phenotypic correlations between THC and production traits (Table 7) were negative and small. Cows with more health problems and consequently, greater THC, had decreased 305-d production of milk, fat, protein, and fat plus protein. Other studies also found a slightly negative relationship between health disorders and production (Fourichon et al., 1999; Gernand et al., 2012). A small and positive phenotypic correlation (0.14) between SCS and THC in this study was similar to the 0.22 phenotypic correlation reported by Täubert et al. (2013). Cows with high SCS are expected to have more THC because higher SCS often accompanies greater cost of MAST.

Health Treatment Cost and Conformation. None of the genetic correlations of health treatment cost for the 5 categories, THC, and 4 specific health treatments with stature and dairy form (Table 8) were significantly different from zero because the standard errors were large. These results are contrary to Dechow et al. (2004), who reported a large, antagonistic genetic association of 0.85 between dairy form and a composite of all diseases recorded in US dairy herds. The large, but not significant, genetic correlations of stature and dairy form with health treatment cost are likely a reflection of scoring of the cows for stature and dairy form only once in early lactation in this study resulting in little variation (SE = 0.14 and 0.16; Table 3). Therefore, statistical models may have had difficulty detecting the underlying genetic relationships. The addition of observations for conformation traits during late lactation and from multiparous cows (e.g., Dechow et al., 2004) would provide more phenotypic variation to permit elucidation of genetic relationships.

The phenotypic correlations of both stature and dairy form with health treatment costs for each of the 5 categories were small (Table 8); however, some were significantly different from zero. Small phenotypic correlations between the conformation traits and health disorders were also reported by Lund et al. (1994) and Van Dorp et al. (1998). Taller cows in this study were associated with greater cost of MAST ($r = 0.04$), LAME ($r = 0.04$), and META ($r = 0.04$). Furthermore, taller cows were associated with increased displaced abomasum. A long-term selection study on body size of Holsteins (Becker et al., 2012) found cows in a large body size line had 2.6 times the incidence of displaced abomasum as cows in a small body size line for first parity and more than 4 times the incidence of small-line cows for second parity. The large body size line had double the treatment cost for displaced abomasum compared with the small body size line (Becker et al., 2012).

Phenotypically, cows with more dairy form and, therefore, lower BCS (Dechow et al., 2003) were associated with higher costs of REPRO (r = 0.04) and also greater THC (r = 0.05) in the present study. Others (Hansen et al., 2002; Dechow et al., 2004) have hypothesized that the mechanism of causation lies in the association of high dairy form with negative energy balance that is typical for periparturient Holstein cows. Negative energy balance causes a depressed immune system (Goff and Horst, 1997), which could lead to more cost for health treatments—especially for postpartum metabolic disorders but also for some infectious diseases.

The genetic correlation (−0.60) of udder depth with THC indicated bulls transmitting shallower udders also transmitted lower cost of health treatments (Table 8). Perhaps, this genetic relationship was because cost of MAST had the largest genetic correlation (−0.84) among health treatment categories with udder depth. Rupp and Boichard (1999) reported a more modest genetic correlation (−0.26) between udder depth and incidence of mastitis. Furthermore, udder depth had a significant genetic correlation (−0.65) with REPRO cost. The favorable genetic relationships of udder depth with lower cost of MAST, REPRO, and THC may result from concurrent genetic selection for udder depth, SCS, and fertility. The phenotypic correlation (−0.11) between udder depth and MAST cost indicated cows with shallower udders had lower MAST cost. Udders closer to the ground may have functional problems while milking or may have more contact with bedding in stalls (Hansen et al., 1999). Therefore, the relationship of udder depth and MAST cost may be a result of only extremely deep udder depth and not a result of extremely shallow udder depth. However, the EBV for stature and udder depth have a large genetic correlation (DeGroot et al., 2002); therefore, inclusion of udder depth in selection indexes as an indicator of reduced MAST cost in the US and internationally must be done with care to avoid a corresponding increase of stature.

Heritability of THC and Production Traits for Multiple Parities

The estimated heritability (0.25) of THC for first parity from the multivariate analysis (Table 9) was similar to the heritability (0.27) from the univariate analysis; however, both estimates were remarkably high compared to previous estimates of heritability for health traits. The estimates of heritability for THC for second (0.16) and third (0.17) parity were more modest than the result for first parity. The decrease in heritability of THC with increasing parity may result from the reduced number of cows contributing to the estimates and the removal (culling) of cows with greater THC from parity to parity. Cows with lower first-parity THC are more likely to remain for second and third parity. Zwald et al. (2004a) also reported higher heritability of health traits for first-parity cows than for multiparous cows, and they attributed this result to decreased genetic variance or increased residual variance from environmental factors such as poor management during the previous dry period. Our results suggest substantial genetic control for THC for all 3 parities. Therefore, because of the negative impact of THC on cow profitability, selection against THC should provide substantial economic gain for dairy producers.

