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Influence of periparturient recumbency on selected blood biochemical parameters and milk yield in cows

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Summary

Hypophosphataemia (phosphorus deficiency) is currently one of the most common disorders in high-yielding dairy cattle. It may occur in clinical forms (lameness, periparturient recumbency and postpartum haemoglobinuria – PPH) or subclinical forms. Periparturient recumbency is the most commonly diagnosed condition associated with clinical phosphorus deficiency, but the currently available literature lacks comprehensive information concerning the effect of this condition on parenchymal organ dysfunction during lactation. The aim of this study was to determine the effect of periparturient recumbency in cows on selected parameters of liver, kidney and muscle function during peak lactation as well as on milk production. Based on the occurrence of periparturient recumbency and the values of inorganic phosphorus before calving, the selected animals were divided into two groups: I – X = 0.46 mmol/l and II – X = 0.45 mmol/l, and a control group was created from cows that were regularly monitored in the herds. Blood from the test cows was collected from the external jugular vein 3 weeks before parturition (collection I), between 4 and 7 days after parturition (collection II), and after around 40 days of lactation (collection III) and 100 days of lactation (collection IV). The blood test results obtained indicate that a decrease in Pi concentration after parturition often occurs in high-producing cows, hence low Pi concentrations before parturition may lead to periparturient recumbency. Cows with prepartum hypophosphataemia and periparturient recumbency (group I) show abnormalities in certain liver parameters during lactation. Liver supporting and protecting supplements should be used in these animals. Cows without preparturient hypophosphataemia did not show such severe changes in parenchymal organ function. Group I cows are at a greater risk of musculoskeletal damage during lactation. For these animals, it is advisable to use bedding and stall materials that reduce stress on this system. Clinical hypophosphataemia reduces milk production in cows.

Keywords: dairy cows, inorganic phosphorus, hypophosphataemia, periparturient recumbency

In dairy cattle, phosphorus (P) is typically found in the form of an anion, which is involved in a variety of biological processes in the body, most commonly in cooperation with calcium cations. It contributes to a large number of enzymatic reactions that aid in the process of storing, processing and releasing energy in cells. Phosphorus is a key factor in the development of osteopathic changes and metabolic disorders in the periparturient period. Phosphorus compounds present in the feed play an important role in the process of calcium absorption from the gastrointestinal tract and contribute to the formation of nucleic acids (DNA, RNA), high-energy compounds (ATP – adenosine 5'-triphosphate, phosphocreatine), phospholipids and other components of cellular, microsomal and mitochondrial membranes. An adequate concentration of Pi (inorganic phosphorus) ensures the successful completion of glycolysis, glyconeogenesis or the maintenance of the physiological pH in the body. Phosphorus is an essential element for the proper functioning of organisms and a building block of the skeletal system (bones, teeth); it is necessary for maintaining the structure and integrity of cell membranes, and is an integral part of the myelin sheath of nerves (12, 13, 18). In the body, up to 85% of phosphorus is found in the bones and only 1% in the extracellular fluid, where it is present in the form of inorganic phosphates or esters (15). Its content in the serum of dairy cows should, according to various authors, oscillate between 1.08 and 2.76 mmol/l, but the physiological values of inorganic phosphorus may vary over a wide range (2, 16, 17, 20, 22, 24, 27, 28). The concentration of inorganic phosphorus in the body depends on the absorption of phosphorus ions in the rumen and small intestine, deposition and mobilization in the bones and the supply of an adequate amount of calcium in the feed ration. The appropriate concentration of Pi in the body is maintained by the activity of selected hormones: parathyroid hormone (PTH), calcitonin and active metabolites of vitamin D, and, to a much lesser extent, by the concentrations of other hormones: gonadal hormones or selected glucocorticoids (11, 16, 19). Both large dairy farms and small extensive dairy farms have reported increasing problems due to phosphorus deficiency in cattle. This is related to regulations limiting its content in the soil, which in turn has led to a reduction in the concentration of P in ruminant feed. In addition, the price of P-containing additives is much higher than that of mineral mixtures routinely used in cattle production. Despite the fact that animal feeds contain sufficient concentrations of phosphorus to meet the nutritional requirements of cows, it has been observed that, without additional P supplementation to the animals, increasing milk production is often associated with various forms of phosphorus deficiency (hypophosphataemia) during lactation (10, 13, 26, 29).

