

## **Product Monograph**

**<sup>Pr</sup> pms-MEMANTINE**

Memantine Hydrochloride Tablets, USP

5 mg and 10 mg

N-methyl-D-aspartate (NMDA) receptor antagonist

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## NAME OF DRUG

<sup>Pr</sup>pms-MEMANTINE

Memantine Hydrochloride Tablets, USP

## THERAPEUTIC CLASSIFICATION

N-methyl-D-aspartate (NMDA) receptor antagonist

## ACTION AND CLINICAL PHARMACOLOGY

Persistent activation of the central nervous system N-methyl-D-aspartate (NMDA) receptors by the excitatory amino acid glutamate has been hypothesized to contribute to the symptomatology of Alzheimer's disease. Memantine is postulated to exert its therapeutic effect through its action as a low to moderate affinity uncompetitive (open channel) NMDA receptor antagonist, which binds preferentially to the NMDA receptor-operated cation channels. It blocks the effects of pathologically elevated sustained levels of glutamate that may lead to neuronal dysfunction. There is no clinical evidence that memantine prevents or slows neurodegeneration or alters the course of the underlying dementing process in patients with Alzheimer's disease. Memantine exhibits low to negligible affinity for other receptors (GABA, benzodiazepine, dopamine, adrenergic, noradrenergic, histamine and glycine) or voltage-dependent  $\text{Ca}^{2+}$ ,  $\text{Na}^{+}$  or  $\text{K}^{+}$  channels. In addition, it does not directly affect the acetylcholine receptor or cholinergic transmission, which have been implicated in the cholinomimetic side effects (e.g., increased gastric acid secretion, nausea and vomiting) seen with acetylcholinesterase inhibitors. Memantine showed antagonist effects at the  $5\text{HT}_3$  receptor with a potency similar to that for the NMDA receptor.

*In vitro* studies have shown that memantine does not affect the reversible inhibition of acetylcholinesterase by donepezil or galantamine.

## PHARMACOKINETICS

### Absorption

Orally administered memantine is completely absorbed. Oral bioavailability is almost 100%. Time to maximum plasma concentration ( $t_{\text{max}}$ ) following single oral doses of 10 to 40 mg memantine ranged between 3 to 8 hours. It has a terminal elimination half-life of about 60-80 hours, with the majority of the dose excreted unchanged in urine. There is no indication that food influences the absorption of memantine.

Studies in volunteers have demonstrated linear pharmacokinetics in the dose range of 10 to 40 mg.

Daily doses of 20 mg lead to steady-state plasma concentrations of memantine ranging from 70 to 150 ng/mL (0.5 - 1 mcM) with large inter-individual variations.

### **Distribution**

The apparent volume of distribution of memantine is approximately 9-11 L/kg and the plasma protein binding is approximately 45%. Memantine rapidly crosses the blood-brain barrier with a CSF/serum ratio of about 0.5.

### **Metabolism and Elimination**

In a study using orally administered  $^{14}\text{C}$ -memantine, a mean of 84% of the dose was recovered within 20 days, more than 99% being excreted renally. Memantine undergoes little metabolism being in majority excreted unchanged in urine (75-90%). The remaining dose is converted primarily to three polar metabolites: the N-gludantan conjugate, 6-hydroxy memantine and 1-nitroso-deaminated memantine. These metabolites possess minimal NMDA receptor antagonist activity. The hepatic microsome CYP450 enzyme system does not play a significant role in the metabolism of memantine.

In volunteers with normal kidney function, total clearance ( $\text{Cl}_{\text{tot}}$ ) amounts to 170 mL/min/1.73 m<sup>2</sup> and part of total renal clearance is achieved by tubular secretion. Renal handling also involves tubular reabsorption, probably mediated by cation transport proteins. The renal elimination rate of memantine under alkaline urine conditions may be reduced by a factor of 7 to 9 resulting in increased plasma levels of memantine (see WARNINGS, Genitourinary Conditions). Alkalisiation of urine may result from drastic changes in diet, e.g. from a carnivore to a vegetarian diet, or from the massive ingestion of alkalising gastric buffers.

### **Special populations**

#### **Elderly patients:**

The pharmacokinetics of memantine in young and elderly subjects is similar. No adjustment of dosage on the basis of age is recommended.

