TULATHROMYCIN – A SEMI-SYNTHETIC MACROLIDE ANTIBIOTIC. I. CHARACTERISTICS AND ANTIBACTERIAL ACTIVITY

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Summary


This article reviews the available literature on the characteristics and antimicrobial activity of the semi-synthetic macrolide antibiotic tulathromycin from the triamilides subclass. The product has a high activity against Gram-negative respiratory pathogens and desirable pharmacological characteristics for high and persistent tissue levels in domestic animals. Representatives of the macrolide and lincosamide group are investigated and the similarities and differences from tulathromycin are outlined. It is emphasised that at the background of increasing bacterial resistance to a number of antimicrobial agents, only few tulathromycin-resistant strains of P. multocida and M. haemolytica have been reported so far. Tulathromycin is considered highly effective against common bacterial agents of respiratory diseases in large ruminants, pigs and sheeps, and may be an alternative for control of resistant bacterial pathogens.

Key words: activity, antibiotics, effectiveness, macrolides, resistance, tulathromycin

CHEMICAL CHARACTERISTICS OF TULATHROMYCIN

Tulathromycin is a new, semi-synthetic macrolide antibiotic, from the sub-class triamilides, approved for treatment and prevention of bovine respiratory disease (BRD) and treatment and metaphylactics of swine respiratory disease (SRD) in the European Union (EU) and the United States of America (USA) (Evans, 2005).

As a result of the search for a new antibiotic that meets the requirement for high efficacy against BRD and PRD with single treatment, a new subclass of macrolides – triamilides was found to possess a high activity against Gram-negative respiratory pathogens and desirable pharmacological characteristics: high and prolonged tissue levels in domestic animals (Letavić, 2002; Nowakowski et al., 2004).
Tulathromycin – a semi-synthetic macrolide antibiotic. I. Characteristics and antibacterial activity

Tulathromycin is a semi-synthetic macrolide antibiotic with unique chemical structure consisting of a regioisometric equilibrated mixture of 13-membered ring azalide (10%) and 15-membered ring azalide (90%), characterised by the presence of three amino groups. It is structurally related to erythromycin, which is monobasic, and to azithromycin, which is dibasic. The molecular formula of tulathromycin is: C_{41}H_{79}N_{3}O_{12}, and its molecular weight is 806.23. The drug molecule has three nitrogen/amino functional groups, and is the first member of a new subclass of macrolides known as "triamilides".

All macrolides have basic molecules with a dissociation constant (pKa) greater than 7. Tulathromycin molecule is more basic than the other macrolides and its pKa value can be from 8.6 to 9.6. This physicochemical feature allows the non-ionised fraction of the drug to attain easily the tissues and plasma and accumulate in acidic environment of some cells. This may explain the large volume of drug distribution and its accumulation in alveolar epithelial fluid and bronchoalveolar lavage cells (Evans, 2005; Villarino et al., 2013).

**TULATHROMYCIN PHARMACODYNAMICS**

**Mechanism of tulathromycin action**

Macrolides and lincosamides have different chemical structures but are functionally similar drugs with bacteriostatic action. They are active against Gram-positive and some Gram-negative microorganisms and may be also effective against intracellular pathogens. Macrolide resistance may develop with mutations of genes encoding ribosomal RNA or some ribosomal proteins. The microorganisms that have acquired resistance to one macrolide may be also resistant to others (Georgiev et al., 2010).

According to the US Pharmacopoeia Convention (USPC, 2007), macrocycles have been evaluated as bacteriostatic in therapeutic concentrations, but they can behave also as slow bactericidal agents, in particular against streptococci. Their bactericidal action has been described as time-dependent. The antimicrobial activity of some macrolides increases parallelly to increasing the pH and is suppressed at low pH, which makes them effective in abscesses and tissue necrosis (Villarino et al., 2013).