Reduced blood levels of this element are now one of the most common problems in high-producing dairy cattle, especially during the periparturient and early lactation periods. It can affect 10-50% of animals in a herd, and in some cases as much as 70% (7, 23). Clinical cases of phosphorus deficiency are manifested by lameness, periparturient recumbency and postpartum haemoglobinuria (PPH), which still occur on farms despite prophylaxis (18, 25, 30). Periparturient recumbency is the most commonly diagnosed form of clinical phosphorus deficiency. In most cases, it can easily be distinguished from postpartum paralysis, limb or muscle injury or rumen acidosis, i.e. other potential causes of the cow's inability to stand (downer cow syndrome). It should be noted that this condition often begins with difficulty standing on the pelvic limbs, hopping from one foot to the other, joint pain and swelling, and even a slight trembling of the limbs. These initial symptoms are not usually associated with periparturient recumbency, diagnosis and treatment begin when the cow is unable to get up on its own. The cows lie down and are unable to return to a standing position. Periparturient recumbency in phosphorus-deficient herds may occur in a few to several per cent of animals – normally in cows after parturition, a time that is crucial for the course of the entire lactation period. Assessing the impact of recumbency on the condition and function of the parenchymal organs, and thus on milk production, appears to be of great importance. Disturbances in the early phase of lactation and an inadequate increase in milk production may contribute to a failure to reach high milk production levels quickly and also to a shortening of the lactation peak (1, 14, 18). At present, there is a lack of comprehensive reports in the literature concerning the effects of phosphorus deficiency in postpartum recumbent cows on liver, kidney and muscle function parameters in lactation.

The aim of this study was to determine the effect of postpartum recumbency in cows on selected parameters of liver, kidney and muscle function during peak lactation. The results obtained were compared with milk yield and blood biochemical parameters in healthy animals without phosphorus deficiency in similar physiological periods in regularly monitored herds.

Material and methods

A total of 33 cows from 3 herds in the central Lublin region that had been regularly monitored for blood parameters were selected for the study. On those farms, Holstein Friesian (HF) cows were kept tethered, they were provided with a mechanical water supply, mineral licks were used regularly, and preventive treatments were limited to two hoof trims per year and the application of dewormers 2 or 3 times per year. The farms used a TMR feeding system, and the feed ration consisted of maize silage, maize grain, hay silage, grass silage, hay, straw, pellets, cereals grown on the farm, feed additives with a protein content of 18-24%, a premix and a mineral and vitamin supplement. Feed rations were formulated on the basis of milk yield, the current physiological period, as well as the age and body weight of the cows. The animals were kept under constant veterinary supervision. Before blood samples were taken, a thorough history and clinical examination of the animals was carried out, and the feeding method, feed quality and milk yield were all assessed.

Blood from the test cows was collected from the external jugular vein 3 weeks before parturition (collection I), between 4 and 7 days after parturition (collection II), and at around 40 days into the lactation period (collection III) and 100 days into the lactation period (collection IV). After the blood test results of the recumbent cows were analysed, the animals were divided into two groups based on the concentration of inorganic phosphorus in their blood before parturition. The first group (group I) consisted of 12 cows with reduced blood Pi concentrations. Based on farmer interviews, most of these cows had lameness or experienced a difficulty lifting their pelvic limbs 2-3 days before the adoption of the recumbency position. The owners also reported a reduced appetite in these animals as compared with the rest of the herd. At the time of the first clinical examination, the animals were lying on their sternum with their limbs correctly positioned. They were willingly consuming all feed rations and water offered to them. Despite the owner's attempts to lift them in the presence of the doctor, the animals did not resume a standing posture. The second group (group II) consisted of nine cows with normal Pi blood levels before parturition. In the past, their owners had not observed that these cattle experienced any difficulty in moving or standing up before the onset of disease. No differences were observed as a result of clinical examination as compared to group I. Animals with trauma in the form of bone fractures, tendon ruptures or muscle damage, as well as those which had suffered severe birth complications, were excluded from the study, either at the time of the first clinical examination or through subsequent laboratory diagnosis. During the lactation period, blood was collected as part of the routine monitoring of dairy cattle herds – this was carried out regularly in consultation with the owners to ensure a sufficiently high milk yield in the herd. The third group (control, group III) consisted of 12 cows from the same farms with no mineral disorders before or after parturition. Serum concentrations of total calcium (Ca), inorganic phosphorus (Pi), magnesium (Mg) and the activity of gamma-glutamyl transpeptidase (GGTP) as well as creatine kinase (CK) and the concentrations of total bilirubin (TB), total protein (TP) and urea (Urea) were determined with a Horiba ABX Pentra 400 automatic analyser.

