



Fluoroquinolones, Oral

Therapeutic Class Review (TCR)

July 17, 2012

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FDA-APPROVED INDICATIONS

Drug	Manufacturer	Abdominal	AECB	Acute sinusitis	Bone and Joint	CAP	Nosocomial Pneumonia	Inhalational Anthrax	Infectious Diarrhea	Gonorrhea	LRTI	Febrile Neutropenia	PID	Plague	Prostatitis	Skin	Typhoid fever	UTI
ciprofloxacin (Cipro®) ¹	generic, Schering	X*	X	X	X	-	X [†]	X	X	X	X	X [†]	-	-	X	X	X	X [#]
ciprofloxacin ER (Cipro XR®) ²	generic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
ciprofloxacin ER (Proquin® XR) ³	Depomed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X ^{##}
gemifloxacin (Factive®) ⁴	Cornerstone	-	X	-	-	X ^{**}	-	-	-	-	-	-	-	-	-	-	-	-
levofloxacin (Levaquin®) ⁵	generic OMJPI	-	X	X	-	X ^{**}	X	X	-	-	-	-	-	X	X	X	-	X
moxifloxacin (Avelox®) ⁶	Schering	X	X	X	-	X ^{**}	-	-	-	-	-	-	-	-	-	X	-	-
norfloxacin (Noroxin®) ⁷	Merck	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-	-	X
ofloxacin (Floxin®) ⁸	generic	-	X	-	-	X ^{***}	-	-	-	X ^{###}	-	-	X	-	X	X	-	X

Abdominal = Intra-abdominal infections, AECB = Acute exacerbation of chronic bronchitis, CAP = Community acquired pneumonia, LRTI = Lower respiratory tract infections, PID = Pelvic inflammatory disease, UTI = Urinary tract infection. †Ciprofloxacin (Cipro) IV, not oral, is indicated and should be used in combination with other agents.⁹

*Ciprofloxacin is indicated for complicated abdominal infections in combination with metronidazole.

**Gemifloxacin (Factive), levofloxacin (Levaquin), and moxifloxacin (Avelox) are indicated for the treatment of CAP due to multi-drug resistant *Streptococcus pneumoniae*.

*** Ofloxacin is indicated for *Haemophilus influenzae* and *Streptococcus pneumoniae* in CAP only.¹⁰

Ciprofloxacin is also indicated for complicated UTI and pyelonephritis caused by *Escherichia coli* in children ages one to 17 years; ciprofloxacin is not first line therapy for these infections.

Ciprofloxacin ER (Proquin XR) is only indicated in uncomplicated UTIs caused by *Escherichia coli* or *Klebsiella pneumoniae*.

Ofloxacin is also indicated for nongonococcal urethritis and cervicitis due to *Chlamydia trachomatis* and in mixed infections with *Chlamydia trachomatis* and *Neisseria gonorrhoea*.

OVERVIEW

Oral fluoroquinolones vary in the spectrum of antimicrobial activity. The older fluoroquinolones have a gram-negative spectrum of activity and are useful in the treatment of urological infections. Newer fluoroquinolones have broad spectrums of activity covering both gram-negative and gram-positive bacteria, and some agents are useful in the treatment of penicillin-resistant *Streptococcus pneumoniae*. Culture and sensitivity information should guide antibiotic selection when available.

Levofloxacin (Levaquin) is indicated for the treatment of plague, including pneumonic and septicemic plague, due to *Yersinia pestis* (*Y. pestis*) and for plague prophylaxis following exposure in adults and pediatrics, six months of age and older.¹¹ It joins streptomycin, doxycycline, tetracycline, and other antibacterials in the tetracycline class as FDA-approved treatments for plague.

While the oral fluoroquinolones are effective choices for treatment of community-acquired pneumonia (CAP), joint guidelines from the American Thoracic Society (ATS) and Infectious Diseases Society of America (IDSA) published in 2007 recommend macrolides (e.g., erythromycin, clarithromycin, azithromycin – strong recommendation) or doxycycline (weak recommendation) for adult patients who are otherwise healthy without risk factors for multi-drug resistant *S. pneumoniae*.¹² For adult outpatients with comorbidities including chronic heart, lung, renal, and hepatic disorders; diabetes; alcoholism; malignancies; asplenia; immunosuppression; or use of any antibiotic within the last three months or other risk factors for multi-drug resistant *S. pneumoniae*; first line therapy may include a respiratory fluoroquinolone (moxifloxacin, gemifloxacin, or levofloxacin 750 mg) or a beta-lactam plus a macrolide as a strong recommendation. Beta-lactam selection may include one of the following: high-dose amoxicillin 1 gm three times daily or amoxicillin/clavulanate. Other beta-lactam alternatives include ceftriaxone, cefpodoxime, or cefuroxime. Doxycycline may be used as an alternative to macrolides in combination with a beta-lactam. The fluoroquinolones should be used judiciously with appropriate dosing in an effort to avoid antibiotic resistance and therefore decreased effectiveness of this class of antibiotics.

Patients with an acute exacerbation of Chronic Obstructive Pulmonary Disease (COPD) will present with a change in the patients' baseline dyspnea, cough, and/or sputum which is more than the day-to-day variation, acute in onset, and may warrant a change in the chronic management of COPD. According to the 2012 update of the Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines, all patients with symptoms of COPD exacerbation should be treated with additional bronchodilators with or without glucocorticosteroids.¹³ Treatment of AECB includes bronchodilator therapy, corticosteroids (oral or intravenous), and possibly supplemental oxygen. Patients with a higher risk for poor outcome include those with presence of other comorbidities, severe COPD, frequent exacerbations (greater than three per year), and antimicrobial use within last three months. These guidelines no longer recommend antibiotic therapy except in cases of infectious exacerbations of COPD or other bacterial infections.