The macrolide group includes:

- azithromycin is designed for use in human medicine. It is well absorbed in the digestive tract and can be active against extra- and intracellular pathogens. Azithromycin is more active in vitro than erythromycin and clarithromycin against some respiratory pathogens. It is the macrolide with the longest therapeutic concentration and good tolerance;

- clarithromycin has a higher activity than erythromycin against Mycobacterium avium, Toxoplasma gondii, Chlamydia psittaci and Mycobacterium leprae. It is applied i.v. in dogs and orally in dogs, foals and donkeys at a daily dose of 10 mg/kg. In rabbits, high doses could result in intrauterine loss of foetuses (USPC, 2007; Georgiev et al, 2010).

- erythromycin is an antibiotic with activity against Gram-positive bacteria such as Staphylococcus aureus, Rhodococcus equi and Streptococcus spp., as well as against some Gram-negative microorganisms such as Haemophilus and Pasteurella sensitive to erythromycin;
josamycin is active in vivo against *Mycoplasma* and Gram-positive cocci: *Staphylococcus* spp., *Streptococcus* spp. and *Diplococcus* spp. In some countries but not in the EC, it is used in chickens and pigs for the prevention and treatment of respiratory diseases, sinusitis and arthritis;

tylosin has a spectrum of action against *Streptococcus* spp., *Staphylococcus* spp., *Erysipelothrix* spp., *Corynebacterium* spp., *B. hyodysenteriae*, *Spirochaeta* spp., *Campylobacter coli*, *Pasteurella* spp. and *Brucella* spp.;

tilmicosin is a semi-synthetic derivative of desmicosin. In vitro, it is effective against Gram-positive microorganisms and *Mycoplasma* and some Gram-negative bacteria, such as *H. somni*, *M. haemolytica*, and *P. multocida*. It is recommended for cattle, pigs and birds (Reese & Betts, 2000; USPC, 2007; Yordanov, 2009; Georgiev et al., 2010; Dimitrova et al.; 2014; 2019; Petkova & Yordanov, 2016). The *E. coli* strains isolated from pigs in 2015 are resistant to many of used antibiotics, including tylosin, tilmicosin and lincomycin, with share of resistant strains from 51 to 100% (Petkova, 2017).

Tulathromycin is the first member of a new macrolide class: triamilides, designed for systemic veterinary use and approved for treatment and prevention of BRD and PRD in more than 30 countries in America, Europe, Oceania and Asia (Villarino et al., 2013). Triamilides are semi-synthetic derivatives of the natural product erythromycin. In its crude form, tulathromycin is a white or off-white crystalline powder that is well soluble in water at pH 8.0 or lower. It is chemically stable when stored at room temperature (up to 25 °C) for 36 months. As a solution, tulathromycin is a 9:1 stable medicine of two isomers that remain in equilibrium. The proportion of isomers in biological fluids and tissues also remains in equilibrium (Letavić et al., 2002; USPC, 2007).

The three-basic structure of tulathromycin makes it able to penetrate Gram-negative pathogens, which are the commonest causes of BRD and SRD. Like other macrolides, tulathromycin binds to 50S subunits of bacterial ribosomes, thereby inhibiting protein synthesis leading to inhibition of cell division and cell death. Tulathromycin exhibits mixed bacteriostatic and bactericidal activity. It differs from other macrolides in that it has a longer duration of action. This feature, together with the slow release from the cells, is a likely explanation for the long-term retention of the drug in the lungs and other tissues. The value of the current pulmonary half-life for calves is 184 and for pigs: 142 hours (Evans, 2005; Georgiev et al., 2010; Villarino et al., 2013).

The minimum bactericidal concentration (MBC) was found to be similar to the minimum inhibitory concentration (MIC) of 70% of *M. haemolytica* and *P. multocida* strains isolated from cattle and pigs in North America. Tulathromycin metabolises slowly, with much of the drug being excreted unchanged in faeces and urine (Evans, 2005; Godinho et al., 2005a).

The special feature of this new drug class is increased penetration into Gram-negative bacterial pathogens, resulting in an increased drug potency (Nowakowski et al., 2004; Villarino et al., 2013).

**TULATHROMYCIN PHARMACOKINETICS**

Tulathromycin is concentrated noticeably in some areas, including lung epithelial
Tulathromycin – a semi-synthetic macrolide antibiotic. I. Characteristics and antibacterial activity

lining fluid, macrophages, and neutrophils, but its distribution and accumulation are found to vary in extent and duration (Cox et al., 2010; Villarino et al., 2013).