Haematological and biochemical blood test results were analysed statistically using the Mann-Whitney rank-sum test. Calculations were performed at a significance level of $p < 0.05$ and 0.01.

Results and discussion

Animals with periparturient recumbency were found to have low concentrations of inorganic phosphorus in their blood with unchanged or only slightly altered calcium levels (Tab. 1). By contrast, through monitoring the herds, the present study demonstrated that some of these animals were already phosphorus-deficient before parturition. However, the owners of the cows did not opt for supplementation with phosphorus preparations and justified this by citing their previous experience in using phosphorus supplements after parturition. According to the authors, it is significant that only a fraction of the cows with prepartum phosphorus deficiency developed periparturient recumbency. The results presented in this study are difficult to compare with findings of other authors, as the available literature examines only the condition of animals at the time of periparturient recumbency, ignoring their prepartum medical status. Bires et al. (3), Cheng et al. (6), and Correa et al. (8) reported very low Pi values in cows with postpartum recumbency, which is consistent with our findings in groups I and II at the onset of the condition. During lactation, a statistically significant increase in phosphorus concentration was observed in all study groups. The authors observed that there was a significant difference between the values in the group of cows with Pi deficiency before parturition and those without any deficiency during the same period (Tab. 1 – collection III). Bires et al. (3), Cheng et al. (6), and Correa et al. (8) also reported an increase in Pi values in cows after recumbency. However, since Pi was not measured before calving in their studies, it is not possible to compare their results with our own findings. The present study improves the understanding of the impact of phosphorus concentration before calving on the course of recumbency and the subsequent changes in P concentration during lactation. At the onset of disease, Pi concentrations were very low in both study groups. In group II, a statistically significant increase in phosphorus concentration was observed, with its value approaching the average of the control group.

Tab. 1. Blood test results of the cows

Parameters		Group I; n = 12 Collection				Group II; n = 9 Collection				Group III; n = 12 Collection			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
Pi (mmol/l)	x̄	1.14	0.46	1.06	1.17	1.54	0.45	1.51	1.46	1.59	1.21	1.58	1.57
	± SD	0.10	0.18	0.15	0.15	0.10	0.08	0.11	0.09	0.10	0.17	0.22	0.19
Ca (mmol/l)	x̄	2.08	2.00	1.99	2.10	2.22	2.10	2.08	2.03	2.18	2.01	2.19	2.17
2.25-3.03	± SD	0.05	0.07	0.07	0.05	0.09	0.07	0.06	0.05	0.11	0.14	0.22	0.31
Mg (mmol/l)	x̄	1.00	1.05	0.87	0.92	0.85	0.84	0.96	0.97	1.09	1.15	1.11	1.12
0.78-1.23	± SD	0.11	0.12	0.07	0.07	0.11	0.07	0.08	0.08	0.09	0.08	0.11	0.14
GGTP (U/L)	x̄	15.67	25.00	43.75	32.58	13.44	28.11	28.44	26.22	12.95	23.29	18.21	15.19
	± SD	5.37	6.48	6.51	8.01	4.50	5.56	5.05	3.19	3.12	4.11	3.01	2.73
TB (μmol/l)	x̄	4.93	6.21	7.48	6.71	3.52	6.40	4.71	4.24	2.92	3.45	2.39	2.11
1.9-7	± SD	1.34	1.52	1.44	1.43	1.32	0.75	0.77	0.68	0.34	0.41	0.29	0.59
TP (g/l)	x̄	70.00	70.00	67.00	67.50	70.44	70.67	72.78	71.89	72.32	71.86	73.74	73.22
	± SD	2.83	2.56	2.04	1.57	2.30	1.00	1.39	1.83	3.11	2.43	2.76	1.09
Urea (mmol/l)	x̄	2.30	2.45	4.90	4.44	2.16	3.04	4.37	3.50	3.15	2.90	2.75	2.63
1.66-7.47	± SD	0.61	0.77	1.55	0.98	0.58	1.05	1.09	1.06	0.69	0.35	0.47	0.41
AST (U/L)	x̄	82.50	191.00	161.58	134.83	87.22	120.22	94.00	83.11	103.20	115.55	76.70	70.52
	± SD	8.63	63.63	39.24	32.57	15.94	31.45	8.60	9.28	16.44	11.85	22.89	12.54
CK (U/L)	x̄	146.42	736.75	475.83	349.08	183.00	565.11	221.67	193.22	254.4	309.68	190.65	158.67
	± SD	51.73	281.06	179.77	91.20	59.19	147.74	70.58	48.17	38.97	37.45	21.67	53.78
Milk yield (l/day)	x̄	0	14	29	36	0	21	36	39	0	23	39	44