#### **Reduced Hepatic Function:**

Memantine is metabolized to a minor extent into metabolites with no NMDA-antagonistic activity, and is excreted primarily in an unchanged form by the kidneys. In a study comparing the pharmacokinetics of memantine in subjects with normal hepatic function and moderate hepatic impairment (Child-Pugh B), moderate hepatic impairment did not significantly alter the pharmacokinetics of memantine following administration of a single 20 mg oral dose of memantine (see PRECAUTIONS and DOSAGE AND ADMINISTRATION).

#### **Reduced Renal Function:**

In elderly volunteers with normal and reduced renal function (creatinine clearance of 50 to  $\leq 80$  mL/min/1.73 m<sup>2</sup>), a significant correlation was observed between creatinine clearance and total renal clearance of memantine. Following a single 20 mg oral dose of memantine, systemic exposure in geriatric subjects with mild and moderate renal impairment was 14% and 39% greater, respectively, compared to geriatric subjects with normal renal function (see PRECAUTIONS and DOSAGE AND ADMINISTRATION).

## CLINICAL TRIALS

### **Comparative Bioavailability**

The objective of this study is to compare the rate and extent of absorption of pms-MEMANTINE 10 mg tablet (test) versus Ebixa<sup>®</sup> (reference), administered as 1 x 10 mg tablet under fasting conditions. 18 healthy adult male, light smokers and/or non-smokers are enrolled in single centre, bioequivalence, blinded, randomized, 2-way crossover study.

Memantine (1 x 10 mg tablet, fasted) From measured data <b>uncorrected for potency</b> Geometric Mean Arithmetic Mean (CV %)				
Parameter	Test*	Reference†	% Ratio of Geometric Means	Confidence Interval 90%
AUC <sub>0-72</sub> (ng·h/mL)	506.30 514.97 (13.05)	499.85 503.47 (12.70)	102.30	99.96-104.69
C <sub>max</sub> (ng/mL)	11.15 11.39 (17.28)	11.03 11.23 (16.53)	101.07	97.18-105.11
T <sub>max</sub> § (h)	7.00 (3.00-8.02)	7.00 (2.0-10.0)		

\* pms-MEMANTINE, Pharmascience Inc, Canada

† Ebixa<sup>®</sup>, Lundbeck, Canada

§ Expressed as the median (range)

AUC<sub>t</sub> and T<sub>1/2</sub> are not reported; these parameters could not be accurately estimated due to the long half-life of the active ingredient and design of the study.

## **Study Results**

The potential efficacy of memantine hydrochloride as a treatment for the symptomatic management of moderate to severe Alzheimer's disease was demonstrated by the results of 2 randomized, double-blind, placebo-controlled 6-month clinical studies. Both studies were conducted in patients with Alzheimer's disease. The mean age of patients participating in the memantine hydrochloride trials was 76 with a range of 50 to 93 years. Approximately 66% of patients were women. Female patients participating in the clinical trials were required to be at least 50 years of age and at least 2 years postmenopausal or surgically sterile. The racial distribution was approximately 91% Caucasian. Patient demographics were similar in a third randomized, double-blind, placebo controlled, 6-month clinical trial in patients with moderate to severe Alzheimer's disease: mean age was 78 years, approximately 71% were female and approximately 81% were Caucasian. In all studies, for patients randomized to memantine hydrochloride, treatment was initiated at 5 mg/day and increased weekly by 5 mg/day to a dose of 20 mg/day (10 mg twice a day).

### **Study Outcome Measures:**

In each study, the efficacy of memantine hydrochloride was evaluated using validated assessments for patients with moderate to severe dementia in a dual outcome strategy that included assessment of activities of daily living (modified Alzheimer's Disease Cooperative Study – Activities of Daily Living inventory) (Study 1 and Study 2), and a clinician's global assessment of change (Clinician's Interview Based Impression of Change with caregiver input [Study 1]) or a measure of cognition (Severe Impairment Battery [Study 2 and Study 3]).

The Alzheimer's Disease Cooperative Study – Activities of Daily Living inventory (ADCS-ADLsev) measures the functional capabilities of patients and is based on interview of a caregiver familiar with the behaviour of the patient. The modified ADCS-ADLsev includes 19 items that rate the patients' abilities to eat, dress, bathe, telephone, travel, shop, and perform other household chores from the highest level of independent performance to complete loss. Lower total modified ADCS-ADLsev scores indicate greater functional impairment.