Estimates of heritability for the production traits (Table 9) were similar to those used for routine genetic evaluation of US Holstein cows (VanRaden and Cole, 2014) for the production traits ($h^2 = 0.20$) and for SCS ($h^2 = 0.12$). However, estimates of heritability for 305-d production for first parity from this study were lower than the estimates reported by Rupp and Boichard (1999) of 0.26, 0.31, and 0.26 for milk, fat, and protein production, respectively, for French Holstein cows. The heritability (0.18) for SCS in this study is in agreement with the estimate of heritability (0.17) of Van Dorp et al. (1998).

Moderate heritabilities for production traits of dairy cattle have permitted substantial improvement in production over the past 50 years. The heritability of THC in this study suggests substantial improvement should likewise be possible for reducing health treatment cost of dairy cows if health treatments are recorded in a uniform manner on farms for the most common and most expensive health disorders.

Prediction of Breeding Values

The EBV for THC of sires (n = 53) with at least 10 daughters from the univariate analysis of first-parity cows are plotted versus the mean THC of the corresponding daughters (Figure 1). The EBV for THC ranged from \$67 to −\$49, and this is a difference of roughly \$116 between the highest and lowest for first-parity THC. However, most of the sires had EBV for THC between \$20 and −\$40. The regression coefficient was 0.92, which indicated the EBV for THC of sires were very good predictors of the extent of THC for their daughters. The range of EBV for THC suggests sire selection could be highly effective in successfully reducing the THC of dairy cows.

CONCLUSIONS

The genetic evaluation of health traits for dairy cows in the US has been inhibited by inconsistent and incomplete health data because producers in the US are not incentivized or required to record health events. Most previous efforts to estimate genetic parameters of health traits had observations limited to the recording of a single binary outcome per disorder for each parity. The comprehensive recording of health data by the

8 herds in this study permitted the application of health treatment costs on the 14 different types of treatment and also enabled inclusion of multiple treatments per lactation for genetic analysis. These two factors provided greater expression of genetic variation and may have furnished a more appropriate data structure than binary data for a genetic analysis of health disorders.

Genetic correlations between THC and health treatment cost for each of the 5 treatment categories were large and positive for first parity. The moderate genetic correlation between THC and 305-d milk production for first parity suggested historical selection for increased fluid milk production may have caused a correlated increase of THC in modern Holstein cows; however, our results suggest selection for fat (kg) and protein (kg) has a reduced association with THC.

Results from this study indicate the collection of uniform and comprehensive health treatment data in the US is potentially feasible using current herd management software. However, the EBV for THC of dairy cattle must be included in a selection index with appropriate economic weights that have taken into account the relationship of THC with other traits included in the selection index. Selection for reduced THC should lessen the chances of antibiotic residues in meat and milk and should lead to the enhanced welfare of cows and an improved public perception of the dairy industry.

ACKNOWLEDGEMENTS

The authors are grateful to the owners/managers of the 8 herds for their participation in this study. The authors also wish to thank Minnesota Select Sires Co-op, Inc. for mating individual heifers and cows and the scoring of conformation traits. Funding for this project was provided by Coopex Montbeliarde, Roulans, France; Viking

Genetics, Randers, Denmark; Creative Genetics of California, Oakdale, CA; Select Sires, Inc., Plain City, OH; and Minnesota Select Sires Co-op, Inc., St. Cloud, MN.

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Table 1. Numbers of cows analyzed for cost of health treatments by herd and parity

	Parity		
Herd	1	2	3
A	394	246	125
B	227	157	100
C	427	299	181
D	402	279	150
E	179	117	59
F	152	105	48
G	250	159	66
H	183	125	71
Total	2,214	1,487	800
Percentage of total by parity (%)	49	33	18

Table 2. Specific health treatments included in the health treatment categories

Category	Abbreviation	Treatment
Mastitis	MAST	Mastitis Mastitis diagnostic test[1]
Lameness	LAME	Hoof treatment[2]
Reproduction	REPRO	Cystic ovaries Retained placenta Metritis Miscellaneous reproduction[3]
Metabolic	META	Milk fever Displaced abomasum Ketosis Digestive[4]
Miscellaneous	MISC	Respiratory Injury Other treatments

[1] Mastitis diagnostic test included milk culture and California Mastitis Test (Immucell, Portland, ME).
[2] Hoof treatment included dermatitis, infectious pododermatitis, foot ulcer, and other hoof treatments.
[3] Miscellaneous reproduction included abortion treatments, caesarean section, pyometria, uterine disorders (adhesion, mass, prolapse, and torsion), and mummified calf.
[4] Digestive included clostridium, traumatic reticuloperitonitis, hemorrhagic bowel syndrome, peritonitis, twisted cecum, lack of appetite, or any other digestive treatment.

