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Caprine arthritis-encephalitis: A holistic review of disease etiology, diagnosis, and control measures

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Abstract
A lentivirus infection Caprine Arthritis Encephalitis Virus (CAEV) mostly affects goats, resulting in a chronic illness that progresses and causes pneumonia, mastitis, encephalitis, and arthritis. Belonging to the Retroviridae family, the virus is comparable to other lentiviruses, such as HIV in humans and the Maedi-Visna virus in sheep. Kids who consume contaminated milk or colostrum are the main carriers of the infection, though horizontal transmission by direct contact or contaminated equipment can also cause infection. Older goats usually show arthritic abnormalities, whereas younger goats are more likely to experience neurological problems. Because of lower output, higher veterinary expenses, and the requirement to cull affected animals, CAEV has a substantial financial impact on goat farming. Serological tests identifying antibodies, like ELISA, are typically used to confirm a diagnosis.

Keywords: CAE; CAEV; SRLV; Caprine; small ruminant lentivirus; arthritis, encephalitis

1. Introduction
Caprine arthritis-encephalitis syndrome (CAE) is also known as chronic arthritis-synovitis, big knee, viral leuko-encephalomyelitis, and progressive interstitial pneumonia (Bulgin,1990.) [5]. Characterised in adult goats by peri arthritis and chronic proliferative synovitis, and in goat offspring by acute afebrile leuko-encephalomyelitis (Dawson,1987) [8]. Additional symptoms of the illness include enlargement of the joint capsule, which makes a person lame. Infection with the Caprine Arthritis Encephalitis virus has also been linked to pneumonia, synovitis, mastitis, and slowed growth. Dairy goats with caprine arthritis encephalitis virus infection have lower lifetime production (Nord and Adnoy 1997) [17]. The caprine arthritis-encephalitis virus (CAEV) causes a chronic, slow-developing, and debilitating disease in goats. In dairy goats, it reduces milk production and quality, lower birth rates, slower weight gain, and decreases conception rates. Caprine arthritis-encephalitis (CAE) and Maedi visna (MV) are long-lasting lentivirus infections found in goats and sheep, often collectively referred to as small ruminant lentiviruses (SRLVs). One mode of CAEV transmission is through colostrum and milk, while the exact source of horizontal transmission in the absence of lactation remains unclear. However, faeces and lung fluids can carry the virus (Brotto *et al*. 2021) [4]. Laboratory tests for early detection, including antibody and viral nucleic acid testing, should be utilized. Prevention and control measures involve identifying infected animals, especially in the early stages, to assess infection rates, which is the first step in any eradication effort.

Aetiology
Caprine arthritis-encephalitis virus (CAEV) is part of the small ruminant lentiviruses (SRLVs), an enveloped, single-stranded RNA virus belonging to the Lentivirus genus within the Retroviridae family. There are multiple genetically distinct strains of CAEV, each varying in virulence. This family includes seven genera: Alpha, Beta, Gamma, Delta, and Epsilon retrovirus, all having a single-stranded RNA genome. These viruses are known as "slow" or lentiviruses (from the Latin word ‘lenti’, meaning slow), a reference to the long interval between infection and the onset of clinical symptoms. [Jones,2014] [11]. Small ruminant lentiviruses are linear, positive-sense RNA viruses, with a genome consisting of two identical RNA strands that code for three structural genes: gag, env, and pol. The gag gene is first

translated into a gag polyprotein (p55), [Panei *et al*. 2017] [18] which is cleaved at the cell surface to produce viral capsid (p28), matrix (p19), and nucleocapsid (p16) proteins. The env gene encodes the viral envelope, consisting of the surface glycoprotein gp135 and the transmembrane protein gp45, facilitating interaction with cell receptors and entry. The pol gene produces a polyprotein (gag-pol-pro), whose cleavage yields essential enzymes like reverse transcriptase, integrase, and protease. [Czopowicz *et al*. 2018] [7].

