



Behavioral and metabolic markers of cow morbidity in early lactation

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The high productivity of cows on modern dairy farms means that their bodies are used almost at full capacity. Even minor violations in the conditions of keeping or feeding can lead to a significant increase in the morbidity of animals. In such conditions, preventive veterinary medicine is the main task of a veterinarian. In practice, preventing the development of the disease means the veterinarian's ability to predict the occurrence of a problem, identify its cause in time and offer preventive measures. The purpose of this work was to get acquainted with behavioral and metabolic markers for predicting morbidity in cows during early lactation. According to the methodology for systematic reviews of the literature, a search and analysis of scientific articles according to the topic of the study, which were published during 2000–2023, was carried out. To search for scientific articles, the scientometric databases of the Web of Science Core Collection and PubMed were used. Analysis of the study of behavioral and metabolic markers of morbidity in cows during early lactation showed the significant relevance of the problem for dairy farming. A significant number of scientific articles are devoted to the study of this issue. A significant amount of the results of scientific research has practical significance and is used in production. The other part serves as a basis for the formation of new substantiated scientific hypotheses. This gives reason to believe that solving the problem of timely diagnosis and prevention of cow diseases during the transition period is a matter of the near future. Certain physiological and behavioral parameters (duration of chewing and feeding, time of rest and motor activity, social interaction) during the dry period can be important indicators of metabolic changes or diseases in cows at the beginning of lactation. The accuracy of forecasting with the help of such parameters increases with the increase in the duration of the study and the number of indicators used. Physiological and behavioral parameters recorded by automated milking systems can be successfully used to diagnose and predict health problems of dairy cows. Further research in this field is an important challenge for veterinary science. An increase in the time spent in a lying position, the number of periods of rest and agonistic contractions per day, a decrease in the duration of chewing, feeding and motor activity, especially in the last trimester of pregnancy, are associated with an increased likelihood of transition period diseases (ketosis, abomasum displacement, reproductive disorders, etc.). The study of behavioral and metabolic markers of morbidity in cows during early lactation proved the significant relevance of the problem for dairy farming. A significant number of scientific articles are devoted to the study of this issue. We believe that solving the problem of timely diagnosis and prevention of cow diseases during the transition period is an important task of veterinary medical science today.

Keywords: cows; diseases; diagnosis; markers; prevention; prognosis.

Introduction

With the high productivity of cows on modern dairy farms, their bodies are used practically to the limit of their capabilities. Even minor omissions in housing or feeding conditions can lead to a significant increase in animal morbidity. In such conditions, the main focus of a veterinarian's work shifts towards preventive veterinary medicine. Preventing the development of a disease in practice means the ability of a veterinarian to predict the occurrence of a problem, timely define its cause and suggest preventive measures.

Early diagnosis of animal diseases involves the use of diagnostic markers (Vergara et al., 2014). Such early diagnostic markers can be physiological changes in the body of animals. They are characterized by physical disorders or subclinical latent metabolic shifts, which are manifested by changes in the blood composition, malfunctions of other organs and systems of the body and are detected only by appropriate laboratory methods (Duffield et al., 2009; Huzzey et al., 2011; Yamakawa et al., 2012; Smith et al., 2017; Wisnieski et al., 2019; Tsiamadis et al., 2020).

The results obtained by Wisnieski et al. (2019) indicate that cattle at risk for some gastrointestinal diseases of the transition period can be detected during the dry period. According to the authors, this is important for disease prevention because earlier identification of cows at risk of health

disorders will allow earlier implementation of preventive strategies. The issue of genetic predisposition of cows to diseases remains open but promising. Thus, Freebern et al. (2020) identified six significant gene associations and 20 candidate genes for predicting susceptibility to disease in cattle. Due to the integration of multitissue transcriptomic data, their results provided useful information for future functional studies and a better understanding of the biological relationship between genetics and disease susceptibility in this animal species. Other authors (Lopes et al., 2020; Brasier et al., 2023; Czachor et al., 2023) have shown that genomic studies can be successfully used to predict the selection of traits to estimate adaptive capabilities or disease susceptibility in Holstein cattle.