Table 3. Least squares means, standard errors, and percent of total health cost (THC) for the treatment costs of 5 health categories, THC, 4 specific health treatments, and the average conformation scores (1 to 9 scale) for first parity from univariate analysis

Trait	LSM	SE	Percentage of total
Category[1]	------------($)------------		(%)
MAST	10.88	2.36	20
REPRO	15.28	4.54	28
LAME	12.89	2.13	23
META	8.02	3.82	15
MISC	8.13	2.28	15
THC	55.18	7.89	100
Specific health treatment			
Metritis	9.95	3.53	18
Retained placenta	2.12	1.22	4
Displaced abomasum	4.91	3.33	9
Ketosis	0.60	0.42	1
Conformation	---------Score---------		
Stature	5.6	0.14	--
Dairy form	5.4	0.16	--
Udder depth	6.7	0.13	--

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.

Table 4. Least squares means and pooled SE for total health treatment cost (THC), 305-d production, and SCS for parities 1 to 3 from multivariate analysis across parities

	Parity			
Trait	1	2	3	Pooled SE
THC ($)	57.91	73.92	87.95	13.95
Milk (kg)	10,943	12,628	13,018	261
Fat (kg)	395	449	464	9.5
Protein (kg)	332	389	401	7.1
Fat + Protein (kg)	726	838	865	15.8
SCS	2.21	2.33	2.63	0.13

Table 5. Estimates of heritability (in bold on the diagonal, with SE in parentheses) from the univariate analysis, and genetic correlations (above the diagonal, with SE in parentheses) and phenotypic correlations (below the diagonal, with SE in parentheses) from pairwise bivariate analysis for the treatment costs of 5 health categories[1] and total health treatment cost (THC) for first parity

	MAST	REPRO	LAME	META	MISC	THC
MAST	**0.13*** (0.05)	0.85* (0.20)	0.34 (0.28)	0.52 (0.27)	0.66 (0.34)	0.92* (0.10)
REPRO	0.00 (0.02)	**0.04** (0.03)	0.41 (0.35)	0.73* (0.29)	0.59 (0.40)	0.91* (0.09)
LAME	0.03 (0.02)	−0.01 (0.02)	**0.10*** (0.04)	0.56* (0.25)	0.21 (0.38)	0.65* (0.18)
META	0.02 (0.02)	0.14* (0.02)	0.02 (0.02)	**0.12*** (0.05)	0.40 (0.37)	0.85* (0.10)
MISC	0.04* (0.02)	0.02 (0.02)	−0.05* (0.02)	0.16* (0.02)	**0.04** (0.03)	0.72* (0.20)
THC	0.34* (0.02)	0.66* (0.01)	0.27* (0.02)	0.63* (0.01)	0.39* (0.02)	**0.27*** (0.07)

[1] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.

* Estimate was significantly different from zero based on 95% CI.

Table 6. Estimates of heritability (in bold on the diagonal, with SE in parentheses) from the univariate analysis, and genetic correlations (above diagonal, with SE in parentheses) and phenotypic correlations (below diagonal, with SE in parentheses) from pairwise bivariate analysis for the cost of 4 specific health treatments for first parity

	Metritis	Retained placenta	Displaced abomasum	Ketosis
Metritis	**0.02** (0.02)	0.66 (0.48)	0.79* (0.23)	---[1]
Retained placenta	0.21* (0.02)	**0.12*** (0.05)	−0.37 (0.27)	0.88* (0.20)
Displaced abomasum	0.16* (0.02)	0.01 (0.02)	**0.12*** (0.05)	0.97* (0.15)
Ketosis	---[1]	0.06* (0.02)	0.24* (0.02)	**0.18*** (0.07)

* Estimate was significantly different from zero based on 95% CI.

[1] Convergence was not achieved.

Table 7. Genetic and phenotypic correlations (SE in parentheses) of total health cost (THC) with 305-d production and SCS for first parity from pairwise bivariate analysis

	THC	
Trait	Genetic	Phenotypic
Milk	0.44* (0.18)	−0.07* (0.02)
Fat	0.07 (0.21)	−0.08* (0.02)
Protein	0.28 (0.20)	−0.10* (0.02)
Fat + Protein	0.18 (0.21)	−0.09* (0.02)
SCS	0.93* (0.13)	0.14* (0.02)

* Estimate was significantly different from zero based on 95% CI.