Urinary tract infections (UTI) occur more commonly in women.¹⁴ Acute cystitis is a symptomatic bladder infection characterized by frequency, urgency, dysuria, and suprapubic pain in a woman with a normal genitourinary tract. The 2010 updated guidelines for the management of acute uncomplicated cystitis consider the optimal approach to antibiotic selection and resistance patterns and the potential for the selection of drug-resistant organisms and colonization or infection for multi-drug resistant organisms. The empiric antibiotic selection for acute uncomplicated cystitis is nitrofurantoin 100 mg twice daily for five days. Nitrofurantoin has been shown to provide comparable efficacy to

trimethoprim-sulfamethoxazole given for three days (Strength of recommendation: A [good evidence to support]; quality of evidence: I [evidence from greater than one randomized controlled trial]). Empiric antibiotic selection may include trimethoprim/sulfamethoxazole (TMP/SMZ) double-strength (160/800 mg) twice daily for three days when local uropathogens are less than 20 percent resistant or if the infecting strain is known to be sensitive. The fluoroquinolones, ofloxacin, ciprofloxacin and levofloxacin, are highly efficacious, but use of fluoroquinolones has been linked to infections with methicillin-resistant *Staphylococcus aureus* and with increasing fluoroquinolone resistance in gram negative bacilli. Fluoroquinolones are considered alternatives for acute cystitis (A-III). Cephalosporins (cefdinir, cefaclor, and cefpodoxime) and amoxicillin-clavulanate given as three to seven day regimens are appropriate regimens when the other recommended agents can not be used (B-I). In general, beta-lactams have inferior efficacy and more adverse effects compared to other antimicrobials for UTIs.

Acute pyelonephritis is a renal infection with costovertebral angle pain and tenderness, often with fever. A urine culture and susceptibility test should be performed when pyelonephritis is suspected. Ciprofloxacin oral with or without an initial parenteral ciprofloxacin 400 mg dose is an appropriate selection for patients not requiring hospitalization. Prevalence of resistant of community local uropathogens to fluoroquinolones should not exceed ten percent. The first antimicrobial dose given parenterally may include ceftriaxone or an aminoglycoside (24 hour dosing method preferred) rather than a fluoroquinolone, especially when fluoroquinolone-resistant uropathogens are expected to exceed ten percent. Alternative oral fluoroquinolone regimens include ciprofloxacin ER for seven days or levofloxacin 750 mg daily for five days. Other alternative regimens include TMP-SMX for 14 days when the uropathogen is known to be susceptible (A-I); however, if TMP-SMX is used when susceptibility is not known, give an initial parenteral dose of ceftriaxone 1gm or an aminoglycoside (24 hour dosing method).

For the treatment of pelvic inflammatory disease (PID), the 2010 Centers for Disease Control and Prevention (CDC) sexually transmitted diseases guidelines recommend oral antibiotic therapy for patients with mild to moderately severe symptoms.¹⁵ Oral regimens have been shown to provide outcomes similar to parenteral therapy. In April 2007, the CDC recommended cephalosporins, specifically intramuscular ceftriaxone and oral cefixime, be preferred agents for treatment of gonorrhea throughout the United States. Outpatient regimens for the treatment of PID include intramuscular ceftriaxone plus doxycycline with or without oral metronidazole. Intramuscular cefoxitin plus oral probenecid plus doxycycline with or without metronidazole may also be considered. Other injectable third generation cephalosporins plus doxycycline with or without metronidazole are considered another possible outpatient treatment regimen for PID. Fluoroquinolones, levofloxacin or ofloxacin with or without metronidazole, may only be considered if the community prevalence and individual risk of gonorrhea is low. Tests for gonorrhea must be performed prior to initiating therapy. If the patient is positive for gonorrhea, antibiotic susceptibility may guide therapy or if the isolate is fluoroquinolone-resistant or susceptibility is unknown, parenteral cephalosporin therapy is recommended.

In the current (2005) Practice Guidelines for the Diagnosis and Management of Skin and Soft-Tissue Infections from IDSA include fluoroquinolones as an alternative to amoxicillin-clavulanate in the treatment of infections due to animal or human bites. Fluoroquinolones are also included in combination therapy of skin infections in immunocompromised patients. Community-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) skin infections are often susceptible to fluoroquinolones and if used, an agent with enhanced gram-positive activity is recommended.¹⁶

Updated IDSA guidelines for the treatment of skin and soft-tissue infections are expected in the spring of 2012 – **to date, no updates are available**.

According to the 2007 American Academy of Otolaryngology guidelines on the treatment of adult sinusitis, adults with mild or moderate acute bacterial rhinosinusitis (ABRS) may be observed with watchful waiting. For those with severe ABRS, or the patient worsens or fails to improve with watchful waiting, therapy with amoxicillin should begin.¹⁷ If treatment failure is observed following seven days of antibiotic therapy, a nonbacterial cause or infection with drug-resistant bacteria should be considered and should prompt a switch to alternate antibiotic therapy and re-evaluation of the patient. Optimal therapy of multi-drug resistant *S. pneumoniae* and beta-lactamase-producing *Haemophilus influenzae* and *Moraxella catarrhalis* would include high-dose amoxicillin-clavulanate (4 g per day amoxicillin equivalent) or a respiratory fluoroquinolone (levofloxacin, moxifloxacin, or gemifloxacin). These agents would also cover less common pathogens. Patients with penicillin allergy could receive a fluoroquinolone. Updated IDSA guidelines for the management of acute and chronic rhinosinusitis are expected in the spring 2012 – **to date, no updates are available**.

This review will compare and contrast the relative strengths, weaknesses, and distinguishing characteristics of the members of the oral fluoroquinolones. Few clinical trials directly compare the clinical efficacy and adverse effects of the oral fluoroquinolones.

PHARMACOLOGY

Fluoroquinolones are synthetic, broad-spectrum antibacterial agents. The fluorine molecule provides increased potency against gram-negative organisms and broadens the spectrum to include gram-positive organisms; the piperazine moiety confers antipseudomonal activity. These agents are bactericidal. Fluoroquinolones promote cleavage of bacterial DNA in the DNA-enzyme complexes of DNA gyrase (associated with gram-negative activity) and type IV topoisomerase (associated with gram-positive activity), resulting in rapid bacterial death.¹⁸ Mutations of the topoisomerase IV gene combined with gene mutations that alter DNA gyrase lead to high-level fluoroquinolone resistance in *S. pneumoniae*.¹⁹ Fluoroquinolones exhibit a prolonged post-antibiotic effect (PAE); organisms may not resume growth until two to six hours after quinolone exposure even at undetectable drug levels.²⁰