Epidemiology

The caprine arthritis encephalitis virus is present in every country in the world. The virus can infect people of any age or breed, and once it does, it stays with the bearer for the duration of their lives. Age alone does not affect the incidence of infections; sex has no effect either. The majority of goats contract the virus when they are young, live a lifetime positive, and show symptoms months or years later. Pure breed animals and those older than two years old also have a higher occurrence of caprine arthritis encephalitis. Early in the 1970s, caprine arthritis encephalitis was first identified.

Transmission

The primary mode of transmission is through the neonate's ingestion of colostrum and milk from birth until weaning. [Al-Qudah *et al*. 2006] [1]. Horizontal transmission within herds can happen through direct contact between animals and exposure to contaminated surfaces like feed troughs and waterers. The virus is present in various bodily fluids, including respiratory and genital secretions, saliva, semen, and milk. [Rowe,1997] [22]. Transmission through direct contact may involve respiratory or oral routes, contact with secretions, and milking practices. While vertical transmission is believed to occur, it is considered rare and not a significant source of spread. Goat milk epithelial cells are vulnerable to infection by the Caprine arthritis encephalitis virus. Other potential, but less significant, transmission methods include contaminated milking machines, humans spreading the virus between goats by acting as fomites, and the use of contaminated needles or surgical equipment. Intrauterine transmission and the presence of the virus in infected goat semen are also considered minor transmission sources [Rowe,1997] [22].

Disease course

Goats that are naturally infected with the caprine arthritis-encephalitis virus usually divide into two groups: goats that progressor (30%) and goats that do not progressor (NP) (70%). Non-Progressor goats normally remain asymptomatic and generate humoral and cellular responses to Caprine arthritis encephalitis virus antigens; nevertheless, NP goats can have moderate mastitis and loss of body condition. But by the time they reach sexual maturity, progressor goats get severe arthritis and may even become partially lame. The disease progresses differently in each progressor animal; some show mild to moderate lameness for years, while others have acute, rapid development that results in significant movement restriction.

Pathogenesis

Virus-infected macrophages present in colostrum and milk are absorbed whole through the gut lining, allowing the infection to spread throughout the body via infected mononuclear cells. Periodic viral replication and the maturation of macrophages result in characteristic lymphoproliferative lesions in target tissues, including the lungs, synovium, choroid plexus, and udder. The virus does not cause immune deficiency but instead triggers chronic mononuclear inflammation in various tissues. Arthritis develops slowly, characterized by an infiltration of lymphocytes, macrophages, and plasma cells into the synovium. [Narayan *et al*.1989] [15]. Post-mortem examinations revealed severe congestion in the brain and spinal cord, with milder congestion in the lungs, kidneys, liver, and gastrointestinal tract. Swelling of the knee joints in both forelimbs was observed, along with suppurative synovial fluids and jelly-like subcutaneous tissue in the trunk due to fat necrosis from starvation. Histological samples showed severe generalized congestion in the lungs, brain, and spinal cord, along with thickened inter-alveolar septa, inflammatory cells in the lungs, spongiosis, and vacuolization in the central nervous organs. Red neurons and evidence of vasculitis were also found in the cerebrum. The virus infects monocyte-lineage cells in susceptible hosts, starting with monocyte precursors in the bone marrow. Once these mature into macrophages, viral replication begins, selectively targeting certain macrophage types. This selective replication correlates with the disease's clinical progression and the tissues involved, particularly the mammary gland, synovia, lungs, and central nervous system. Macrophages that become Kupffer cells in the liver do not significantly transcribe viral RNA, resulting in an absence of liver lesions. Non-suppurative meningitis with lymphocyte and macrophage accumulation spreads throughout the leptomeninges and neuroparenchyma [Narayan *et al*. 1985] [16]. Three weeks after initial infiltration by monocytes and lymphocytes, plasma cells and demyelination appear. The lungs show signs of interstitial pneumonia, and inflammation is present in the mammary gland adventitia and synovial lining. The virus evades the immune system through several mechanisms:

1. It infects monocyte-macrophage lineage cells, neutralizing a key non-specific defence mechanism.
2. By infecting bone marrow stem cells and limiting viral gene expression, it prevents recognition by cytotoxic cells, allowing these stem cells to act as a viral reservoir.
3. Proviral DNA can remain latent and unexpressed for extended periods.
4. CAEV does not trigger neutralizing antibodies during infection.