The Severe Impairment Battery (SIB) assesses selected aspects of cognitive performance including elements of attention, orientation, language, memory, visuospatial ability, construction, praxis, and social interaction and is sensitive to longitudinal changes in cognitive function in patients with moderate to severe dementia. Lower total SIB scores indicate greater cognitive impairment.

The ability of memantine hydrochloride to produce an overall clinical effect was assessed using a Clinician's Interview Based Impression of Change, which evaluates four domains: general (overall clinical status), functional (including activities of daily living), cognitive, and behavioural. The CIBIC-Plus represents the assessment of a skilled clinician using validated scales based on his/her observation at an interview with the patient, in combination with information provided by a caregiver familiar with the behaviour of the patient over the interval rated. The CIBIC-Plus is scored as a seven point categorical rating, ranging from a score of 1, indicating "markedly improved" to a score of 4, indicating "unchanged" to a score of 7, indicating "markedly worse."

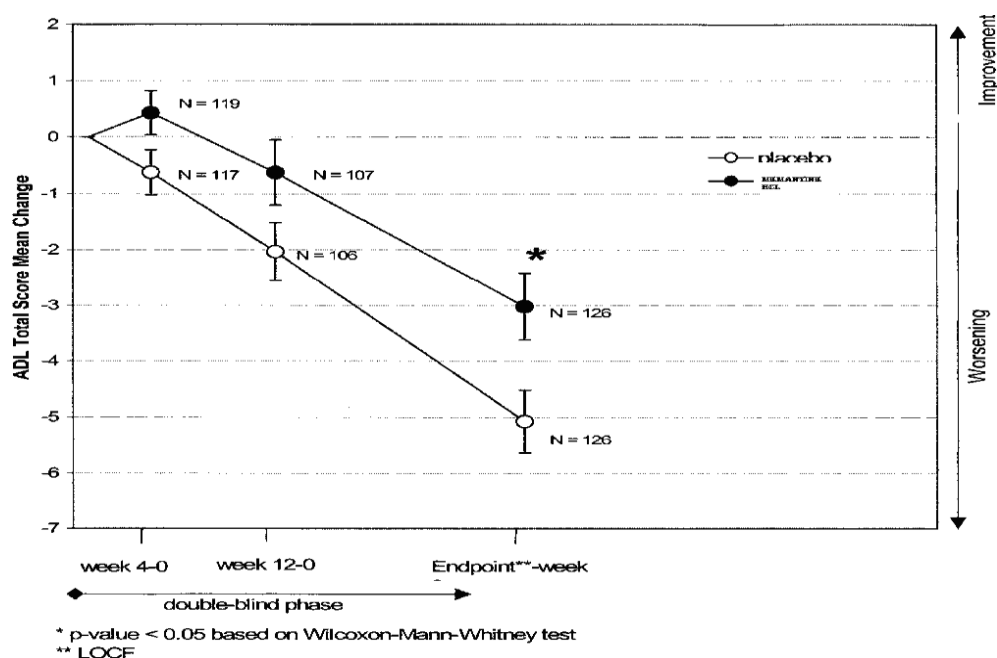
Clinical trial results are summarized for the last observation carried forward (LOCF) analysis of the Intent-to-Treat (ITT) population. The ITT population corresponds to all patients who were randomized to treatment regardless of treatment received and the LOCF analysis is based on carrying

the last observation while on treatment forward to the study endpoint when patients were unable to complete the study.