PHARMACOKINETICS^{21,22}

Fluoroquinolones exhibit concentration-dependent (versus time-dependent) bactericidal effects with more pronounced bactericidal activity as serum drug concentrations approach 30 times the minimum inhibitory concentration (MIC) or when the area-under-the-inhibitory-curve (AUC) exceeds 250.^{23,24} The exact level of the targeted AUC varies in the literature.²⁵ Fluoroquinolones have a post-antibiotic effect of approximately one to two hours up to two to six hours.^{26,27}

Fluoroquinolones are well absorbed following oral administration, with bioavailability for most agents in excess of 85 percent. Exceptions are ciprofloxacin, which is 70 to 80 percent bioavailable; gemifloxacin (Factive), which is 71 percent bioavailable; and norfloxacin (Noroxin), which is 30 to 40 percent bioavailable.^{28,29,30} Serum drug levels achieved after oral administration are comparable to those with intravenous (IV) dosing, which allows for early transition from IV to oral therapy and potential reduction of treatment costs.³¹

Fluoroquinolones are widely distributed throughout the body with tissue concentrations higher than achieved in plasma. The agents penetrate well into stool, bile, prostatic tissue, lung tissue, urine, and

kidneys. Because cerebrospinal fluid concentrations are consistently low, the fluoroquinolones are inadequate for first-line treatment of meningitis.³²

Below is a summary of the pharmacokinetic parameters.

Drug	Bioavailability (%)	Half-Life (hr)	Metabolites	Excretion (%)
ciprofloxacin (Cipro) ³³	~ 70	4	Four metabolites – less active than parent (15 percent of parent dose)	Urine: 40-50 Feces: 20-35
ciprofloxacin extended release (Cipro XR) ³⁴	--	6.3-6.6	Four metabolites – less active than parent (15 percent of parent dose)	Urine: 35 Feces: 20-35
ciprofloxacin extended release (Proquin XR) ³⁵	--	4.5	Four metabolites – less active than parent (11 percent of parent dose)	Urine: 41 Feces: 43
gemifloxacin (Factive) ³⁶	71	7	N-acetyl, E-isomer, and carbamyl glucuronide of gemifloxacin (<10 percent of oral dose)	Urine: 36 Feces: 61
levofloxacin (Levaquin) ³⁷	99	6-8	Desmethyl and N-oxide metabolites (little pharmacological activity)	Urine: 87 Feces: <4
moxifloxacin (Avelox) ³⁸	90	12	Two metabolites - sulfate and glucuronide conjugates	Urine: 34 Feces: 63
norfloxacin (Noroxin) ³⁹	30-40	3-4	Many metabolites, some active	Urine: 31-40 Feces: 30
ofloxacin (Floxin) ⁴⁰	98	9	Desmethyl and N-oxide metabolites (5 percent of parent)	Urine: 65-80 Feces: 4-8

Extended-release formulations of ciprofloxacin (Cipro XR, Proquin XR) are not interchangeable.⁴¹

Antimicrobial Activity

The older fluoroquinolones, ciprofloxacin and ofloxacin, have minimal gram-positive activity, but they are the most active against aerobic gram-negative bacilli. Limited microbial susceptibility and acquired resistance limit the usefulness of older agents in the treatment of staphylococcal, streptococcal, and enterococcal infections.⁴² Ciprofloxacin remains the most potent of the fluoroquinolones against some strains of *Pseudomonas aeruginosa*.⁴³ Norfloxacin has a primarily gram-negative spectrum of activity.

Newer fluoroquinolones, gemifloxacin, levofloxacin, and moxifloxacin, have improved gram-positive coverage as compared to older agents. Newer agents have *in vitro* activity against *S. pneumoniae*. Gemifloxacin, levofloxacin, and moxifloxacin provide coverage for penicillin-resistant and multi-drug resistant strains of *S. pneumoniae*. However, levofloxacin- and fluoroquinolone-resistant *S. pneumoniae* isolates have been reported.^{44,45} Compared with levofloxacin, moxifloxacin is four to eight times more active against *S. pneumoniae in vitro*. Moxifloxacin also has shown greater *in vitro* activity against *Staphylococcus aureus* and some enterococcal strains.⁴⁶

The Gonococcal Isolate Surveillance Project (GISP) annual report for 2010 showed continued high prevalence of resistance to both penicillin and tetracycline for gonococcal isolates (> 27 percent).⁴⁷ In 2010, the percentage of ciprofloxacin-resistant strains of gonococcal isolates in the United States increased from 9.6 percent in 2009 to 12.5 percent in 2010. Multi-drug resistant gonococcal isolates resistant to penicillin, tetracycline, and fluoroquinolones have been identified. The multidrug resistant

gonococcal strains show decreased susceptibility to cefixime. Cephalosporins (ceftriaxone, cefixime) are recommended for the treatment of gonorrhea according to the CDC.⁴⁸

Spectrum of Activity^{49,50,51,52,53,54,55,56,57,58,59}

Drug	Gram-positive bacteria	Gram-negative bacteria		Anaerobic bacteria	Atypical pathogens	STD pathogens
		All Gram negative bacteria	<i>Pseudomonas</i> species			
ciprofloxacin (Cipro, Cipro XR, Proquin XR) ^a	+	++++	++++	0	++	++
gemifloxacin (Factive)	++ ^d	+++	++	nr	+++	nr
levofloxacin (Levaquin)	++ ^d	+++	+++	+	+++	+++
moxifloxacin (Avelox) ^{b,c}	++ ^d	+++	++	++	+++	+++
norfloxacin (Noroxin)	+	+++	+++	0	nr	++
ofloxacin (Floxin)	+	+++	++	0	+++	+++

nr = not reported

^a Ciprofloxacin does not provide reliable activity against *Chlamydia*

^b Only moxifloxacin (Avelox) produces reliable anaerobic activity

^c Only moxifloxacin (Avelox) produces reliable anaerobic activity

^d Includes activity against penicillin-resistant and multi-drug resistant *Streptococcus pneumoniae* in the setting of CAP

CONTRAINDICATIONS/WARNINGS^{60,61,62,63,64,65,66,67}

Ciprofloxacin and ciprofloxacin ER (Cipro XR) are contraindicated with coadministration of tizanidine (Zanaflex®).