The transition period (± 3 weeks after calving) is particularly dangerous in terms of high morbidity in dairy cattle (Talukder et al., 2015). It is possible to predict the probability and level of cow morbidity during this period by analyzing the physiological and behavioral changes that develop in cows during dry period or late lactation (Kaufman et al., 2018; Daros et al., 2022). In this regard, we believe that the study of behavioral and metabolic changes during the late lactation or dry period can be an important diagnostic component of predicting and monitoring the incidence of diseases in cows in transition. The aim of this study was to review the literature estimating the efficacy of behavioral and metabolic markers for predicting cow morbidity during early lactation.

According to the methodology for systematic literature reviews (Gupta, 2018), we searched and analyzed scientific articles on the topic of the study which were published during 2000–2023. To search for scientific articles, we used the Web of Science Core Collection (<http://apps.web-of-knowledge.com>) and PubMed (<http://pubmed.ncbi.nlm.nih.gov>).

The following keywords were used in the search: diagnosis, behavior, prognosis, abomasum displacement, acidosis, ketosis, metabolism, disease susceptibility.

The keywords “cow and diseases and diagnosis” were used to find 36,409 scientific articles since 1961, of which 9,485 or 26.1% were published in the last ten years. Adding the term “prevention”, a total of 21,055 articles were found, of which 8,026 or 38.1 were for the last 10 years. The addition of the phrase “early lactation” resulted in a total of 1,200 publications, of which 626 or 52.2% were found in the last ten years. These data indicate that the relevance of studying cow diseases in general has been and remains quite high. Also, during the last decade, attention has been increasing to the study of preventive methods of cow diseases control (38.1% of works) and special attention is focused on the diseases of early lactation period (52.2% of works over the past 10 years).

Proudfoot and Huzzey (2022) also draw attention to the fact that in recent years there has been an increase in the number of studies describing how the behavior of dairy cows changes during the weeks before and after parturition (the transition period). The authors note that during this time, dairy cows face several challenges, including pain associated with pregnancy and childbirth, social stresses associated with moving around pens, changes in feeding rations, and adjusting to milking in the milking parlor or to a robotic milking system.

In this paper, we have focused on scientific publications that address the importance of behavioral and metabolic markers of cow morbidity during the early lactation period.

Rest time and physical activity can be useful for predicting health status of dairy cows during the transition period

The availability of data on rest time and physical activity is an important factor for elaborating the preventive strategy and improving the individual management of dairy cows (Hendriks et al., 2019).

Stangaferro et al. (2016) evaluated the effectiveness of an automated monitoring system (AMS) in detecting metabolic and somatic diseases in cows. It was found that the sensitivity of the AMS was 98% for abomasum displacement ($n = 41$); 91% for ketosis ($n = 54$); 89% for digestive disorders ($n = 9$) and 93% for all metabolic shifts and digestive disorders together ($n = 104$). Overall, it was concluded that the general sensitivity of AMS, which combines rumen function and animal behavior, can be a useful tool for identifying cows with metabolic and digestive disorders.

Barracough et al. (2020) point to the existence of a direct link between metabolic shifts and cow behavior. In particular, the authors found that after calving, cows with clinically severe hypocalcaemia were less active (took fewer steps during the day) and spent 88 and 125 min/day more time in a lying down position compared to cows with subclinical hypocalcaemia and normocalcaemia, respectively. Similar results were obtained by Hendriks et al. (2020). The day before calving, cows with clinically expressed hypocalcaemia spent in a lying position for 1.4 hours longer than animals without clinical signs of hypocalcaemia. On the day of calving, clinically sick animals lay down 2.6 hours longer. The number of periods of lying down during the day increased from 16.3 times/day in cows with normal calcium levels to 18.2 and 19.2 times/day in cows with subclinical and clinical forms of hypocalcaemia, respectively. According to the authors, this indicates that clinical hypocalcaemia is associated with significant long-term behavioral effects that occur in cows during critical conditions, including the postpartum period.

Sahar et al. (2020) found that cow behavior before calving was associated with postpartum diagnosis of ketosis and metritis. In particular, cows that spent less time feeding had a higher chance of getting ketosis and metritis. The probability of staying healthy increased by 1.3 times for every additional 15 minutes spent on feeding. In addition, cows that had fewer agonistic interactions with other animals before calving were more likely to develop ketosis and metritis in early lactation. The chances of staying healthy increased 1.9 times for every 6 additional confrontations.

