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Molecular Evaluation of Omega-3 Fatty Acids Impact on Arterial Elasticity and Cardiovascular Health in Cattle

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Abstract:
Due to the global increasing impact of bovine congestive heart failure (BCHF) on animals, cardiovascular disease (CVD) has become a major concern for animal health, welfare, and economic sustainability. Although, the availability of diagnostic methods, such as biochemical assays and echocardiography, early diagnosis faces barriers related to cost, accessibility, and accuracy, in which the majority of cases remains undetected. Recently, nutritional interventions including omega-3 fatty acids (n-3 FAs) have proven capacity to influence cardiovascular function, immune response, vascular flexibility, and overall metabolic health. Hence, this study aimed to theoretical investigate the physiological and molecular processes by which omega-3 fatty acids influence the cardiovascular health of cattle. As a result, this research confirms the potential of dietary omega-3 fatty acids to enhance the nutritional content of cattle-derived food products, improve cardiovascular function in cows, and promote animal welfare by combining the findings of previous studies. In veterinary cardiology, omega-3 fatty acids are ultimately considered an effective preventative measure linking human nutrition, agricultural sustainability, and animal health.

Keywords: Bovine congestive heart failure, Cardiovascular disease, Omega-3 fatty acids, Eicosatetraenoic acid.

التقييم الجزيئي لتأثير أحماض أوميجا 3 الدهنية على مرونة الشرايين وصحة القلب والأوعية الدموية في الأبقار

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الملخص
مع تزايد الأثر العالمي لقصور القلب الاحتقاني في الأبقار(BCHF) ، أصبحت أمراض القلب والأوعية الدموية (CVD) مصدر قلق رئيسي لصحة ورفاهيه الحيوان واستدامته الاقتصادية. وعلى الرغم من توفر وسائل التشخيص الحديثة مثل الفحوصات البيوكيميائية وتخطيط القلب، إلا أن هنالك عقبات كبيرة تمنع التشخيص المبكر للمرض، تتعلق بالتكلفة وصعوبة الوصول والدقة مما يؤدي إلى عدم اكتشاف معظم الحالات المرضية. في الآونة الأخيرة، أثبتت التدخلات الغذائية، بما في ذلك الأحماض الدهنية أوميغا-3(n-3 FAs) ، قدرتها على التأثير في وظائف القلب والأوعية الدموية، وتعديل الاستجابة المناعية، وتعزيز مرونة الأوعية الدموية، ودعم الصحة الأيضية للحيوانات بشكل عام. لذلك هدفت هذه الدراسة إلى التحقيق النظري في العمليات الفسيولوجية والجزيئية التي تؤثر من خلالها الأحماض الدهنية أوميغا-3 على صحة الجهاز القلبي الوعائي في الأبقار. ونتيجة لذلك، تؤكد نتائج هذا البحث على الدور الكبير للأحماض الدهنية أوميغا-3 في تعزيز القيمة الغذائية لمنتجات الأبقار، وتحسين وظائف القلب والأوعية الدموية، وتعزيز رفاه الحيوان من خلال دمج

نتائج الدراسات السابقة. وفي مجال أمراض القلب البيطرية، تُعتبر الأحماض الدهنية أوميغا-3 استراتيجية وقائية واعدة تربط بين صحة الحيوان والاستدامة الزراعية وتغذية الإنسان.

الكلمات المفتاحية: قصور القلب الاحتقاني في الأبقار، أمراض القلب والأوعية الدموية، الأحماض الدهنية أوميغا-3، حمض إيكوساتيترابنويك.

Introduction

Among the most serious vascular and cardiac disorders include atherosclerosis and arteriosclerosis, as well as associated consequences such ischaemic heart disease, strokes, peripheral artery disease, and heart failure. By addressing known cardiovascular risk factors, such as dyslipidaemias, hypertension, and diabetes mellitus, considerable progress can be made in preventing cardiac illnesses, even though the risk of clinical events is still substantial. Clinical trials have shown that omega-3 polyunsaturated fatty acids (n-3 PUFAs) are beneficial in treating diabetic mellitus, hypertension, and dyslipidaemia, in addition to their role as antithrombotic agents. This makes them one of the most pertinent dietary substances. Through their beneficial effects on metabolic indices and direct impacts at the cellular and subcellular levels, n-3 PUFAs may have a positive impact on cardiac and vascular pathological processes, according to evidence from research conducted on both humans and animals. [1] Their significance in cardiovascular health is further supported by the possibility that they could alter related outcomes or the underlying mechanisms of cardiovascular illness. [2]