### Study 1 (Twenty-Eight-Week Study):

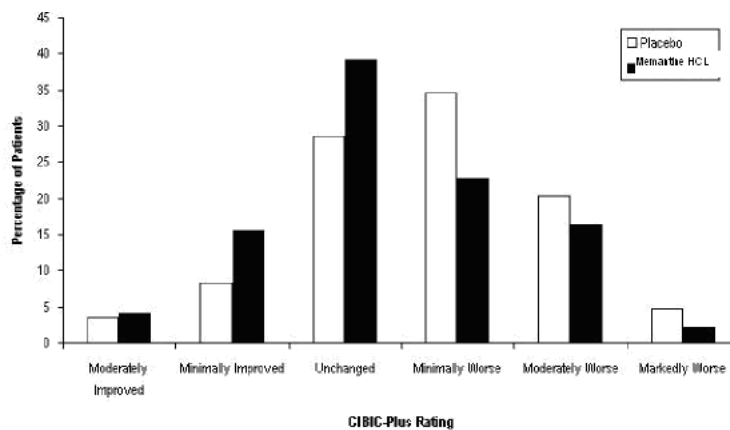
Study 1 was a 28 week study in which 252 patients with moderate to severe Alzheimer's disease (diagnosed according to DSM-IV and NINCDS-ADRDA criteria, with Mini-Mental State Examination scores  $\geq 3$  and  $\leq 14$  and Global Deterioration Scale Stages 5-6) were randomized to memantine hydrochloride or placebo. Sixty-seven percent and 77% of patients randomized to placebo and memantine hydrochloride, respectively, completed the study. The two primary efficacy endpoints were the mean change from baseline to endpoint (Week 28 LOCF) on the ADCS-ADLsev and CIBIC-Plus rating at endpoint (Week 28 LOCF).

At endpoint (Week 28 LOCF), the mean change from baseline in the ADCS-ADLsev score was statistically significantly less for the memantine hydrochloride -treated patients compared to the patients on placebo (treatment difference of 2.1 units ( $p = 0.022$ )) (Figure 1).



**Figure 1:** Time course of the change from baseline in ADCS-ADL<sub>sev</sub> score at week 28-LOCF (ITT population)

The percentage distribution of CIBIC-Plus scores for patients in each treatment group is shown in Figure 2. The mean CIBIC-Plus rating for the memantine hydrochloride group was numerically superior, but not statistically significantly superior, to that of the placebo group (treatment difference of 0.25 units,  $p = 0.06$ ).



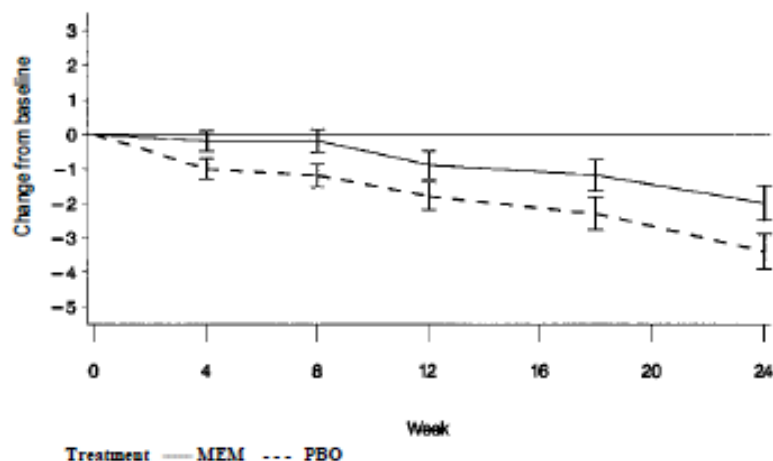
**Figure 2: Distribution of CIBIC-Plus ratings at week 28 -LOCF (ITT population)**

The Severe Impairment Battery was used as a secondary efficacy measure. At study endpoint (Week 28 LOCF), the mean difference in the SIB change scores from baseline for the memantine hydrochloride-treated patients compared to the patients on placebo was 5.9 units, with the memantine hydrochloride group showing less decline than the placebo group.