The labeling for all oral fluoroquinolones now includes a boxed warning regarding the increased risk of tendonitis and tendon rupture in all ages. The risk is further increased in older patients usually over 60 years of age, in patients taking corticosteroid drugs and in patients with kidney, heart, or lung transplants. This adverse effect most frequently involves the Achilles tendon, and rupture of the Achilles tendon may require surgical repair. Tendonitis and tendon rupture in the rotator cuff (the shoulder), the hand, the biceps, the thumb, and other tendon sites have also been reported. Other risk factors include strenuous physical activity, renal failure, and previous tendon disorders such as rheumatoid arthritis. Tendonitis and tendon rupture have also occurred in patients taking fluoroquinolones who do not have the above risk factors. Tendon rupture can occur during or after completion of therapy; cases occurring up to several months after completion of therapy have been reported. Fluoroquinolones should be discontinued if the patient experiences pain, swelling, inflammation or rupture of a tendon. Patients should be advised to rest at the first sign of tendonitis or tendon rupture, and to contact their healthcare provider regarding changing to a non-quinolone antimicrobial drug.

Quinolones may also exacerbate muscle weakness in patients with myasthenia gravis; avoid use in patients with known history of the condition.

Pseudomembranous colitis has been reported with nearly all antibacterial agents including the oral fluoroquinolones. Pseudomembranous colitis should be considered in patients who present with diarrhea after use of antibacterials.

Serious hypersensitivity and/or anaphylactic reactions have been reported with fluoroquinolone use. Clinical manifestations may include one or more of the following: fever, rash, or severe dermatologic reactions (e.g., toxic epidermal necrolysis, Stevens-Johnson syndrome); vasculitis; arthralgia; myalgia; serum sickness; allergic pneumonitis; interstitial nephritis; acute renal insufficiency or failure; hepatitis; jaundice; acute hepatic necrosis or failure; anemia, including hemolytic and aplastic; thrombocytopenia, including thrombotic thrombocytopenic purpura; leukopenia; agranulocytosis; pancytopenia; and/or other hematologic abnormalities. The drug should be discontinued immediately at the first appearance of a skin rash, jaundice, or any other sign of hypersensitivity and supportive measures instituted.

Reports of central nervous system (CNS) stimulation, convulsions, dizziness, confusion, tremors, hallucinations, depression, toxic psychoses, **increased intracranial pressure (including pseudotumor cerebri)**, and suicidal thoughts or acts have been reported following fluoroquinolone administration. All fluoroquinolones should be used with caution in patients with known or suspected CNS disorders that predispose a patient to seizures (epilepsy, severe cerebral arteriosclerosis) or lower the seizure threshold or in the presence of other risk factors that may predispose to seizure or can lower the seizure threshold (certain drug therapy, renal dysfunction).

Rare reports of sensory or sensorimotor axonal polyneuropathy affecting small and/or large axons resulting in paresthesias, hypoesthesias, dysesthesias, and weakness have been reported in patients receiving fluoroquinolones. Fluoroquinolones should be discontinued if the patient experiences symptoms of neuropathy including pain, burning, tingling, numbness, weakness, or is found to have deficits in light touch, pain, temperature, position sense, vibratory sensation, or motor strength in order to prevent the development of an irreversible condition.

Fluoroquinolones are not effective therapies for syphilis.⁶⁸ Because treatment for gonorrhea may mask the symptoms of syphilis, patients receiving treatment for gonorrhea should have appropriate testing performed for syphilis.

Coadministration of ciprofloxacin and theophylline has resulted in serious and fatal reactions. Reactions have included cardiac arrest, seizure, status epilepticus, and respiratory failure. Although similar serious adverse effects have been reported in patients receiving theophylline alone, the possibility that these reactions may be potentiated by ciprofloxacin cannot be eliminated. If concomitant use cannot be avoided, serum levels of theophylline should be monitored and dosage adjustments made as appropriate.

Post-marketing reports of severe and sometimes fatal hepatotoxicity have occurred with levofloxacin (Levaquin) use. Use of levofloxacin should be discontinued immediately if the patient develops signs and symptoms of hepatitis. Severe hepatotoxicity generally occurred within 14 days of initiation of therapy, and most cases occurred within six days. Most cases of severe hepatotoxicity were reported in patients over 65 years of age and were not associated with hypersensitivity. Levofloxacin should be

discontinued immediately if the patient develops signs and symptoms of hepatitis. Moxifloxacin should be used with caution in patients with mild, moderate, or severe liver cirrhosis.

Moderate to severe photosensitivity or phototoxicity reactions which may be manifested as exaggerated sunburn reactions involving areas exposed to light have been associated with the use of fluoroquinolones after sun or UV light exposure. Therefore, excessive exposure to these sources of light should be avoided. Drug therapy should be discontinued if photosensitivity/phototoxicity occurs.

Disturbances of blood glucose, including symptomatic hyper- and hypoglycemia, have been reported with levofloxacin and ofloxacin, usually in diabetic patients receiving concomitant treatment with an oral hypoglycemic agent (e.g., glyburide) or with insulin.^{69,70} In these patients, careful monitoring of blood glucose is recommended. If a hypoglycemic reaction occurs in a patient being treated with levofloxacin or ofloxacin, therapy should be discontinued and appropriate therapy should be initiated immediately. The concomitant administration of ciprofloxacin and norfloxacin with glyburide has, on rare occasions, resulted in severe hypoglycemia. No clinically significant changes in blood glucose were reported with moxifloxacin when given with glyburide.

QTc interval prolongation

As a class, fluoroquinolones have been associated with QTc interval prolongation. Fluoroquinolones have warnings in the product labeling to avoid use of these drugs in patients with pre-existing prolonged QTc interval, in those receiving agents concurrently known to prolong the QTc interval, in patients with uncorrected hypokalemia, or those receiving Class IA or III antiarrhythmics.^{71,72,73,74,75,76,77} QTc interval prolongation appears to be a dose-related effect; recommended dosages should not be exceeded. Reduce the dosage of all fluoroquinolones except moxifloxacin (Avelox) for patients with renal insufficiency to avoid excessively high serum levels. No excess in cardiovascular morbidity or mortality has been reported in over 15,500 patients in controlled studies, and there was no increased mortality in 18,000 patients receiving oral moxifloxacin in post-marketing trials where ECGs were not monitored.⁷⁸