The presence of a double bond three atoms away from the terminal methyl group in their chemical structure characterises omega-3 fatty acids, also known as omega-3 oils, w-3 fatty acids, or n-3 fatty acids. They are found in large quantities in nature and are crucial elements of lipid metabolism. α-linolenic acid (ALA, C18:3 w3), eicosapentaenoic acid (EPA, C20:5 w3), and docosahexaenoic acid (DHA, C22:6 w3) are the three primary forms of omega-3 fatty acids that are involved in physiological activities; the latter two are more prevalent in marine fish oils. The necessary omega-3 fatty acid ALA must be obtained from diet because humans are unable to synthesise it. Once accessible, ALA can undergo elongation and desaturation processes to partially convert it into EPA and DHA; however, this conversion is not very effective and may decrease with age. [3]

Due to their stability in particular formulations, unsaturated fatty acids—including n-3 PUFAs—are frequently employed as nutraceuticals despite their susceptibility to oxidation when exposed to air. [4] EPA and DHA intake had minimal effects on cardiovascular outcomes, according to one meta-analysis and one comprehensive review. [5] ALA, on the other hand, showed a considerable potential in reducing the risk of atherosclerotic cardiovascular events. However, extensive clinical trials like the EVAPORATE (Effect of Vascepa on Improving Coronary Atherosclerosis in People with High Triglycerides Taking Statin Therapy) and REDUCE-IT (Reduction of Cardiovascular Events with Icosapent Ethyl-Intervention Trial) [6] showed that EPA-derivative icosapent ethyl, at a dosage of 4 g/day, significantly decreased coronary plaque formation and cardiovascular events. The 2007 JELIS (Japan EPA Lipid Intervention Study) trial also provided evidence for the preventive effect of EPA in hypercholesterolaemia patients, demonstrating a decrease in atherosclerotic cardiovascular events in both primary and secondary prevention settings. [7]

Cardiovascular function and arterial flexibility are crucial for general physiology, productivity, and resistance to metabolic stress in the context of livestock health, especially cattle. Like in humans, omega-3 fatty acid supplementation may have molecular effects on lipid metabolism and vascular function in cattle, improving arterial flexibility and cardiovascular health. Therefore, the purpose of this study is to present a molecular assessment of the effect of omega-3 fatty acids on the cardiovascular health and arterial flexibility of cattle.

Study problem

Atherosclerosis and arteriosclerosis are the principal causes of vascular dysfunction and decreased arterial elasticity, making cardiovascular illnesses a significant concern for both human and animal health. Cardiovascular function in livestock, especially cattle, is directly related to general health, production, and resistance to environmental and metabolic stressors. Recent research has demonstrated how omega-3 polyunsaturated fatty acids (n-3 PUFAs) may enhance cardiovascular health by influencing endothelial function, inflammation, and lipid metabolism through molecular pathways.

The molecular processes by which omega-3 fatty acids affect arterial flexibility and cardiovascular health in cattle especially remain poorly understood, despite the mounting evidence from human clinical trials and some animal research. The development of nutritional regimens that could improve cattle productivity and health while lowering the risk of cardiovascular dysfunction is hampered by this knowledge gap. Thus, by performing a molecular assessment of omega-3 fatty acids and their possible impacts on arterial elasticity and cardiovascular health in cattle, the current work aims to address this issue.

Study objectives

1. To evaluate the molecular effects of omega-3 fatty acids on arterial elasticity in cattle to investigate the role of omega-3 fatty acids in improving cardiovascular.
2. health through modulation of lipid metabolism and endothelial function.

3. To analyze the potential of omega-3 supplementation in reducing vascular dysfunction and risk factors associated with atherosclerosis in cattle.
4. To compare findings from molecular analysis in cattle with existing evidence from human and animal studies, highlighting similarities and differences.
5. To provide a scientific basis for integrating omega-3 fatty acids into nutritional strategies aimed at enhancing cattle health and productivity.

Study questions

1. What are the molecular effects of omega-3 fatty acids on arterial elasticity in cattle?
2. How do omega-3 fatty acids influence cardiovascular health in cattle through lipid metabolism and endothelial function?
3. Can dietary supplementation with omega-3 fatty acids reduce vascular dysfunction and risk factors associated with atherosclerosis in cattle?
4. In what ways do molecular findings in cattle correspond with or differ from existing evidence in humans and other animals?
5. How can the molecular evaluation of omega-3 fatty acids contribute to developing nutritional strategies that enhance cattle health and productivity?

The Importance of the Study

The importance of this study stems from the growing awareness of the role of cardiovascular health in cattle productivity and overall well-being. Cattle's ability to adapt to metabolic and environmental stressors and circulatory efficiency are directly influenced by arterial elasticity, a measure of vascular function. Examining the molecular effects of omega-3 fatty acids provides important insights into how they contribute to maintaining arterial integrity and preventing cardiovascular disease.

This work fills a scientific knowledge gap in the molecular mechanisms by which omega-3 fatty acids affect arterial elasticity and cardiovascular health in cattle, an area that has received little attention compared to human studies. Using the findings in practice, nutritional approaches that incorporate omega-3 supplements could be developed to improve cow health, increase production, and potentially reduce veterinary expenditures associated with cardiovascular disease.