This feature, along with slow release from cells is the probable explanation for the long-term retention of the drug in the lungs and other tissues (Evans, 2005; Georgiev et al., 2010; Villarino et al., 2013).

In cattle, the pharmacokinetics of tulathromycin is characterised by rapid absorption from the injection site, prolonged distribution to the tissues, with a maximum plasma concentration of 0.5 µg/mL, which is reached approximately 30 minutes after dose administration and slow elimination. The apparent elimination half-life ($t_{1/2}$) is 90 hours in plasma. Significant concentrations of tulathromycin in neutrophils and alveolar macrophages have been demonstrated. The magnitude of local accumulation and prolonged persistence of the drug in the target tissues of the lungs result in an appropriate treatment regimen, as a single administration and a positive clinical outcome of the respiratory disease (Cox et al., 2010).

In pigs, the pharmacokinetic profile of tulathromycin after intramuscular administration of a single dose of 2.5 mg/kg was also characterised by rapid and extensive absorption, rapid distribution and slow elimination. The maximum plasma concentration was 0.6 µg/mL, reached approximately 30 minutes after injection. The levels of tulathromycin in the lung homogenates were significantly higher than those in the plasma. The elimination half-life ($t_{1/2}$) was 90 hours. The bioavailability of tulathromycin after intramuscular administration in pigs was about 88% (Waag et al., 2008).

In sheep, following an intramuscular administration of a single dose of 2.5 mg/kg, a maximum plasma concentration of 1.19 µg/mL was attained after approximately 15 minutes. The elimination half-life ($t_{1/2}$) was 69.7 hours. The bioavailability of tulathromycin after intramuscular administration in sheep is 100% (Benchaoui et al., 2004; Nowakowski et al., 2004; Evans, 2005; Nanjiani et al., 2005; USPC, 2007).

Tulathromycin is recommended for use in large ruminants (s.c.), in pigs (i.m. and i.v.) and in sheep (i.m.), at 2.5 mg/kg, as a single dose. Co-administration with other macrolides and lincosamides is not recommended. The withdrawal periods for meat and internal organs from tulathromycin-treated animals were as followed: for cattle – 22 days; for pigs – 13 days and for sheep – 16 days (Evans, 2005; USPC, 2007; Waag et al., 2008; Villarino et al., 2013).

SPECTRUM OF ANTIBACTERIAL ACTIVITY

Tulathromycin has a spectrum of activity similar to that of erythromycin, but is much more active against Mycoplasma spp. It penetrates well into Gram-negative bacteria, respiratory pathogens in calves (M. haemolytica, H. somni, P. multocida and M. bovis) and pigs (A. pleuropneumoniae, B. bronchiseptica, P. multocida, H. parasuis and M. haemolytica). It is used for both treatment and metaphylaxis. According to Reese et al. (2004) its antimicrobial activity against H. somni and other fastidious microorganisms is dependent on the pH and pCO$_2$ of the surrounding environment. MIC was reported to increase as pH decreases and pCO$_2$ increases (Evans, 2005; Gudinho et al., 2005a; Hart et al., 2006; Villarino et al., 2013).
Lees et al. (2016) tested the antibacterial activity of tulathromycin against *M. haemolytica* and *P. multocida*. Three antibacterial activity parameters were studied in *vitro* - MIC, MBC and time-killing curve for each organism, as each index was measured in two nutrient media: Mueller-Hinton broth (MHB) and calf serum. It was concluded that pharmacodynamic data from biological fluids such as serum will be used to determine the therapeutic dose of tulathromycin.

*Activity against Gram-negative pathogenic bacteria*

Tulathromycin is highly potent against Gram-negative respiratory pathogens and has prolonged pharmacokinetics in bovine and porcine lungs. Aqueous tulathromycin solution is administered at low volume doses and exhibits high efficacy levels against BRD and SRD via a single parenterally administered dose. The drug is bactericidal (from 4× and 8× MIC) against *M. haemolytica*, *A. pleuropneumoniae* and *P. multocida* (Evans, 2005; Godinho et al., 2005a, b).