Fluoroquinolones prolong the QT interval by blocking voltage-gated potassium channels, especially the rapid component of the delayed rectifier potassium current I(Kr), expressed by hERG (the human ether-a-go-go-related gene). According to the available case reports and clinical studies, moxifloxacin carries the greatest risk of QT prolongation from all available quinolones in clinical practice and it should be used with caution in patients with predisposing factors for Torsades de Pointes (TdP). Although gemifloxacin, levofloxacin, and ofloxacin are associated with a lower risk of QT prolongation compared with moxifloxacin, they should also be used with caution in patients at risk for QT prolongation. Ciprofloxacin appears to be associated with the lowest risk for QT prolongation and the lowest TdP rate.⁷⁹

In the double-blind CAPRIE trial, moxifloxacin IV/oral and levofloxacin IV/oral were compared for cardiac rhythm safety in 394 elderly hospitalized patients for the treatment of community acquired pneumonia (CAP).⁸⁰ Holter monitoring for at least three days revealed a ventricular arrhythmia rate of 8.3 and 5.1 percent for moxifloxacin and levofloxacin; this difference was not statistically significant. Nonsustained ventricular tachycardia occurred in 7.3 percent of patients receiving moxifloxacin and 5.1 percent of patients receiving levofloxacin. One case of sustained monomorphic ventricular tachycardia occurred in the moxifloxacin group. One patient on levofloxacin developed torsades de pointes.

QTc Warnings

Drug	Cases of TdP per 10 million Rx (95% CI) ⁸¹	QT guidance	Guidance for patients at high risk
ciprofloxacin (Cipro) ^{82,83,84}	0.3 (0-1.1)	In general, elderly patients may be more susceptible to drug associated effects on the QT interval.	Caution should be taken when using ciprofloxacin with concomitant drugs that can result prolongation in QT interval (i.e. class IA or class III antiarrhythmics) or patients with risk factors for torsades de pointes (i.e. known QT prolongation, uncorrected hyperkalemia).
gemifloxacin (Factive) ⁸⁵	no data	Fluoroquinolones may prolong the QT interval in some patients.	Gemifloxacin should be avoided in patients with a history of prolongation of the QTc interval, patients with uncorrected electrolyte disorders (hypokalemia or hypomagnesemia), and patients receiving Class IA (e.g., quinidine, procainamide) or Class III (e.g., amiodarone, sotalol) antiarrhythmic agents. Pharmacokinetic studies between gemifloxacin and drugs that prolong the QTc interval such as erythromycin, antipsychotics, and tricyclic antidepressants have not been performed. Gemifloxacin should be used with caution when given concurrently with these drugs, as well as in patients with ongoing proarrhythmic conditions, such as clinically significant bradycardia or acute myocardial ischemia. The likelihood of QTc prolongation may increase with increasing dose of the drug; therefore, the recommended dose should not be exceeded especially in patients with renal or hepatic impairment where the Cmax and AUC are slightly higher. QTc prolongation may lead to an increased risk for ventricular arrhythmias including torsades de pointes. The maximal change in the QTc interval occurs approximately 5-10 hours following oral administration of gemifloxacin.
levofloxacin (Levaquin) ⁸⁶	5.4 (2.9-9.3)	Some quinolones, including levofloxacin, have been associated with prolongation of the QT interval on the ECG and infrequent cases of arrhythmia.	Rare cases of torsades de pointes have been spontaneously reported during postmarketing surveillance in patients receiving quinolones, including levofloxacin. Levofloxacin should be avoided in patients with known prolongation of QT interval, patients with uncorrected hypokalemia, and patients receiving class IA (quinidine, procainamide) and class III (sotalol, amiodarone) antiarrhythmic agents. Elderly patients may be more susceptible to drug-associated effects on the QT interval.
moxifloxacin (Avelox) ⁸⁷	0 (0-26)	Moxifloxacin has been shown to prolong the QT interval of the ECG in some patients.	Moxifloxacin should be avoided in patients with known prolongation of the QT interval, patients with uncorrected hypokalemia and patients receiving Class IA or Class III antiarrhythmic agents, due to the lack of clinical experience with the drug in these patient populations. Pharmacokinetic studies between moxifloxacin and other drugs that prolong the QT interval such as cisapride, erythromycin, antipsychotics, and tricyclic antidepressants have not been performed. An additive effect of moxifloxacin and these drugs cannot be excluded; therefore moxifloxacin should be used with caution when given concurrently with these drugs.

QTc Warnings (continued)

Drug	Cases of TdP per 10 million Rx (95% CI) ⁸⁸	QT guidance	Guidance for patients at high risk
norfloxacin (Noroxin) ⁸⁹	no data	Patients should be advised that norfloxacin may cause changes in the electrocardiogram (QTc interval prolongation)	Elderly patients may be more susceptible to drug-associated effects of the QTc interval. Therefore, precaution should be taken when using norfloxacin concomitantly with drugs that can result in prolongation of the QTc interval (e.g., class IA or class III antiarrhythmics) or in patients with risk factors for torsades de pointes.
ofloxacin (Floxin) ⁹⁰	2.1 (0.3-7.6)	Some quinolones, including ofloxacin, have been associated with prolongation of the QT interval on the ECG and infrequent cases of arrhythmia.	Rare cases of torsades de pointes have been spontaneously reported during post-marketing surveillance in patients receiving quinolones, including ofloxacin. Ofloxacin should be avoided in patients with known prolongation of the QT interval, patients with uncorrected hypokalemia, and patients receiving Class IA (quinidine, procainamide), or Class III (amiodarone, sotalol) antiarrhythmic agents.

DRUG INTERACTIONS

Drug	theophylline	phenytoin	cyclosporine	warfarin	digoxin	Class IA and III antiarrhythmics
ciprofloxacin (Cipro, Cipro XR, Proquin XR) ^{91,92,93}	X	X	X	X	-	X
gemifloxacin (Factive) ⁹⁴	-	not studied	not studied	-	-	X
levofloxacin (Levaquin) ⁹⁵	consider monitoring	-	-	reported	-	X
moxifloxacin (Avelox) ⁹⁶	-	-	-	-	-	X
norfloxacin (Noroxin) ⁹⁷	consider monitoring	-	X	X	-	X
ofloxacin (Floxin) ⁹⁸	X	-	-	-	-	X

Oral fluoroquinolones should not be administered at the same time as antacids, multi-valent cation drugs including sucralfate, chewable/buffered didanosine, metal cations such as iron and calcium, and multivitamins containing zinc due to reduced bioavailability of the fluoroquinolone. For ofloxacin, levofloxacin, and norfloxacin, administer the fluoroquinolone at least two hours before and two hours after the administration of antacids and multi-valent cation drugs. For gemifloxacin, the time frame is a minimum of three hours before and two hours after for all metal cations except calcium carbonate. Administer gemifloxacin at least two hours before and two hours after calcium carbonate and sucralfate. For ciprofloxacin XR (Proquin XR), the administration should be at least two hours before and at least four hours after. For ciprofloxacin other than Proquin XR, administer the fluoroquinolone at least two hours before and at least six hours after the metal cation drugs. For moxifloxacin, administration should be at least four hours before and at least eight hours after.