These factors contribute to the virus's latency, persistence, and dissemination, making it challenging to control and lead to chronic, debilitating symptoms in affected animals.

Clinical signs

Polysynovitis-arthritis, the most prevalent sign of infection, usually affects adult goats but can strike young goats as early as six months of age. Different degrees of lameness and joint capsule distention are indicators of polysynovitis-arthritis. Additionally, typical are hypertonia and hyperreflexia. There have also been reports of depression, head tilt, circling, opisthotonos, torticollis, and paddling. However, chronic interstitial pneumonia that progresses to dyspnoea has been reported in adult goats with serological evidence of CAE virus infection. The most commonly affected joints are the carpal bones. The only clinical sign of a CAE virus infection is progressive weight loss. A lamb or kid with swollen carpal joints cannot extend their knee. Constant kneeling as a result of carpi ankylosis in a goat suffering from severe CAE arthritis. In adults, all circumstances result in low output and waste. [Narayan *et al*. 1985] [16]. Children may get

encephalitis, which can progress to ataxia or paralysis and the presentation of neurologic diseases. The clinical course is usually quick; quadriplegia frequently develops in less than a week. The symptoms of the "hard udder" or "indurative mastitis" caused by the CAE virus infection include a firm, enlarged mammary gland and agalactia at parturition. Hard udders, elevated somatic cell counts, and decreased milk supply are examples of clinical symptoms. Numerous research that link CAEV infection to goat milk output have been published.

Diagnosis

Although there are numerous ways to diagnose this illness, a tentative diagnosis was made based on the patient's clinical symptoms, medical history, post-mortem examination, and tissue histological analysis. Children with increasing paresis and adults with polyarthritis and/or indurative mastitis should be suspected of having CAE. Tests including agent identification, nucleic acid recognition techniques, and serological testing can be performed to obtain a confirming diagnosis. Cultures of milk or peripheral blood leukocytes with suitable caprine cells, such as synovial membrane cells, can be used to isolate viruses. Electron microscopy and immunolabelling techniques can be used to confirm the presence of CAEV. To quickly detect, quantify, and identify small ruminant lentivirus strains, numerous standards and a few quantitative polymerase chain reaction (PCR) tests have been devised and are currently being utilized regularly in many laboratories. The easiest approaches are PCR product cloning and/or sequencing. Additionally, serological testing that identifies certain antibodies against the virus can be used to diagnose this illness. The most widely used serological tests are Agar gel immunodiffusion (AGID) and enzyme-linked immunosorbent assay (ELISA); western blot analysis and radio-immunoprecipitation are also carried out, but only in specialized facilities. [Tu *et al*. 2017] [26].

The agar gel immunodiffusion test (AGID)

Based on CAEV serology, the World Animal Health Organization's recommended AGID test is one of the most widely used assays to identify CAE. The OIE recommends both AGID and ELISA. Multiple interactions between serum-based antibodies and viral epitopes produced from cell culture result in the precipitation line in an AGID test. Although the antigen-antibody precipitation line appears in less than 24 hours, it is best to check the data after 48 to 72 hours to ensure their stability. The test's sensitivity, specificity, and ease of use make it appropriate for early use in control and screening initiatives. False-negative results may occur in an AGID test due to delayed seroconversion, slower antibody production, or as a result of the antibodies being at an undetectable level at an early stage of infection. Thus, the AGID test appears to have lower sensitivity compared to ELISA. [Waseem *et al*. 2015] [27].