Explanations: x̄ – average; SD – standard deviation

The obtained phosphorus concentrations fall within the normal range used in the studies (2, 16, 24, 27, 28). In group I, normal Pi concentrations had not been reached by the end of the current study, which means that these cows would enter the dry period and then prepare for the next parturition with low phosphorus levels. This suggests that without a carefully planned phosphorus deficiency prophylaxis, periparturient recumbency may recur in these animals. Pi concentrations obtained for the 2nd blood sampling were significantly lower in both study groups than in the control group. At the 3rd blood sampling, Pi levels were significantly lower in group I than in group III. In the control group, Pi levels were lower than the physiological norms reported by other authors: Baumgartner (2) – 1.6-2.3 mmol/l; Mayer and Harvey (20) – 1.48-2.9 mmol/l and Winnicka (28) – 1.8-2.1 mmol/l only in the postpartum period. In group I, Pi concentrations significantly lower than average were obtained at the 1st blood sampling as compared to the other groups. The other macronutrients tested (Ca and Mg – Tab. 1) were within the normal range for a specific physiological period. At the same time, it should be noted that calcium concentrations in high yielding dairy cows are usually below the lower limit for all cows and above 2 mmol/l (5, 11). This is known as physiological hypocalcaemia in dairy cows. By contrast, subclinical hypocalcaemia in dairy cattle is diagnosed when the serum Ca concentration is lower than 2 mmol/l (5, 11). However, our study shows that the lowest calcium levels were obtained during lactation in group I. This suggests that Pi deficiency has an effect on the degree of calcium absorption in the gastrointestinal tract (4, 8, 11). Chamberlin et al. (5) and Cozzi et al (9) emphasize the importance of GGTP and TB parameters in assessing liver function and the performance in dairy cows. In our study, a statistically significant increase in GGTP activity (Tab. 1) during lactation was found in cows affected by recumbency with concomitant prepartum Pi deficiency (group I) as compared to the other groups. Moreover, these values were higher than the accepted norms (5, 9). In group II, despite the increase in GGTP activity compared to the control group, the results obtained were similar to the values obtained by Chamberlin et al. (5) and Cozzi et al (9). Similar changes were observed for TB in these groups (Tab. 1). Our results suggest that much more advanced liver changes occurred in group I as compared to group II, but both groups had significantly higher values of the abovementioned liver parameters as compared to the control group. No statistically significant changes in blood biochemistry were observed in the assessment of the renal status. On the other hand, it should be noted that the concentration of urea in the 3rd blood sample was statistically significantly higher in the study groups than in the control group, but it was still within the norms set by Moore (21) and Winnicka (28). Urea levels in dairy cows are generally low, so even a slight increase in this parameter may indicate a risk of renal dysfunction during subsequent episodes of periparturient recumbency (21). With regard to the parameters indicating functional status and the possibility of musculoskeletal damage, statistically significant were found mainly in group I at the 2nd blood sampling. In this group, AST and CK activity returned to normal more slowly, reaching normal values only at the end of the study. In group II, the activities of these parameters had returned to the range of values given by Winnicka (28) by the third blood sampling. From these observations it may be concluded that animals deficient in phosphorus prior to parturition experience more severe and prolonged recumbency episodes and take significantly longer to recover. This often places these cows in a risk group for periparturient recumbency during the next lactation. Studies by other authors (3, 6, 8, 14) concerning this issue show results similar to those presented for group II, but the available literature lacks information on preparturient Pi concentrations. Bires et al. (3) and Correa et al. (8) also reported high AST values in some animals with periparturient recumbency. This suggests that those animals might have suffered from phosphorus deficiency before calving, similar to the animals in our own study. An evaluation of milk production showed that animals in group I produced significantly less milk at the beginning of lactation as compared to the other two groups of cows. This confirms the significant effect of preparturient Pi deficiency on milk production in animals affected by periparturient recumbency. In group II, despite the significantly higher milk production than that in group I, the animals reached the peak of lactation later than the healthy animals. Our observations indicate that periparturient recumbency (hypophosphataemia) in any form affects milk production in the herd.