The authors concluded that the duration of feeding and agonistic behavior before calving can be used to identify animals at risk of developing ketosis and metritis during the first weeks after calving.

However, Emam et al. (2023) did not establish a relationship between the duration of chewing, total motor activity, and the amount of dry matter consumed in the diet during the three days before calving and the subclinical course of hypocalcaemia and hypomagnesaemia.

Thus, certain physiological and behavioral parameters (duration of chewing and feeding, duration of rest and motor activity, social interaction) during the dry period can serve as important indicators of metabolic changes or morbidity in cows at the beginning of lactation. The accuracy of forecasting using such parameters increases with the duration of observation and the number of indicators used.

Using the physiological and behavioral indicators recorded by automated milking systems for predicting health status of transition cows

In recent years, the use of automated milking systems or milking robots has become quite common in dairy farming. In addition to ensuring the milking process, such systems can record and accumulate a number of physiological and behavioral indicators. King et al. (2018) investigated the effectiveness of using such indicators for the purpose of diagnosing or predicting cow disease. It was found that within two weeks before the diagnosis of abomasum displacement and mastitis, cows had decreased milk yield, chewing duration, and milking frequency. In cows with abomasum displacement, 4–6 days before the diagnosis, the consumption of concentrated additives in the milking complex decreased, while deviations from basic motor activity and changes in milk temperature were observed. In another study, King et al. (2017) found a decrease in milk yield by 4.4 and 4.1 kg/day 4 days before the diagnosis of abomasum displacement or pneumonia, respectively, and by 1.2 kg/day 5 days before the diagnosis of subclinical ketosis. In addition, 4–7 days before the diagnosis of abomasum displacement, ketosis, mastitis, pneumonia or metritis, the indicators of motor activity and resting time of cows in the lying position changed significantly.

Cook (2023) notes that identifying cows at greater risk of disease before, during, and after calving is an important key to improving management during the transition period. The author used physiological and behavioral data from automated electronic systems to identify cows at high risk of disease during the postpartum transition period. It was found that the use of signal deviations from basic physiological and behavioral indicators led to correct prediction of the incidence of cows' morbidity in 62.5% (95% confidence interval, with deviations of 59.3–65.5%), with a method's sensitivity of 42.4% (95% confidence interval, with deviations of 37.4–45.5%) and specificity of 75.2% (95% confidence interval, with deviations of 71.5–78.6%).

Thus, these results indicate that the physiological and behavioral parameters of automated milking systems can potentially be successfully used to diagnose and predict health problems in dairy cows. Further research in this area is an important task for veterinary medical science.

Metabolic status of cows predicts their morbidity in early lactation period

Along with physiological and behavioral indexes the metabolic status is an important parameter to be considered while predicting the morbidity of cows in the transition period.

The objective of the study done by Sepúlveda-Varas et al. (2018) was to characterize the relationship between behavior, energy metabolism and lesions in the digit area in primiparous dairy cows. It was found that cows with digital diseases spent less time lying down (7.29 ± 0.22 vs. 8.51 ± 0.22 h/day in healthy cows). In addition, cows prone to lameness had fewer periods of lying down per day and these periods were longer than in cows without digital lesions after calving. It was also noted that cows with negative energy balance were more prone to develop lameness during transition period.

According to Daros et al. (2020), lameness in cows at the beginning of the dry period was associated with the occurrence of transitional diseases (ketosis, metritis, afterbirth retention, hypocalcaemia, abomasum dis-

placement). The longer a cow was lame during dry period, the greater was the likelihood of transitional diseases. Cows that lost weight faster during the dry period had an increased likelihood of developing ketosis and metritis. Evaluating the results of their research, the authors concluded that the relationship between lameness and transient diseases is partially mediated by a reduction in feeding time for lame cows. This conclusion is confirmed by the data of Hut et al. (2021), who found that rapid body weight loss at the beginning of lactation was associated with a higher level of lameness after calving. In turn, cows with lameness spent less time feeding during the dry period and early lactation, entering the negative metabolic balance, thus closing the pathological circle.

