Choline is a conditionally essential nutrient, meaning that it can be produced by the body, but under certain conditions the supply might be inadequate [1]. Dogs need choline for the synthesis of neurotransmitters (i.e. acetylcholine) for memory and muscle function. Choline is also part of phospholipids (i.e. phosphatidylcholine), which are important for transport of lipids, building of cell membranes and cell membrane signaling [2].

Moreover, choline has a role in being a methyl donor. Inasmuch, choline can be processed to betaine, which then provides a methyl group for the generation of methionine. Methionine is an essential amino acid used to build proteins. It is made from homocysteine, thereby reducing the heart disease risk, which is associated with homocysteine. These compounds made from choline, transport and provide methyl groups, which are used by the body to control protein function and gene expression important for the proper functioning of the cardiovascular, neurological, reproductive and detoxification systems.

**Figure 1: Structural function of phosphatidylcholine**

**Figure 2: Schematic of the conversion pathways of phosphatidylcholine to its metabolites**

Many of these pathways are challenged during intense physical activity of long duration, such as dog sled races, and the demand for free, non-membrane bound choline is increased to counteract the decrease of plasma choline concentrations during endurance exercise [3, 4]. The exact reasons for why choline concentrations decline during a high exercise performance are unclear, but were suggested to not necessarily reflect choline utilization, instead it might be a consequence of redistribution of fluid pools during exertion [5].
Dogs can make choline, but this is not sufficient to meet all their bodies’ requirements. The rest needs to be taken up from the diet in either free or bound form, which reduces the need for methyl groups supplied by methionine. Particularly dogs receiving a high-fat diet require extensive lipid transport by phosphatidylcholine. If an inadequate amount of choline is made and consumed, liver choline decreases rapidly [6] and the demand for methyl groups cannot be met. In dogs, choline deficiency results in liver dysfunction due to liver fat accumulation [7].

In 2018, a survey of the Association for Pet Obesity Prevention estimated that 60% of cats and 56% of dogs in the United States were overweight or obese. This has serious health consequences including fat accumulation in the liver. A balanced, healthy diet for dogs accompanied with regular physical activity is essential for overall health. In addition, nutritional supplementation strategies may help to reduce the risk of weight-related disorders or optimize nutrition for high-performance dogs. A mean to increase choline intake in dogs is given in krill meal, which provides choline in the bound form of phosphatidylcholine [8, 9].

Because of the methyl group interrelationship, the requirement for dietary choline supplementation depends on the availability of methionine, betaine, folate and vitamin B12. For example, betaine can replace choline addition, since choline provides the methyl group for betaine formation. Other factors that determine the dietary choline requirement are diet composition (protein, fat and carbohydrate levels), as well as gender, age, activity level and energy intake of dogs.

CHOLINE IS ESSENTIAL FOR:

- Building of cell membranes
- Liver fat transport to prevent fatty liver
- Nerve impulse transmission in brain and muscles
- Providing methyl groups that maintain liver, heart and kidney health
In humans, it was found that choline in the form of phospholipids is 12 times more efficient in raising blood choline concentrations compared to choline chloride \([10, 11]\).

While choline salt consumption in humans shows a 86% increase to a maximum plasma concentration after 30 minutes returning to normal levels after four hours, phosphatidylcholine intake raises choline by 265% and takes 12 hours to decline \([11]\).

ANTARCTIC KRILL

Kril meal is made from Antarctic krill (Euphausia superba), which is a crustacean related to shrimp (Fig. 3). But unlike shrimp that live on the ocean bottom, krill aggregate in huge up to twenty-kilo-meter-long swarms and move up and down the water column.

There are 85 different krill species around the world, with Antarctic krill living in the Southern Ocean around the frozen continent. Krill are transparent with some red and green colorations. The red is caused by special astaxanthin pigmentation spots that can change in size and intensity \([12]\). The ability to change pigmentation is important to balance darker coloration for UV protection, when at the surface, versus higher transparency for camouflage. The green can be seen in their digestive system and results from algae they eat. Krill can eat up to 20% of their body weight per day, but they also have the ability to shrink when starving and can survive without food for up to 200 days.

Adult krill can get up to 6 cm long and has blue light emitting spots on the body speculated to play a role in mating, swarm formation or camouflage from above when the sun shines on them. Surprisingly, the krill genome is about 12 times the size of the human genome. Antarctic krill is harvested in the wild and then cooked, dried and ground. Whole krill gives a powder of brownish-orange color rich in proteins, choline, omega-3 fatty acids and astaxanthin.
QRILL Pet is a functional ingredient for pet food, rich in phospholipid omega-3s, choline, marine proteins and astaxanthin. The choline found in krill is all natural and in form of phosphatidylcholine.

KRILL MEAL RESEARCH

A previous study with krill meal was exploring its benefits during an extreme endurance exercise, the 1600-km-long Iditarod dog sled race \[13\]. Iditarod is perhaps the most extreme endurance exercise performed by any domestic animal, and markers of oxidative stress, inflammation and skeletal muscle damage are known to be increased after the race \[14\]. The study reported that supplementation with krill meal for 5 weeks before the race increased the Omega-3 Index, which resulted in less inflammation and muscle damage in the krill group in comparison to a control group \[13\].

The latest study investigated if 8% dietary krill meal inclusion for six weeks can increase the concentration of choline and its metabolites in plasma of Alaskan Huskies in comparison to a control group \[15\].