Conclusions:

– A decrease in Pi concentration after parturition often occurs in high-producing cows, so low Pi concentrations before parturition may lead to periparturient recumbency.

– Cows with prepartum hypophosphataemia and periparturient recumbency (group I) show abnormalities in certain liver parameters during lactation. Liver supporting and protecting supplements should be used in these animals.

– Cows without preparturient hypophosphataemia showed less severe changes in parenchymal organ function.

– Group I cows are at a greater risk of musculoskeletal damage during lactation. For these animals, it is advisable to use bedding and stall materials that reduce stress on this system.

– Clinical hypophosphataemia reduces milk production in cows.

References

1. *Abramowicz B., Kurek Ł., Biernacka D., Sima Sahinduran S., Urosevic M., Lutnicki K.*: The changes in red blood cell characteristics over the course of subclinical phosphorus deficiency in dairy cows. J. Elem. 2022, 27 (1), 7-15.
2. *Baumgartner W.*: Klinische Propädeutic der inneren Krankheiten und Nantkrankheiten der Haus und Heimtiere, 6th ed., Parey, Berlin, Germany 2005.
3. *Bires J., Hlincikova S., Link R., Reichel P., Huska M.*: Clinical and biochemical analysis of peripartal recumbency on a dairy farm. Proceedings of IV Central European Buiatric Congress. Lovran 2003, 199-204.
4. *Bostedt H., Boryczko Z.*: Zaburzenia homeostazy elektrolitowej w okresie okołoporodowym i ich wpływ na przebieg okresu poporodowego u krów [Disorders of electrolyte homeostasis in the periparturient period and their effect on the postpartum period in cows]. Międzynarodowa Sesja Naukowa, Polanica Zdrój 2002, 63-67.
5. *Chamberlin W. G., Middleton J. R., Spain J. N., Johnson G. C., Ellersieck M. R., Pithua P.*: Subclinical hypocalcemia, plasma biochemical parameters, lipid metabolism, postpartum disease, and fertility in postparturient dairy cows. J. Dairy Sci. 2013, 96, 7001-7013.
6. *Cheng Y., Goff J. P., Horst R. L.*: Restoring normal blood phosphorus concentrations in hypophosphatemic cattle with sodium phosphate. Vet. Med. 1998, 93, 383-386.
7. *Cohrs I., Grünberg W.*: Suitability of oral administration of monosodium phosphate, disodium phosphate, and magnesium phosphate for the rapid correction of hypophosphatemia in cattle. J. Vet. Intern. Med. 2018, 32, 1253-1258.
8. *Correa M. T., Erb H. N., Scarlett J. M.*: Risk factors for downer cow syndrome. J. Dairy Sci. 1993, 76, 3460-3463.
9. *Cozzi G., Ravarotto L., Gottardo F., Stefani A. L., Contiero B., Moro L., Brscic M., Dalvit P.*: Short communication: Reference values for blood parameters in Holstein dairy cows: Effects of parity, stage of lactation, and season of production. J. Dairy Sci. 2011, 94, 3895-3901.
10. *Gartner B., Murphy G., Hoey W.*: Effects of induced, subclinical phosphorus deficiency on feed intake and growth of beef heifers. J. Agric. Sci. 1982, 98 (1), 23-29.
11. *Goff J. P., Horst R. L., Mueller F. J., Miller J. K., Kiess G. A., Dowlen H. H.*: Addition of anions to prepartal diet increases 1,25 dihydroxyvitamin D response to hypocalcemia preventing milk fever. J. Dairy Sci. 1991, 74, 154.