The relationship of postpartum uterine diseases with the duration of lactation and metabolic profile in multiparous Holstein dairy cows in the transition period was studied by Cattaneo et al. (2020). It was found that, compared to healthy cows, animals with potential afterbirth retention laid down longer ($P < 0.05$), especially in the period before calving. Such cows lost body weight faster and had a more pronounced inflammatory status, as evidenced by high levels of haptoglobin ($P = 0.04$) and albumin ($P < 0.01$) in blood plasma. Venjakob et al. (2023) studied the relationship between the duration of stay in the calving preparation group and milk production, morbidity, reproductive performance, culling and behavior during the transition period in Holstein dairy cows. According to the study, the risk of clinical hypocalcemia and abomasum displacement was increased in cows that had been in the pre-calving group for more than 30 days. The risk of acute parturient metritis was increased in dairy cows that were in the preparation group for less than 10 days. Cows that were in the preparation group for 14, 21 and 28 days had less deviation from normal behavior than cows that were in the preparation group for 7 and 35 days. The latter ones, during the last 7 days before calving, moved less and had a reduced feeding and chewing time. Also, cows that were in the transition group for less than 10 and more than 30 days had lower milk yields and a higher risk of diseases in early lactation.

Dairy cows are often diagnosed with fever without clinically evident symptoms of disease. The aim of the study by Lomb et al. (2020) was to investigate changes in feeding, social and supportive behavior of cows with fever without other clinical signs of disease. It was found that cows with fever spent less time on feeding compared to the control group (135 vs. 181 ± 7.6 min/day for several days of fever and 158 vs. 185 ± 9.7 min/day during the first day of fever). Cows during the first day of fever took feed faster (109 vs. 91 ± 5 g/min) and had fewer aggressive collisions at the trough (initiator animal with fever – 9.7 vs. 14.6 ± 1.7 replacements/day in healthy cows; initiator animal without fever – 11.1 vs. 15.9 ± 1.6 replacements/day in healthy animals). In general, cows with fever spent less time at the feeder, which, according to the authors, is consistent with reactions to the disease described in other species of animals.

The prognostic value of the duration of rest and the activity of agonistic behavior is emphasized by Caplen & Held (2021). Given the correlation of these indicators with the level of serum amyloid A, the authors concluded that changes in behavior (social, motor) have the potential to indicate subclinical mastitis and recommend further research to substantiate and clarify such conclusions.

Thus, the analysis of the data shows that physiological and behavioral parameters (duration of chewing, feeding, rest, motor and social activity, etc.) in dairy cows in different physiological states can be informative diagnostic and prognostic indicators of disease development during the critical transition period (before, during and after calving). They often coincide and are accompanied by metabolic changes in the blood. In general, the metabolic changes, an increase in lying rest time, in the number of rest periods and the number of agonistic confrontations during the day, a decrease in the duration of chewing periods, feeding and motor activity, especially in the last trimester of pregnancy, indicate an increase in the likelihood of developing diseases associated with the transition period in cows (ketosis, abomasum displacement, reproductive disorders, etc.).

Early disease detection and accurate prognosis are the basis of preventive veterinary medicine

The transitional period, 3 weeks before and 3 weeks after calving, is accompanied by a negative energy balance, which causes metabolic dis-

orders, such as ketosis. Subclinical ketosis is defined as an increase in the concentration of β -hydroxybutyrate to ≥ 1.2 mmol/L in the blood. The value of unesterified fatty acids ≥ 0.7 mmol/L in the blood, in turn, indicates the potential development of a syndrome of insufficient metabolic adaptation (Gruber & Mansfeld, 2019). In our opinion, such metabolic shifts relate not only to individual organs, but to the animal organism as a whole. Determining the significance of some of them in the early disease detection and accurate prognosis is an important task for a veterinarian.

Early disease detection and accurate prognosis are the basis of preventive veterinary medicine. Along with behavioral and metabolic indicators there have to be considered the monitoring of animal diseases and culling records, level of feed consumption, milk production, and the performance and analysis of certain laboratory tests (LeBlanc, 2010). Many scientific publications today are devoted to the study of the informativeness of these indicators for the diagnosis and prognosis of the transition period diseases in high-yield cows.

In particular, from both economic and humane points of view, an important pathology in cows during the first weeks of lactation is abomasum displacement. Thus, the purpose of the study done by Song et al. (2020) was to study the potential use of blood biomarkers for the early diagnosis of abomasum displacement in dairy cows. It was found that dairy cows with abomasum displacement are under a strong negative energy balance, have signs of liver damage and potentially reduced insulin sensitivity. At the same time, analysis of a combination of multihematological biomarkers, including calcium, insulin, ALT, GGT, and creatinine, can help identify cows at risk of developing abomasum displacement in the early postpartum period.