Sweeney et al. (2008) conducted a study on the activity of tulathromycin and ceftiofur either alone or in combination, and in combination with one of the 7 antibacterial agents used to treat BRD against bovine *P. multocida* and *M. haemolytica* isolates to establish synergism, antagonism or indifference. Most *in vitro* data indicated that tulathromycin and ceftiofur, in combination each with the other or with 7 other antibacterial products, produced a predominantly indifferent response, undetectable synergism and rarely detectable antagonism.

Waag et al. (2008) tested the prophylactic efficacy of tulathromycin administered once daily, intramuscularly (i.m.) at 2.5 mg/kg on the 11th, 9th, 7th, 5th and 3rd days before the intranasal inoculation of pigs with a highly pathogenic strain of *A. pleuropneumoniae* (*App*) from serotype 5. After inoculation, health of all pigs was monitored throughout the experimental period. It was reported that with the exception of day 11, the amount of pigs dropped in the tulathromycin group was significantly lower than in the control group (P<0.05%).

Of the 237 swine lung samples studied, Zutić et al. (2008) isolated 13 bacterial species from 198 samples (83.5%). Of all bacterial species, *P. multocida* was the most dominant with 32.64%, followed by *App* with 29.01%. The susceptibility of isolated *App* strains to the antibiotics used in practice was tested by disc-diffusion method DDM (Oxoid). All *App* strains tested were sensitive to tulathromycin but showed high resistance to tetracycline (53%).

*Activity against Gram-positive pathogenic bacteria*

Tulathromycin, like other macrolides, is considered to be bacteriostatic when tested against *Staphylococcus aureus*. Macrolides have been evaluated as bacteriostatic at therapeutic concentrations, but they may also be slow bactericides, in particular against *Streptococcus spp.* (USPC, 2007).

In available literature, no other reports from antibacterial studies and the use of tulathromycin as a therapeutic or prophylactic antimicrobial agent, against animal diseases caused by other Gram-positive pathogenic bacteria were found out.

*Activity against Mycoplasma*

In an *in vitro* test, the sensitivity of 44 *M. hyopneumoniae* strains originating from Hungary, Slovakia and the Czech Republic to 15 different antibacterial drugs was
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Tested. They were found to be effective against most of the strains, but extremely high MICs of tilmicosin, tulathromycin and lincomycin – greater than 64 µg/mL, were also obtained. Against another strain (MycSu18) the following MIC values were found out: gamithromycin – 64 µg/mL; tylosin – 32 µg/mL; tylosalin – 2 µg/mL. Both groups of macrolide agents designated as № 16 (tylosin, tilmicosin and tylosalin) and No 15 (tulathromycin and gamithromycin) were effective against the tested strains, but the MIC data of tulathromycin against the typical strains were three times higher than those reported in the literature (USPC, 2007; Felde et al., 2018).

RESISTANCE OF MICROBIAL PATHOGENS AGAINST TULATHROMYCIN

The resistance of microorganisms to antibiotics is a problem for both veterinary and human medicine. Antimicrobials used in productive animals in Europe are often the same or belong to the same classes as those used in human medicine. Therefore, antimicrobial resistance (AMR) is a major, undesirable, side effect of antimicrobial drugs (AMD) use in humans and animals (Turnidge & Paterson, 2007; Popova, 2009; Zaharieva & Vassileva, 2019).

In all cases, the use of antibacterial agents should be based on the proven sensitivity of the isolated pathogenic strains (Dimitrova, 2009; Lyutskanov, 2013; Dimitrova et al., 2016; Yordanov et al., 2016; Petkova, 2017). According to Mos et al. (2010) the disk diffusion method (DDM) is reliable in antibiotic testing, easily feasible and effective, and its results are comparable to those of broth dilution (MIC).

Information on isolates resistant to tulathromycin is limited. Since tulathromycin was first approved in the USA and Europe, only two tulathromycin-resistant P. multocida strains have actually been reported. One isolate was from a pig in Germany in 2004 (Kaspar et al., 2007) and the other from a BRD calf at a Nebraska fattening farm in 2005 (Kadlec et al., 2011).