12. *Grünberg W., Scherpenisse P., Cohrs I., Golbeck L., Dobbelaar P., Van Den Brink L. M., Wijnberg I. D.*: Phosphorus content of muscle tissue and muscle function in dairy cows fed a phosphorus-deficient diet during the transition period. J. Dairy Sci. 2019, 102, 4072-4093.
13. *Horst R. L.*: Regulation of calcium and phosphorus homeostasis in the dairy cows. J. Dairy Sci. 1986, 69, 604-616.
14. *Kaya A., Akgül Y., Yüksek N.*: Studies on the etiology and treatment of hypophosphataemia developed naturally in cattle from Van region of Turkey. Med. Weter. 2008, 61, 171-174.
15. *Kokot F., Ficek R.*: Regulacja gospodarki wapniowej. Nowe aspekty patofizjologiczne [Regulation of calcium metabolism. New pathophysiological aspects]. Pol. Arch. Med. Wew. 2000, 3, 621-630.
16. *Littledike E. T., Goff J.*: Interactions of calcium, phosphorus, magnesium, and vitamin D that influence their status in domestic meat animals. J. Anim. Sci. 1987, 65, 1727-1743.
17. *Lutnicki K., Kaczmarek B., Kurek Ł.*: Niedobory wybranych makroelementów u bydła mlecznego [Deficiencies of selected macronutrients in dairy cattle]. Życie Weterynaryjne 2015, 90 (12), 802-805.
18. *Malafaia P., Barbosa J. D., Brito M. F., Souza V. C. D., Costa D. F. A.*: Phosphorus for cattle and buffaloes in Brazil: Clinical signs and diagnosis of its deficiency and relevance, and recommended strategies to alleviate issues observed under grazing conditions. Ruminants 2023, 3, 55-75.
19. *Malinowska A.*: Biochemia zwierząt [Animal Biochemistry]. SGGW, Warszawa 1997.
20. *Mayer J. W., Harvey D. J.*: Veterinary Laboratory Medicine. Interpretation & Diagnosis. 3rd ed., Elsevier Inc., St. Louis, Missouri, USA 2004.
21. *Moore F.*: Serum chemistry profiles in dairy cows – a herd management tool? Vet. Med. 1997, 92, 986-991.
22. *Radostits O. M., Gay C. C., Blood D. C., Hinchcliff K. W.*: Veterinary Medicine. 9th ed., Harcourt Publisher Ltd, London, UK 2000.
23. *Singh J., Hundal J. S., Sharma A., Singh U., Sethi A. P. S., Singh P.*: Phosphorus nutrition in dairy animals: A review. Int. J. Curr. Microbiol. App. Sci. 2018, 7, 3518-3530.
24. *Smith P. B.*: Large animal internal medicine. Mosby – Year Book, Missouri 1996.
25. *Stockdale C. R., Moyes T. E., Dyson R.*: Acute post-parturient haemoglobinuria in dairy cows and phosphorus status. Aust. Vet. J. 2005, 83, 362-366.
26. *Valk H., Šebek L. B. J., Beynen A. C.*: Influence of phosphorus intake on excretion and blood plasma and saliva concentrations of phosphorus in dairy cows. J. Dairy Sci. 2002, 85, 2642-2649.
27. *Vrzgula L., Sokol J.*: Hodnoty, metabolickych profilovych testov u domacich zvierat a ich interpretacia. Ustav veterinarnych informcii a osvety USVU, Bratislava 1987.
28. *Winnicka A.*: Wartości referencyjne podstawowych badań laboratoryjnych w weterynarii. Wydawnictwo SGGW, Warszawa 2015.
29. *Wu Z., Satter L. D., Sojo R.*: Milk production, reproductive performance, and fecal excretion of phosphorus by dairy cows fed three amounts of phosphorus. J. Dairy Sci. 2000, 83, 1028-1041.
30. *Zhang Z., Bi M., Yang J., Yao H., Liu Z., Xu S.*: Effect of phosphorus deficiency on erythrocytic morphology and function in cows. J. Vet. Sci. 2017, 30, 18 (3), 333-340.

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