Disturbances of blood glucose, including hyperglycemia and hypoglycemia, have been reported in patients treated concomitantly with some fluoroquinolones and an antidiabetic agent.⁹⁹ Therefore,

careful monitoring of blood glucose is recommended when levofloxacin, ofloxacin, norfloxacin, and ciprofloxacin XR (Proquin XR) are coadministered with an antidiabetic agent.

ADVERSE EFFECTS

Drug	Nausea	Diarrhea	Dizziness	Vomiting	Abdominal pain	Headache	Phototoxicity
ciprofloxacin (Cipro) ¹⁰⁰ n=49,038	2.5	1.6	<1	1	<1	<1	<1
ciprofloxacin ER (Cipro XR) ¹⁰¹ n=961	4	2	2	2	<1	3	<1
ciprofloxacin ER (Proquin XR) ¹⁰² n=524	1.4	<1	<1	<1	1.7	2.3	<1
gemifloxacin (Factive) ¹⁰³ n=8,119	3.7	5	1.7	1.6	2.2	4.2	≤0.1
levofloxacin (Levaquin) ¹⁰⁴ n=7,537	7	5	3	2	2	6	reported
moxifloxacin (Avelox) ¹⁰⁵ n= >15,500	6	5	2	0.1-2	0.1-2	0.1-2	<0.1
norfloxacin (Noroxin) ¹⁰⁶ n=2,032	4.2	0.3-1	1.7	0.3-1	0.3-1	2.8	reported
ofloxacin (Floxin) ¹⁰⁷	10	4	5	4	1-3	9	reported

Adverse effects are reported as a percentage. Adverse effects data are obtained from package inserts and are not meant to be comparative or all inclusive. nr = not reported.

Photosensitivity/phototoxicity warnings appear in the prescribing information for all oral fluoroquinolones. Patients taking a fluoroquinolone are advised to avoid excessive exposure to sunlight or artificial ultraviolet light to prevent skin eruptions or sunburns.

Rash, most commonly described as maculopapular and mild to moderate in severity, has been reported in 0.4 to four percent of patients receiving gemifloxacin (Factive) with the highest occurrence seen in women less than 40 years old taking gemifloxacin for seven days (12 percent of women less than 40 years old) or ten days (15.3 percent of women less than 40 years old).¹⁰⁸ Women taking hormone replacement therapy and gemifloxacin were also observed to have a higher rate of rash than men. Gemifloxacin therapy is not recommended to exceed seven days. Longer duration of treatment is associated with a higher incidence of rash in all patients except men over 40 years of age. Gemifloxacin should be discontinued when a rash appears. Eighty percent of rashes resolved within 14 days. Approximately 10 percent of the rashes (0.5 percent of all patients) were described as of severe intensity and approximately 10 percent of those with rash were treated with systemic steroids.

SPECIAL POPULATIONS^{109,110,111,112,113,114,115,116}

Pediatrics

In initial studies of fluoroquinolones, bone and joint abnormalities (osteochondrosis) were seen in young dogs. Permanent damage to cartilage in weight-bearing joints was concerning. Adverse effects in tendons have been reported. Benefits of systemic fluoroquinolone use versus risks associated with use in pediatrics must be considered.¹¹⁷ The American Academy of Pediatrics stated fluoroquinolone use in children should only be considered when there are no other safe or effective alternatives to treatment of an infection caused by multi-drug resistant bacteria or to provide oral therapy when parenteral treatment is not feasible, and no other oral agent is effective.¹¹⁸ Safety and effectiveness of gemifloxacin (Factive), moxifloxacin (Avelox), ofloxacin, and norfloxacin (Noroxin) have not been established in children less than 18 years of age.

Ciprofloxacin is indicated for patients younger than 18 years of age for the treatment of complicated urinary tract infections and pyelonephritis in children ages one to 17 years.¹¹⁹ Ciprofloxacin is not a first choice antimicrobial in pediatrics due to increased adverse events compared to controls including events related to joints and/or surrounding tissues over six weeks (9.3 percent ciprofloxacin-treated patients versus six percent in control-treated patients). Ciprofloxacin and levofloxacin (Levaquin) are indicated in the treatment of inhalational anthrax (post-exposure) for children greater than six months of age. Levofloxacin also has an indication for use in pediatric patients aged 6 months and older for both treatment and prophylaxis of plague. An increased incidence of musculoskeletal disorders such as arthralgia, arthritis, tendonopathy, and gait abnormality have been reported in pediatric patients receiving ciprofloxacin or levofloxacin compared to controls. Ciprofloxacin ER (Cipro XR, Proquin XR) has not been studied in children.^{120,121}

Pregnancy

Fluoroquinolones are all Pregnancy Category C.

Geriatrics

Geriatric patients are at increased risk for developing severe tendon disorders including tendon rupture when being treated with a fluoroquinolone. Concomitant systemic corticosteroids further increase the risk. Tendon disorders may involve the Achilles, hand, shoulder, or other tendon sites and can occur during or after completion of therapy; cases occurring up to several months after fluoroquinolone treatment have been reported.

Renal Insufficiency

All fluoroquinolones, except moxifloxacin (Avelox) and ciprofloxacin ER (Proquin XR), require adjustment of dose and/or interval for patients with renal insufficiency.

Hepatic Insufficiency

No dosage adjustment is recommended for mild, moderate, or severe hepatic insufficiency (Child Pugh Classes A, B or C) for moxifloxacin (Avelox). The excretion of ofloxacin may be reduced in patients with severe liver function disorders (e.g., cirrhosis with or without ascites). A maximum dose of 400 mg of ofloxacin per day should therefore not be exceeded.