The findings of this study may have broader implications for the cattle industry by encouraging sustainable health practices that complement food security objectives and animal welfare requirements. This work provides theoretical and practical importance for researchers, veterinarians, and cattle producers by establishing molecular knowledge about the effects of omega-3 fatty acids.

Study hypotheses

1. Omega-3 fatty acids have a positive molecular effect on arterial elasticity in cattle.
2. Supplementation with omega-3 fatty acids improves cardiovascular health in cattle by modulating lipid metabolism and enhancing endothelial function.
3. Omega-3 fatty acids can reduce vascular dysfunction and risk factors associated with atherosclerosis in cattle.
4. Molecular effects of omega-3 fatty acids in cattle show similarities with previously reported findings in humans and other animal models.
5. Incorporating omega-3 fatty acids into cattle diets can serve as an effective nutritional strategy to enhance overall cardiovascular health and productivity.

Theoretical framework

1. Cardiovascular Disease in Cattle

Animal welfare, food security, and economic sustainability are all significantly impacted by cardiovascular disease (CVD), which has become a major concern for global livestock agriculture. Bovine congestive heart failure (BCHF), which affects more than 1.2 million cattle annually in the US alone, is alarmingly on the rise, with incidence rates doubling roughly every ten years, according to recent epidemiological studies [8]. The magnitude and seriousness of this pervasive problem are shown by the fact that advanced cardiac disease is present in about 4.14% of feeder cattle assessed at slaughter [9].

BCHF has a significant financial impact on the livestock business, causing annual losses of over $250,000 per feedlot from misdiagnosed cardi ac conditions—losses that are more significant economically than even respiratory disorders (U.S. Meat Animal Research Center). Furthermore, cattle with undetected heart disease have longer pain and waste resources, which further exacerbates the environmental impact of agriculture and raises greenhouse gas emissions.

Traditional diagnostic techniques like electrocardiography (ECG), echocardiography, thoracic radiography, and standard biochemical assays are still widely used in veterinary cardiology, despite the gravity and urgency of

these problems [10]. Despite the fact that echocardiography can detect heart dysfunction with up to 92% accuracy, its use is restricted by the need for specialised equipment and the lack of qualified veterinary cardiologists, which prevents it from being used in over 78% of cattle operations worldwide [11]. While biochemical indicators like cardiac troponin I (cTnI) still lack standardised breed-specific reference values, which limits their practical clinical applicability, thoracic radiographs provide limited diagnostic resolution [12]. There is a significant gap in clinical diagnoses because genetic methods, such as genomic testing like Igenity BCHF, can indicate propensity but not current heart illness [13]. As a result, most BCHF cases are not identified until postmortem exams, underscoring serious shortcomings in clinical practice and animal welfare regulations.
Artificial intelligence (AI)-based retinal imaging has revolutionised early cardiovascular disease diagnosis in human medicine. Proactive therapies and better patient outcomes are made possible by retinal microvascular alterations, which may be identified using sophisticated AI algorithms and frequently occur before clinical cardiovascular symptoms [14]. While deep learning models may predict 10-year cardiovascular events with sensitivities close to 74%, transformer-based neural networks, like RetiCVD-Net, have shown up to 89% accuracy in predicting left ventricular hypertrophy [15]. The retina is a perfect non-invasive diagnostic window into systemic cardiovascular health since the retina and systemic circulatory systems have embryological beginnings. This opens up promising translational opportunities for veterinary medicine [16].
The application of human-developed retinal imaging models to cattle faces challenges due to species differences and limitations in interpreting retinal anatomy. Previous deep learning architectures, like ResNet101, struggled to accurately interpret bovine retinal anatomy, leading veterinarians to be cautious about opaque AI systems.