The results demonstrated that a nutritional strategy, such as the addition of phosphatidylcholine to the diet, can help to significantly increase plasma choline concentrations (Fig. 5), which correlated with changed concentrations of various choline metabolites (Fig. 6).
These results could be of importance in a long-lasting race setting, when a drop in plasma choline is expected as seen in humans [16]. As a consequence of lowered free plasma choline concentrations, the generation of acetylcholine (a neurotransmitter important for muscle function) might be reduced and thereby negatively affect athletic performance. Noteworthy, from a performance perspective, is also the significant increase in betaine in the krill group, which is thought to promote muscle function and plasma volume expansion as shown after betaine supplementation in humans [17]. The study also found a significant reduction of plasma total homocysteine. Homocysteine is known to increase the risk of endothelial cell injury and cardiovascular disease in humans by increasing reactive oxygen species and altering lipoprotein metabolism [18]. A similar correlation has been identified in dogs [19]. Another metabolic derivative of choline that was significantly increased in the krill meal supplemented dogs was dimethylglycine, which was suggested to have possible protective effects on glucose metabolism [20].

The results of the krill meal supplementation study are encouraging to ensure that sufficient choline is available for optimal cell and body system functions. This is of particular interest for dogs that perform long-distance races or have health ailments affecting the liver, brain and heart.

Additionally, the omega-3 fatty acids from krill may further benefit the health of dogs by decreasing inflammation. Low-grade chronic inflammation is a characteristic of various diseases such as obesity, cardiovascular disease, arthritis, diabetes, fatty liver disease and some cancers.

Similarly, the astaxanthin present in krill meal has anti-inflammatory and antioxidant properties through its ability to scavenge free radicals, thereby counteracting oxidative stress and damage to proteins, lipids and DNA. Since Antarctic krill is protected from overfishing by CCAMLR and Aker BioMarine Antarctic AS has obtained the Marine Stewardship Certification to prove sustainable fishing, QRILL Pet is an attractive feed ingredient that ensures optimal health of pets in a sustainable manner.
CHOLINE – AN ESSENTIAL NUTRIENT FOR DOGS
The benefits of Phosphatidylcholine from krill in dog food

CHOLINE FORMS
- Phosphatidylcholine
- Choline chloride
- Choline bitartrate
- Glycerophosphocholine
- Citicoline
- Choline from krill (natural source of phosphatidylcholine)

SOURCES
- Meat
- Liver
- Fish
- Wheat germ
- Soybean
- Egg
- Krill

HEALTH BENEFITS OF CHOLINE
- Brain & Memory
- Heart
- Reproduction
- Improved health
- Optimal muscle performance
- Detoxification (methylation)
- Cardiovascular function
- Cognitive function

HOW TO ENSURE YOUR DOG IS GETTING SUFFICIENT CHOLINE

1700mg per kg dry matter
NRC recommendation (2006) for all dogs
Recommended choline intake

WHY CHOLINE FROM KRILL?

52% increase of plasma choline in dogs after 6 weeks on a QRILL Pet diet

REFERENCES

Choline from krill is a natural source of phosphatidylcholine (PC). Another study has shown that consumption of choline in PC form also stays longer in the body.
ABOUT THE AUTHOR

Lena Burri, Ph.D., has been involved in fundamental research and is together with co-authors credited with several original protein discoveries. She has published scientific articles in leading journals, and contributed book chapters, review articles and peer-reviewed manuscripts on many subjects, including omega-3 fatty acids. Lena earned her Master of Science from the University of Basel (Switzerland) and her Ph.D. at the Ludwig Institute for Cancer Research (Switzerland).

Her post-doctoral education included stays at Melbourne University (Australia), University of British Columbia (Canada) and University of Bergen (Norway). She now works as R&D Director for Animal Nutrition and Health for Aker BioMarine.

THOMAS WÆRNER & CO.

Thomas Wærner is a professional dog musher and a member of the QRILL Pet Mushing Team, the world’s first professional long-distance dog sled team. His dog team participated in the krill meal supplementation study described in this whitepaper.

In 2019, Thomas and his dog team won both of the biggest long-distance sled dog races in Norway, Finnmark race and Femund race. During these races the teams cover distances up to 1200 km. Thomas also received the veterinarian award at the Finnmark race, which is handed out to the musher who demonstrated outstanding dog care and health.

He owns and runs the Berserk kennel in Synnfjell, Norway. His previous achievements include the Finnmark race in 2013, 3rd place at the Femund race in 2013 and “Rookie of the year” at the Iditarod race in 2015.
REFERENCES


ABOUT QRILL PET

QRILL Pet is a product of Aker BioMarine, a leading biotechnology company developing and supplying krill-derived products for consumer health and animal nutrition. When developing our functional marine ingredient for pets, we kept our focus on the needs of pets and pet food formulators. Aimed at keeping pets healthy, QRILL Pet delivers long-chain omega-3 fatty acids, marine proteins, choline and the antioxidant astaxanthin. The unique distinction of krill omega-3s is that they are mainly bound to phospholipids.

QRILL Pet is currently the only MSC (Marine Stewardship Council) certified krill meal in the world. The ingredient comes from one of the most sustainable fisheries in the world and can be traced back to the exact catch location of the krill.