SELECTED DOSAGES^{122,123,124,125,126,127,128,129}

Drug and Availability	AECB/Lower respiratory tract infection	CAP	Acute Sinusitis	Plague	Prostatitis	UTI (regimen selected based on the severity of infection)
ciprofloxacin (Cipro) 250, 500, 750 mg tablets, 250 mg/5 mL (5%) and 500 mg/5 mL (10%) suspension	500-750 mg every 12 hours for 7-14 days	--	500 mg every 12 hours for 10 days	--	500 mg every 12 hours for 28 days	250 mg every 12 hours for 3 days; 250-500 mg every 12 hours for 7-14 days Pediatrics: 10-20 mg/kg every 12 hours (not to exceed 750 mg) for 10-21 days
ciprofloxacin ER (Cipro XR) 500, 1,000 mg tablets	--	--	--	--	--	500 mg daily for 3 days; 1,000 mg daily for 7-14 days
ciprofloxacin ER (Proquin XR) 500 mg tablets	--	--	--	--	--	500 mg daily for 3 days with the main meal of the day
gemifloxacin (Factive) 320 mg tablets	320 mg daily for 5 days	320 mg daily for 5-7 days	--	--	--	--
levofloxacin (Levaquin) 250, 500, 750 mg tablets 25 mg/mL oral solution	500 mg daily for 7 days	500 mg daily for 7-14 days	500 mg daily for 10-14 days	500 mg daily for 10-14 days	500 mg daily for 28 days	250 mg daily for 3-10 days or 750 mg daily for 5 days
		750 mg daily for 5 days	750 mg daily for 5 days	--		
moxifloxacin (Avelox) 400 mg tablets	400 mg daily for 5 days	400 mg daily for 7-14 days	400 mg daily for 10 days	--	--	--
norfloxacin (Noroxin) 400 mg tablets	--	--	--	--	400 mg every 12 hours for 28 days	400 mg every 12 hours for 3-21 days
ofloxacin (Floxin) 200, 300, 400 mg tablets	400 mg every 12 hours for 10 days	400 mg every 12 hours for 10 days	--	--	300 mg every 12 hours for 6 weeks	200 mg every 12 hours for 3-10 days

All fluoroquinolones except moxifloxacin (Avelox) require dosage adjustment in patients with renal impairment.

Ciprofloxacin ER (Cipro XR and Proquin XR) tablets should not be crushed, chewed or split.

Administration of ciprofloxacin ER (Proquin XR) tablets with milk products or calcium-fortified juice alone should be avoided since concurrent administration may reduce absorption of Proquin XR.

Gemifloxacin (Factive) tablets should be swallowed whole with plenty of liquid and may be taken without regard for food.

Levofloxacin (Levaquin) solution should be given one hour before or two hours after a meal. Levofloxacin tablets may be given without regard to food.

CLINICAL TRIALS

Search Strategies

Studies were identified through searches performed on PubMed and review of information sent by manufacturers. Search strategy included the FDA-approved use of all drugs in this class. Randomized, controlled trials performed in the United States comparing oral agents within this class within the last seven years in an outpatient setting for the approved indications are considered the most relevant in this category. Studies included for analysis in the review were published in English, performed with human participants and randomly allocated participants to comparison groups. In addition, studies must contain clearly stated, predetermined outcome measure(s) of known or probable clinical importance, use data analysis techniques consistent with the study question, and include follow-up (endpoint assessment) of at least 80 percent of participants entering the investigation. Despite some inherent bias found in all studies including those sponsored and/or funded by pharmaceutical manufacturers, the studies in this therapeutic class review were determined to have results or conclusions that do not suggest systematic error in their experimental study design. While the potential influence of manufacturer sponsorship/funding must be considered, the studies in this review have also been evaluated for validity and importance.

Numerous clinical trials were published comparing the fluoroquinolones in both inpatient and outpatient settings in the 1990s. Little evidence exists that shows one fluoroquinolone is superior to others for the approved indications when given in equivalent dosages. Due to changes in susceptibility of *Pseudomonas* and other organisms to fluoroquinolones since the 1990s, only studies published since 2000 are included.¹³⁰ Nationwide and regional variances in pathogen susceptibility and resistance rates must be taken into consideration when evaluating studies. Many short-term clinical trials in outpatients with minor infections lose a significant portion of patients due to lack of follow-up. Losses are greater than 25 percent of enrolled patients in some trials.

Many trials performed with the fluoroquinolones compare the agents to other broad-spectrum antibiotics such as macrolides, cephalosporins, and extended-spectrum penicillins. While relative efficacy is important, the comparisons lend little insight into relative efficacy and safety of agents within this class. Studies comparing available fluoroquinolones to trovafloxacin (Trovan), gatifloxacin (Tequin), and lomefloxacin (Maxaquin) were not included as these fluoroquinolones are no longer available in the United States.

Efficacy studies of levofloxacin for plague could not be conducted in humans with plague for ethical and feasibility reasons. Therefore, approval of this indication was based on an efficacy study conducted in animals.¹³¹

ciprofloxacin ER (Cipro XR) and ciprofloxacin (Cipro)

In a multicenter, randomized, double-blind, double-dummy Phase III trial consisting of 891 women with acute uncomplicated UTI, pyuria, and a positive pre-therapy urine culture $\geq 10^5$ colony-forming units/mL, ciprofloxacin ER 500 mg daily for three days was compared to ciprofloxacin 250 mg twice daily for three days for bacterial eradication.¹³² Clinical response rates were 95.5 and 92.7 percent for ciprofloxacin ER and ciprofloxacin, respectively (95% CI, -1.6 to 7.1). Bacterial eradication rates were 94.5 and 93.7 percent for ciprofloxacin ER and ciprofloxacin, respectively (95% CI, -3.5 to 5.1). The

most common pathogens were *E. coli*, *Enterococcus faecalis*, *Proteus mirabilis*, and *Staphylococcus saprophyticus*.

Ciprofloxacin ER 1,000 mg once daily and ciprofloxacin 500 mg twice daily were compared in 1,035 patients with complicated urinary tract infections or acute uncomplicated pyelonephritis.¹³³ Treatment continued for seven to 14 days. In the randomized, double-blind, North American trial, patients were enrolled if they had a positive pre-treatment urine culture and pyuria in the preceding 48 hours. Bacteriologic efficacy determined between five and 11 days after treatment initiation were 89 percent and 85 percent for ciprofloxacin ER and ciprofloxacin, respectively (95% CI, -2.4 to 10.3). Clinical cure rates were similar with 97 percent for ciprofloxacin ER and 94 percent for ciprofloxacin (95% CI, -1.2 to 6.9). Late follow-up was done 28 to 42 days after therapy initiation; similar cure rates were observed. *E. coli* was the most common organism identified in urine cultures. Similar rates of adverse events were reported.