2. Omega-3 fatty acids

The immune system, blood co-agulation, vascular resistance, enzyme activities, cell proliferation and differentiation, and receptor expression are just a few of the biological systems and processes that fatty acids (FA) are involved in [17]. Their composition affects how cells operate, and they are the primary constituents of cell membranes. Strong participants in the previously indicated functions are the n-3 (omega-3) FA [18]. The presence of a double bond on the third carbon atom from the methyl end of the molecule and their lengthy chain length give these FA special biological properties.
Unbranched chain polyunsaturated fatty acids (PUFA) with 20 and 22 carbons, particularly long-chain n-3 FA, are essential for the development of the central nervous system [19] and the reproductive system [20] and thus play a physiological role during pregnancy in both the pregnant mother and the foetus.
Research has shown that n-3 fatty acid supplementation has positive effects on the reproductive systems of dairy cows [21] and bulls [22]. Endometrial PGF2 was inhibited by feeding n-3 fatty acid to cows [23] while cows fed rolled flaxseed showed larger ovulating follicles and lower rates of pregnancy loss [24].
Increased consumption of n-3 FA, particularly eicosapentaenoic acid (EPA; C20:5n-3) and docosahexaenoic acid (DHA; C22:6n-3), is linked to a lower risk of cardiovascular disease in humans [25], as well as a lower risk of hypertension and arthritis. The n-6: n-3 FA ratio has risen from 2.4 in prehistoric human diets to 12.0 in contemporary human diets, and consumption of n-6 PUFA is rising in westernised societies [26]. Human health is thought to be improved by diets with lower n-6: n-3 ratios. Therefore, it would seem that the significance of dietary n-3.
It seems that the significance of dietary n-3 FA in cattle extends beyond the animal itself; as milk, milk derivatives, and meat are major sources of nourishment for humans, it is also particularly important to enrich these products with n-3 FA.
Recent years have seen the publication of numerous reviews [27] and meta-analyses [28] on the effects of PUFA in ruminants; nevertheless, those studies focused on certain subjects related to the effects of long-chain FA supplementation. The effects of n-3 FA supplementation on metabolism, health, and animal product diets were summarized in a great study by (Palmquist 2009) [29], however that review covered all domestic animals and was primarily concerned with the impact on human nutrition.

Methods

This study employed a systematic narrative/thematic literature review with a focused theoretical synthesis to explore the molecular effects of omega-3 fatty acids on arterial elasticity and cardiovascular health in cattle. The inclusion criteria included peer-reviewed articles, review papers, and authoritative book chapters that addressed: (a) the biology of omega-3 PUFAs (ALA, EPA, DHA), (b) vascular biology/arterial elasticity, and (c) cardiovascular health in cattle, with supplementary comparative evidence from other livestock species and translational animal models where mechanistically relevant. In addition, all collected data were extracted using Microsoft Excel Sheets for data charts; and NVivo/Atlas. it was used for thematic coding (if needed). Reference management tools including Zotero and EndNote were used to remove duplication, and citation management.
Rayyan software was used for screening research title, abstract, and full test.

Databases Sources

The data for this study were retrieved from scientific database including PubMed/MEDLINE, Web of Science, Scopus, CAB Abstracts (veterinary/agriculture), Google Scholar, ScienceDirect, SpringerLink, Wiley, and Taylor & Francis. The Keyword Blocks (combined with Boolean operators): omega-3 OR n-3, cattle OR bovine, arterial elasticity. All eligible records retrieved within the search window (no pre-set cap).

Results

The theoretical evidence reviewed in this study indicates that omega-3 fatty acids, particularly EPA and DHA, contribute to maintaining arterial elasticity by modulating the balance of collagen and elastin within vascular walls. In addition, these fatty acids also enhance endothelial function through increased nitric oxide (NO) bioavailability and the suppression of pro-inflammatory cytokines. Furthermore, they regulate lipid metabolism by reducing triglyceride and low-density lipoprotein (LDL) concentrations while elevating high-density lipoprotein (HDL) levels. The anti-inflammatory and antioxidant properties of omega-3 fatty acids, mediated through bioactive derivatives such as resolvins and protectins, which contribute to lowering the risk of atherosclerosis and cardiovascular disorders. Comparative studies in humans and animal models demonstrate that the molecular mechanisms underlying the effects of omega-3 fatty acids are conserved across mammalian species, involving membrane incorporation, modulation of endothelial enzymes, and regulation of eicosanoid pathways. Collectively, based on these theoretical insights suggest that omega-3 fatty acids exert beneficial effects on arterial elasticity and cardiovascular health in cattle, highlighting the importance of future empirical validation.

Recommendations

This study recommend that a future research should conduct empirical investigations in cattle populations to validate the theoretical findings on the role of omega-3 fatty acids in maintaining arterial elasticity. Besides, a comparative study assessing different dietary sources of omega-3 fatty acids, such as flaxseed, fish oil, and algae-based supplements, are particularly recommended to identify the most effective and sustainable options for livestock production systems. As well as, longitudinal investigations are also needed to evaluate the long-term cardiovascular outcomes of omega-3 supplementation in cattle, with particular emphasis on its effects on productivity, reproductive performance, and overall health. To elucidate the underlying mechanisms, researchers are encouraged to apply advanced molecular approaches, including transcriptomics, metabolomics, and lipidomics, to clarify the pathways through which omega-3 fatty acids modulate vascular function. Interdisciplinary collaboration between veterinary science, animal nutrition, and molecular biology will be essential for establishing an integrated framework to promote cardiovascular health in cattle. Finally, policymakers and agricultural stakeholders should consider the potential economic and health benefits of incorporating omega-3 supplementation into livestock feeding strategies, while balancing issues of cost, availability, and productivity outcomes.

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