Table 8. Genetic and phenotypic correlations (SE in parentheses) of conformation[1] with the treatment costs of 5 health categories, total health cost (THC), and 4 specific health treatments for first parity from pairwise bivariate analysis

	Stature		Dairy form		Udder depth	
Trait[2]	Genetic	Phenotypic	Genetic	Phenotypic	Genetic	Phenotypic
MAST	−0.22 (0.21)	0.04* (0.02)	−0.30 (0.21)	0.01 (0.02)	−0.84* (0.17)	−0.11* (0.02)
REPRO	0.09 (0.33)	0.01 (0.02)	−0.36 (0.34)	0.04* (0.02)	−0.65* (0.27)	0.02 (0.02)
LAME	0.01 (0.22)	0.04* (0.02)	−0.12 (0.22)	−0.01 (0.02)	−0.37 (0.24)	0.00 (0.02)
META	0.21 (0.22)	0.04* (0.02)	−0.21 (0.24)	0.02 (0.02)	−0.35 (0.22)	−0.02 (0.02)
MISC	−0.40 (0.31)	−0.01 (0.02)	−0.07 (0.30)	0.04* (0.02)	−0.35 (0.31)	−0.04* (0.02)
THC	−0.05 (0.17)	0.04 (0.03)	−0.23 (0.18)	0.05* (0.02)	−0.60* (0.16)	−0.04* (0.02)
Metritis	0.33 (0.48)	0.01 (0.02)	−0.21 (0.45)	0.02 (0.02)	−0.74 (0.39)	0.01 (0.02)
Retained placenta	0.19 (0.22)	0.04* (0.02)	−0.27 (0.22)	0.02 (0.02)	−0.25 (0.23)	0.05* (0.02)
Displaced abomasum	0.31 (0.21)	0.04* (0.02)	−0.07 (0.23)	0.01 (0.02)	−0.27 (0.23)	−0.01 (0.02)
Ketosis	0.21 (0.20)	0.03 (0.02)	−0.07 (0.21)	0.04* (0.02)	−0.43* (0.20)	−0.02 (0.02)

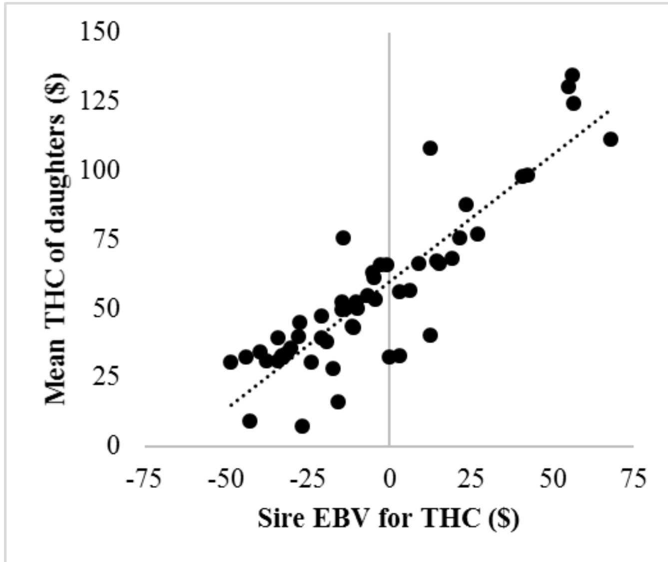
[1] Higher scores were assigned to taller cows for stature, more angular cows for dairy form, and more shallow cows for udder depth.
[2] MAST = mastitis, REPRO = reproduction, LAME = lameness, META = metabolic, and MISC = miscellaneous.
* Estimate was significantly different from zero based on 95% CI.

Table 9. Estimates of heritability (SE in parentheses) for total health treatment cost (THC) and 305-d production and SCS for parities 1 to 3 from multivariate analysis across parities

	Parity		
Trait	1	2	3
THC	0.25* (0.07)	0.16* (0.06)	0.17 (0.11)
Milk	0.23* (0.06)	0.20* (0.06)	0.19* (0.09)
Fat	0.20* (0.06)	0.21* (0.07)	0.14 (0.08)
Protein	0.20* (0.06)	0.11* (0.05)	0.12 (0.08)
Fat + protein	0.18* (0.06)	0.16* (0.06)	0.13 (0.08)
SCS	0.18* (0.06)	0.19* (0.07)	0.10 (0.09)

* Estimate was significantly different from zero based on 95% CI.

Figure 1. The EBV for total health cost (THC) of 53 sires with at least 10 daughters versus the mean THC of the corresponding daughters for first parity.



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