The efficacy and safety of ciprofloxacin ER and ciprofloxacin were compared in 523 adult women with acute uncomplicated UTI.¹³⁴ In a multicenter, randomized, double-blind study, patients with a positive pre-treatment urine culture were randomized to ciprofloxacin ER 500 mg once daily or ciprofloxacin 250 mg twice daily. Treatment duration was three days. At the test of cure visit (days four to 11 after therapy), microbiological eradication rates were 93.4 and 89.6 percent for ciprofloxacin ER and ciprofloxacin, respectively. Clinical cure rates were 85.7 for ciprofloxacin ER and 86.1 percent for ciprofloxacin. After four to six weeks, microbiological and clinical outcomes were similar between the groups. Nausea (0.6 versus 2.2 percent) and diarrhea (0.2 versus 1.4 percent) were lower in the ciprofloxacin ER group.

gemifloxacin (Factive) and levofloxacin (Levaquin)

In a randomized, double-blind, double dummy, multicenter, parallel-group study, a total of 360 adults with acute exacerbation of chronic bronchitis (AECB) were randomly assigned to receive gemifloxacin 320 mg daily for five days or levofloxacin 500 mg daily for seven days.¹³⁵ A total of 335 patients completed the study. In the intent-to-treat population, clinical success rate at follow-up was 85.2 percent for gemifloxacin and 78.1 percent for levofloxacin. The clinical efficacy of gemifloxacin for five days in AECB was at least as good as levofloxacin for seven days. Fewer patients withdrew from the gemifloxacin arm of the trial. ($p=0.02$).

Five-day fluoroquinolone therapy is associated with faster recovery, fewer relapses, and less hospitalization. Both moxifloxacin and gemifloxacin are FDA approved for 5-day therapy in AECB.¹³⁶

levofloxacin (Levaquin) and ciprofloxacin (Cipro)

In a multicenter, randomized, double-blind trial, levofloxacin 500 mg daily and ciprofloxacin 500 mg twice daily were compared for efficacy and safety in the treatment of chronic bacterial prostatitis in 377 patients.¹³⁷ Treatment duration was 28 days. Clinical success rates, which included both cured and improved patients, were similar between the two drugs (levofloxacin 75 percent; ciprofloxacin 72.8 percent). Bacteriological eradication rates were similar with 75 and 76.8 percent for levofloxacin and ciprofloxacin, respectively. The most common pathogens were *E. faecalis* and *E. coli*. Six-month relapse rates were also similar. Both drugs were well tolerated.

Fluoroquinolones are the agent of choice for treating bacterial caused prostatitis and in some cases of chronic prostatitis when a causal organism has not been identified.¹³⁸ In European men ($n=117$) a study

was done using levofloxacin 500 mg/day in those diagnosed with chronic bacterial prostatitis. In this group there was a 92 percent success rate (95% CI 84.8% - 96.5%) at five-12 days post treatment.

A multicenter, double-blind trial compared the efficacy and safety of levofloxacin 750 mg intravenously (IV) or orally daily for five days to ciprofloxacin 400 mg IV and/or 500 mg orally twice daily for ten days for the treatment of complicated UTIs or acute pyelonephritis.¹³⁹ Patients were evaluated at the end of therapy, post-therapy and post-study for microbiologic eradication and clinical outcomes. A total of 1,109 subjects were enrolled; 619 with confirmed diagnosis of acute pyelonephritis or UTI and a uropathogen with a colony count 10^5 colony forming units/mL or greater were included in the modified intent-to-treat population. The eradication rates in the modified intent-to-treat population at the end of therapy were 79.8 percent for levofloxacin- and 77.5 percent for ciprofloxacin-treated patients (95% CI, -8.8 to 4.1 percent). In the microbiologically evaluable population (n=506), eradication rates were 88.3 percent for levofloxacin and 86.7 percent for ciprofloxacin-treated subjects (95% CI, -7.4% to 4.2%). Outcomes were comparable for the two treatments at the post-therapy and post-study visits. The manufacturer of levofloxacin supported the study.

SUMMARY

Oral fluoroquinolones vary in the spectrum of antimicrobial activity. The older fluoroquinolones have a gram-negative spectrum of activity and are useful in the treatment of urological infections. Newer fluoroquinolones have broad spectrums of activity covering both gram-negative and gram-positive bacteria, and some agents are useful in the treatment of penicillin-resistant *S. pneumoniae*.

Fluoroquinolones effectively treat urinary tract infections and CAP, although fluoroquinolones are not considered first-line empiric antibiotics for these infections. In the treatment of CAP in healthy patients, empiric antibiotics include erythromycin, azithromycin, or clarithromycin or doxycycline. Gemifloxacin (Factive), levofloxacin (Levaquin), and moxifloxacin (Avelox), the respiratory fluoroquinolones, are active against multi-drug resistant *S. pneumoniae* and should be considered in the presence of comorbidities such as chronic heart, lung, liver or renal disease; diabetes mellitus; alcoholism; malignancies; asplenia; immunosuppressing conditions or use of immunosuppressing drugs; or use of antimicrobials within the previous three months (in which case an alternative from a different class should be selected). Fluoroquinolones may also be considered in regions with a high rate of infection and high-level macrolide-resistant *S. pneumoniae* for patients without comorbidities. Levofloxacin is an option for use in the treatment and prevention of plague in both pediatrics and adults.

For the treatment of UTIs, empiric antibiotics may include one of the following: trimethoprim/sulfamethoxazole, amoxicillin, nitrofurantoin, cephalosporin, or a fluoroquinolone. Ciprofloxacin and ciprofloxacin ER (Cipro XR, Proquin XR), levofloxacin (Levaquin), norfloxacin (Noroxin) and ofloxacin are indicated for the treatment of UTIs.

Many factors must be considered when choosing the most appropriate fluoroquinolone for a particular patient. Culture and sensitivity information should guide antibiotic selection when available. Little evidence exists suggesting clinical outcomes, safety, and tolerability differ among the fluoroquinolones when administered for appropriate indications.

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