Cows with a left displaced abomasum have a 40% lower concentration of vitamin E (Qu et al., 2013). The authors investigated whether lower circulating concentrations of α -tocopherol precede abomasum displacement. It was found that reduced serum α -tocopherol levels are a potential early indicator of abomasum shift in cows. The use of test strips for determining the level of ketone bodies Ketocheck or Ketolac (Geishauser et al., 1997; Geishauser et al., 2000) or alanine aminotransferase activity and beta-hydroxybutyrate content (Geishauser et al., 1997) in the first two weeks after calving may also be predictive of the development of abomasum displacement in cows.

The study of milk composition in the first three weeks after calving, showed that the ratio of protein to fat in milk $< \text{or} = 0.72$ increased the chances of developing abomasum displacement in a cow by 8.2 times (with a test sensitivity of 80% and specificity of 68%) (Geishauser et al., 1998).

With the onset of lactation, dairy cows experience a decrease in blood calcium content. At the same time, animals develop hypocalcemia in clinical (total serum calcium concentration < 1.50 mmol/L) or subclinical (≤ 1.14 mmol/L) form. The aim of the study done by Rodríguez et al. (2017) was to evaluate the potential associations between subclinical hypocalcemia and other diseases of the transition period in cows. Different threshold values of serum calcium concentration were determined – ≤ 1.93 , ≤ 2.05 , ≤ 2.05 and ≤ 2.10 mmol/L, for ketosis, afterbirth retention, metritis and abomasum displacement, respectively. Other researchers, while noting the important diagnostic role of calcium (Oetzel, 2004), assert that there is currently insufficient evidence of the prognostic value of calcium levels for animal culling, abomasum displacement, or other transitional pathologies (Bach & McArt, 2021).

All diseases of the transitional period are accompanied by the development of inflammation and tissue damage. A sensitive indicator of such changes is the reaction of acute phase proteins. The results of some studies (Stengärde et al., 2010; Maden et al., 2012) indicate that haptoglobin can potentially be used to detect inflammatory pathologies in the early postpartum period. According to other authors (Bach et al., 2019; Kerwin et al., 2022), along with haptoglobin, the level of unsaturated fatty acids is a promising indicator of the development of pathologies during the transition period or culling of cows at the beginning of lactation.

Boulay et al. (2014) determined the prognostic value of preoperative determination of lactic acid concentration in cows with abomasum torsion or its displacement to the right. It was found that at a lactate level of ≤ 2 mmol/L, the prognosis of surgery is positive, from 2 to 6 mmol/L – doubtful and requires a proper risk assessment with the animal's owner.

Surgery with a lactic acid level of ≥ 6 mmol/L is not justified and such animals should be culled due to the high probability of a negative outcome. Higher chances of diagnosing abomasum displacement were found at lower milk yields, higher percentage of milk fat, lower percentage of milk protein, and higher fat to protein ratio (Geishauser et al., 1999). Currently, the prognostic value of vitamins, provitamins (retinol, β -carotene, etc.) (Strickland et al., 2021) and the pH of the rumen (Heirbaut et al., 2022) for transition diseases in dairy cows is being studied.

The results of the study by Rodriguez et al. (2021) indicate that the dynamic of body condition during the late dry period is more important than the assessment of a single measurement. Cows with a faster loss of fatness are more likely to become sick or culled early in lactation.

Thus, the transition period in cows (3 weeks before and after calving) is characterized by dramatic changes in physiological state, housing and feeding conditions. This causes changes in the behavior and hematological profile of animals. That is why much research today is devoted to the study of their prognostic and diagnostic value. It has been found that acute phase proteins, liver enzymes, lactic and fatty acids, certain vitamins, milk quality and body condition can be important diagnostic and prognostic indicators for transition diseases in dairy cows.