Enzyme-linked immunosorbent assay (ELISA)

Another serological method that the OIE has suggested for regulatory purposes since 2008 is the ELISA test. These techniques can be broadly divided into three categories: competitive ELISAs based on the use of anti-viral monoclonal antibodies, tests that use entire viruses, and recombinant proteins (or synthetic peptides) as antigens. Recombinant p55 gag23, p25, p16, and p14 core proteins24, gp46 transmembrane protein25, and pure gp135 envelope protein are examples of peptide or recombinant antigens used in indirect ELISAs that have been reported (Herrmann *et al*. 2003) [6]. Additionally, p25 or TM-derived synthetic peptides have been employed. According to the findings, single recombinant ELISAs are typically less sensitive than entire viral ELISAs. [Schultz, E. B] It is feasible to achieve test sensitivities and specificities that are comparable to those of whole virus ELISAs by including both a core antigen and an envelope antigen. An assay based on serum sample testing to measure the displacement of another monoclonal antibody after CAEV-63 was caught by one monoclonal antibody for competitive ELISA (Herrmann *et al*. 2003) [6]. In comparison to radioimmunoprecipitation, the ELISA was found to have 100% sensitivity and 96.4% specificity to RIPA [Elfahal *et al*. 2013] [9].

Polymerase chain reaction (PCR)

Due to proviral DNA's integration into the cellular genome and subsequent reproduction in immune system cells, CAEV infections continue to exist. Therefore, it is possible to identify the presence of the CAEV provirus using molecular biology methods like PCR. The diagnostic process has been made easier by this capacity. The results show that the real-time PCR diagnostic approaches have better sensitivity than the traditional serological AGID and ELISA procedures, which take 40–60 days to show positive detection results. The positive detection results obtained from the real-time PCR methods are approximately 15 days after the infection [Shuralev *et al*. 2021] [25].

The Western Blot (WB)

Western blot is often used as a ‘‘gold standard’’ test for SRLV diagnosis. However, the complex and time-consuming procedures make WB less suitable for regular screening.

The specificity is represented by visual band confirmation of the correct molecular weight. Researchers have shown that WB is either equally sensitive or more sensitive than ELISA in terms of WB sensitivity [Rodrigues *et al*. 2018] [21].

Differential diagnosis

Encephalitis: Scrapie, Listeriosis, Toxoplasmosis. The neurological form includes copper deficiency, lumbar cord abscesses, selenium and vitamin E deficiency, bacterial septicemia, septic arthritis or spinal cord injury. The arthritic form includes septic arthritis, Chlamydia- and Mycoplasma-induced arthritis, and trauma. On occasion, the respiratory and cachexia forms of CAEV will manifest without clinical arthritis or encephalitis. The chronic form of pneumonia must be differentiated from lungworm infection, chronic bacterial pneumonia and pulmonary abscesses. The mastitis form of CAEV is often observed with the arthritic form of CAEV. The two primary differentials for mastitis in goats include bacterial infections and CAEV.

Treatment

There are no targeted treatments for the clinical syndromes caused by CAE virus infection. Nonetheless, supportive care might be helpful for individual goats. For goats with polysynovitis arthritis, NSAIDs like phenylbutazone or aspirin can be administered. Additionally, antimicrobial therapy is recommended to address secondary bacterial infections that could exacerbate interstitial pneumonia or indurative mastitis, which are associated with CAE virus infection.

Control strategies for CAEV

Several factors, such as economics, available facilities, labour, and emotional investment, influence which control strategies are most suitable for a particular goat population. Various countries have implemented either voluntary or mandatory control programs, achieving significant success when producers fully adopt management practices. [Panneum *et al*. 2017] [19]. Some nations also offer accreditation programs, allowing goats to be certified as CAEV-free after two negative herd tests conducted 6 to 12 months apart, with annual retesting for reaccreditation. For the most stringent control measures, infected herds may be depopulated and replaced with known CAEV-negative animals. Testing and culling positive goats, or isolating infected animals from those that test negative, is crucial for preventing horizontal transmission. When deciding on culling or isolation to testing intervals, delayed seroconversion in CAEV-infected yet test-negative animals within herds is a key consideration.