Other studies evaluating the in vitro susceptibility of targeted bovine and porcine respiratory pathogens have been conducted in various European countries after the drug was approved for use (Godinho, 2008). The study included 170 bovine and 133 porcine isolates. The sensitivity results were compared with those obtained prior to the launch of tulathromycin on the market and showed no change in the sensitivity of the key target species.

Alexander et al. (2013) tested of M. haemolytica isolates obtained from calves over a 3-year period for resistance to tulathromycin. For this purpose, nasopharyngeal samples were taken from 5,814 calves at loading and from the same animals after 60 days of fattening. M. haemolytica was isolated from 796 (13.7%) and from 1,038 (20.6%) of the samples, respectively.

Therapeutic concentrations of tulathromycin, tilmicosin, or tylosin-tartrate, respectively were administered in M. haemolytica positive calves (18.5, 2.9, and 2.4%). As a result, no M. haemolytica isolates resistant to tulathromycin were detected in the first and second year, while in the third year 5 isolates (0.4%) were resistant. The isolates were obtained from 3 calves descending from one box, all of serotype 1 and genetically related in origin. These 5 isolates were multi-resistant, but genes specific for macrolide resistance have not been identified. The results of this study indicated that M. haemolytica resistance to tulathromycin,
of the total population of calves for fattening in Western Canada, was low and did not change over the 3-year tulathromycin treatment period.

CONCLUSIONS

Tulathromycin is a new, triamilide, semisynthetic macrolide antibiotic approved for use in veterinary medicine. The pharmacokinetics of drug is characterised by rapid absorption from the injection site and good distribution to the peripheral tissues. The high and prolonged concentration in the lung tissue and alveolar macrophages and the slow release from the cells explain its high clinical efficacy from administration of a single dose. Tulathromycin metabolises slowly, with much of the drug being excreted unchanged in faeces and urine. Much of the drug being excreted un-

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Antibiotic 100 mg of tulathromycin/mL. For subcutaneous injection in beef and non-lactating dairy cattle and intramuscular injection in swine only. Not for use in female dairy cattle 20 months of age or older or in calves to be processed for veal. CAUTION Federal (USA) law restricts this drug to use by or on the order of a licensed veterinarian. DESCRIPTION DRAXXIN Injectable Solution is a ready-to-use sterile parenteral preparation containing tulathromycin, a semi-synthetic macrolide antibiotic of the subclass triamilide. Each mL of DRAXXIN contains 100 mg of tulathromycin as the free base in Macrolide antibiotics are typically characterized by macrocyclic lactones having a ring-size ranging between 12-16 atoms and also possess inherent extensive branching through the methyl substituents. In general, these antibiotics essentially exhibit a narrow spectrum of antibacterial activity, most importantly against the Gram-positive microorganisms. Biological Source It is a semi-synthetic macrolide antibiotic related to erythromycin A which is obtained from Saccharopolyspora erythraea. Although antibiotic generally refers to antibacterial, antibiotic compounds are differentiated as antibacterials, antifungals and antivirals to reflect the group of microorganisms they antagonize (Brooks et al., 2004; Russell, 2004). Penicillin was the first antibiotic discovered in September 1928 by an English Bacteriologist, late Sir Alexander Fleming who accidentally obtained the antibiotic from a soil inhabiting fungus Penicillium notatum but its discovery was first reported in 1929 (Aminov, 2010), and clinical trials first conducted on humans in 1940 (Russell, 2004; Schlegel, 2003). However, antibiotics are not totally selective in their antibacterial activity. Oxazolidinones are a group of synthetic antibiotics approved only recently for use. Table: Top 10 antibacterial companies by global sales of antibiotics in 2004 (Source: Wood Mackenzie[69]). Rank. Company. He tested more than 100 synthetic dyes for biological activity against Trypanosoma equinum, responsible for a disease that horses suffered from. Trypanosoma equinum. The first active compound was trepan red. Weak, unimportant antibacterial activity Powerful irreversible inhibitor of β-lactamases - suicide substrate Used as a sentry drug for ampicillin Augmentin = ampicillin + clavulanic acid Allows less ampicillin per dose and an increased activity spectrum Timentin = ticarcillin + clavulanic acid.