Economic, business or management factors can influence cows' morbidity rate during early lactation

Risk factors associated with the incidence of abomasum displacement and ketosis were studied on 60 Swedish dairy farms using multivariate logistic regression modeling (Stengärde et al., 2012). It was found that higher daily milk yields in multiparous cows and large farm size ($P = 0.054$ and 0.066 , respectively) were generally associated with high levels of morbidity in the herd. The absence of daily cleaning of the feed table increased the chances of having a herd with a high level of morbidity by twelve times ($P < 0.01$), and keeping cows in only one group during dry season by eight times ($P = 0.03$). These data are confirmed by the results of studies done by Stengärde et al. (2011), who found that herds with a high morbidity rate had a larger number of cows and produced an average of 1400 kg of milk per cow per year more than herds with a low disease incidence rate. These results confirm the importance of housing, management and feeding conditions in the prevention of metabolic disorders in dairy cows during calving and early lactation.

The main objective of the studies analyzed above was to identify changes in prenatal behavior associated with the spread of postpartum pathologies in dairy cows. Most research results suggest that such a link exists. The relationship between behavioral changes, physiological parameters, metabolic shifts, and diseases of cows during the transition period is causal (Belaid et al., 2021). This allowed the next group of scientists to specify the directions of their research and study the effectiveness of one or more prognostic indicators for a particular pathology.

Stangaferro et al. (2016) used the parameters of ruminant and motor activity to identify dairy cows at risk of developing metritis. It was found that the overall sensitivity of this indicator was 55% for all (regardless of severity, $n = 349$) cases of metritis, but it was higher for cows with metritis and other diseases (78%) than for cows with metritis alone (53%). The importance of assessing motor activity is also indicated by the results of studies by Edwards & Tozer (2004). They found that although locomotor activity was generally lower among sick cows, cows with ketosis, left abomasum displacement, and digestive disorders walked longer distances than average 8, 9, and 8 days before diagnosis of each disease, respectively.

The pathophysiological relationship between carbohydrate metabolism and abomasum displacement was studied by Pravettoni et al. (2004). It was found that insulin resistance is a common phenomenon in cows with a left abomasum displacement. The analysis of the results of this study showed that abomasum atony in cows with abomasum displacement depends on the persistence of high insulin concentrations in the blood serum. In particular, seven days after surgical correction of the left abomasum displacement, abomasoduodenal myoelectric patterns were still significantly lower in insulin-resistant cows compared to those of non-insulin-resistant cows. The authors assert that this may be an explanation for the pathogenetic mechanism of left abomasum displacement and its frequent recurrence in dairy cows.

Monitoring the rumination duration before calving is an effective way to identify cows at risk of the disease at the beginning of lactation. Abuelo et al. (2021) found that, on average, cows with lameness developed in the first 60 days of lactation ruminated 15.00 ± 6.08 min/day less than healthy animals in the first three days of the dry period. Also, according to Cook et al. (2021), the duration of chewing in cows before calving can help predict future reproductive disorders.

Thus, the analysis of the study of behavioral and metabolic markers of cow morbidity during early lactation showed the significant relevance of the problem for dairy farming. A significant number of scientific articles are devoted to the study of this issue. Most of the research results are of practical importance and are used in production management. Another part of the results serves as a basis for the formation of new well-founded scientific hypotheses. This gives reason to believe that solving the problem of timely diagnosis and prevention of cow diseases during the transition period is likely to be achieved in the near future.

Conclusions

Certain physiological and behavioral parameters (duration of chewing and feeding, time of rest and motor activity, social interaction) during the dry period can be important indicators of metabolic changes or diseases in cows at the beginning of lactation. With the use of the parameters the accuracy of prediction increases with the duration of the study and the number of indicators used. Physiological and behavioral parameters recorded by automated milking systems can be successfully used to diagnose and predict health problems in dairy cows. Further research in this area is an important challenge for veterinary science. Increased time spent lying down, the number of rest periods and agonistic contractions per day, reduced chewing time, feed intake and motor activity, especially in the last trimester of pregnancy, are associated with an increased likelihood of developing transition diseases (ketosis, abomasum displacement, reproductive disorders, etc.).

Thus, the study of behavioral and metabolic markers of cow morbidity during early lactation has shown the significant relevance of the problem for dairy farming. A significant number of scientific articles are devoted to the study of this issue. We believe that solving the problem of timely diagnosis and prevention of cow diseases during the transition period is an important task of veterinary medical science today.

The authors declare no conflict of interest.

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