Vaccine

Peptide-based Vaccines

The vaccine consisted of a short peptide that included both a T helper cell and B-cell epitope, found in the gag protein of CAEV. This T-cell epitope can trigger a significant T-cell proliferative response in vaccinated goats with varying genetic backgrounds and enhances the antibody response to the B-cell epitope. This suggests that it may serve as a universal antigen carrier for goat vaccines. In goats homozygous for MHC class I and II genes, the initial immune response showed MHC-dependent variations, with some exhibiting rapid-high and others slow-low responses. However, the memory immune response was strong in both groups, indicating that this vaccine, based on the immunodominant T helper epitope, can overcome genetic differences. [Russo *et al*. 1993] [23].

DNA Vaccines

The macrophage-tropic lentivirus CAEV is commonly used to develop lentiviral vaccination strategies, focusing on modulating cytokine responses during the priming of Th lymphocytes through immunization with plasmid DNA encoding CAEV envelope proteins. This approach is supported by well-established studies showing that cross-regulatory cytokines influence the differentiation of Th1 and Th2 lymphocyte subsets during antigen presentation. Consequently, the effectiveness of a prime-boost vaccination to control immune responses to CAEV, a macrophage-tropic lentivirus responsible for progressive arthritis in its natural host, was assessed. Vaccination of Saanen goats with pUC-based plasmid DNA expressing CAEV envelope proteins triggered Th1-skewed immune responses against the vector-encoded surface envelope (SU), with this Th1 response further amplified after boosting with purified SU in Freund's incomplete adjuvant (SU-FIA). Four goats vaccinated with env-expressing plasmids and boosted with SU-FIA were challenged intravenously and evaluated based on immunological, virological, and disease markers. The results indicated that a prime-boost strategy using a plasmid expressing the CAEV env gene followed by booster shots with purified Env protein did not result in sterilizing immunity but achieved long-term control of the virus after the challenge**.**

Control programs are designed based on common transmission risks, such as virus spread to newborns through colostrum and horizontal transmission among adult goats. Removing kids immediately from CAEV-positive does and feeding them colostrum and milk free of the virus can help limit CAEV spread. Safe milk sources include colostrum and milk from CAEV-negative does, heat-treated colostrum, heat-treated or pasteurized goat milk, or cow's colostrum, milk, or milk replacer. Heat-treating colostrum at 56°C for one hour has been shown to eliminate CAE virus activity while preserving the integrity of the colostrum's immunoglobulins. Additionally, to reduce transmission through milking machines, milking CAEV-positive does last or stopping machine use altogether may help. However, hand-milking may not be practical for many dairies, and milking infected does last and can be challenging in some herds [Panneum *et al*. 2017] [19]. Maintaining a closed herd and only introducing animals from known negative herds, or quarantining newly acquired test-negative animals for up to 6 months, is another effective strategy. [Peterhans *et al*. 2004] [20]. It's also important to consider the risks associated with live animal trading, auction markets, and returning goats from shows. Although control programs are generally effective, they can face challenges. For example, strictly removing kids before they nurse from their mothers can be difficult for producers. Infected goats may be hard to isolate due to fencing or facility constraints. Double fencing and a two-meter separation, along with separate feeding and water areas, have been recommended for effective segregation.

Conclusion

Caprine arthritis encephalitis (CAE) is a long-term illness that causes significant financial losses in goat farming. Since no cure exists for the CAE virus (CAEV), prevention is the primary method of control. Infected goats experience a drop in milk production of around 10-15%, leading to economic loss. Moreover, there is a risk of spreading the virus through semen from infected goats. Besides reducing productivity, CAEV has both health and economic impacts, including restrictions on the international trade of goats and their genetic material by countries with control measures in place. ELISA tests are generally more sensitive than AGID in detecting CAEV antibodies, while molecular tests like PCR and isothermal amplification are more effective at identifying infection before antibodies form. Control measures such as promptly separating kids, feeding heat-treated milk, segregating seronegative and seropositive animals, and milking infected animals last can bring economic benefits to producers.

Conflict of Interest

Not available

Financial Support

Not available

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