### **Study 2 (Twenty-Four-Week Study):**

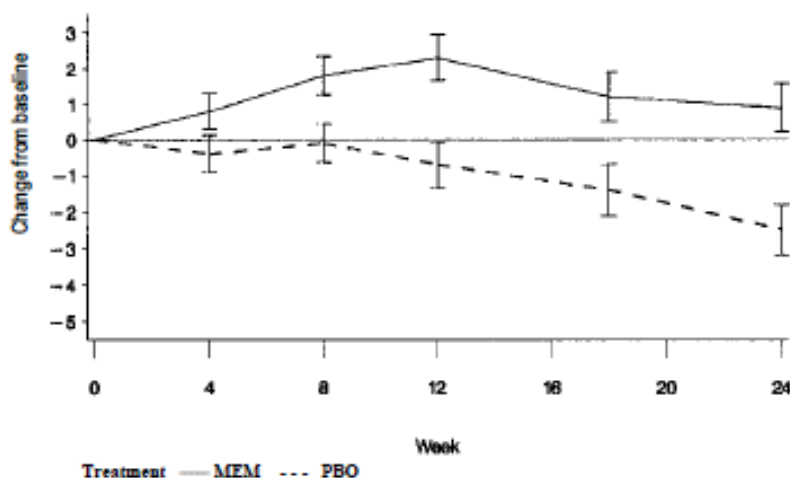
Study 2 was a 24 week study that evaluated the efficacy of memantine as adjunctive therapy with donepezil in 404 patients with moderate to severe Alzheimer's disease (diagnosed by according to NINCDS-ADRDA criteria, with Mini-Mental State Examination scores  $\geq 5$  and  $\leq 14$ ). Prior to randomization to treatment with memantine hydrochloride or placebo, patients had been treated with donepezil for at least 6 months and were on a stable dose of donepezil for 3 months. All patients continued to receive donepezil while being treated with placebo or memantine. Seventy-five percent and 85% of randomized patients on placebo/donepezil and memantine hydrochloride /donepezil, respectively, completed the study. The two primary endpoints were the mean changes from baseline to endpoint (Week 24 LOCF) on the ADCS-ADL<sub>sev</sub> and SIB.

The mean change in the ADCS-ADL<sub>sev</sub> scores from baseline to Week 24 LOCF was statistically significantly less for the memantine hydrochloride/donepezil treated patients compared to the patients on placebo/donepezil (treatment difference 1.4 units,  $p = 0.028$ ).



**Figure 3:** Time course of the change from baseline in ADCS-ADL<sub>sev</sub> score at 24 weeks-LOCF (ITT Population)

At study endpoint (Week 24 LOCF) the mean difference in the SIB change scores for the memantine hydrochloride /donepezil treated patients compared to the patients on placebo/donepezil was 3.4 units ( $p < 0.001$ ). Memantine hydrochloride /donepezil treatment was statistically significantly superior to placebo/donepezil.



**Figure 4:** Time course of the change from baseline in SIB score at 24 weeks-LOCF (ITT Population)

The CIBIC-Plus was a secondary efficacy measure. The mean CIBIC-Plus rating for the memantine hydrochloride/donepezil group was lower than that of placebo/donepezil group (treatment difference of 0.25 units).

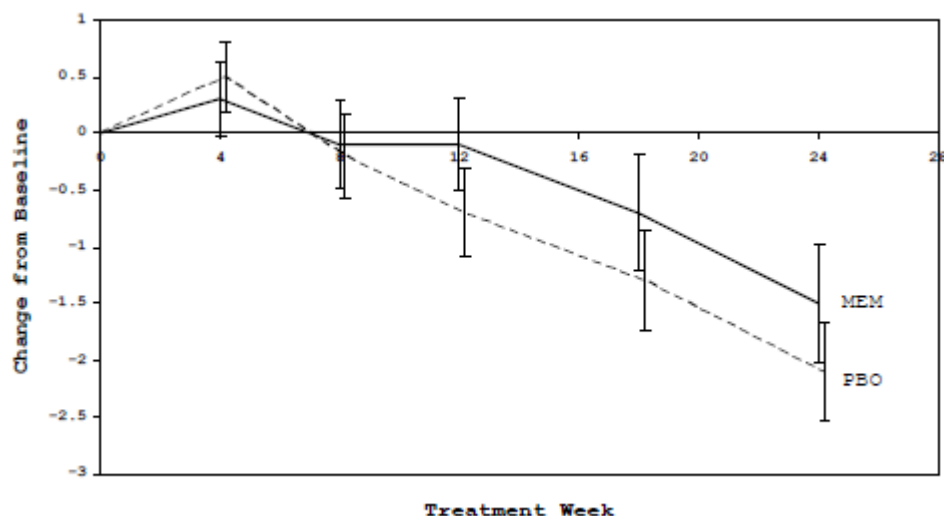
### Study 3 (Twenty-Four-Week Study):

Study 3 was a 24 week study, in which 350 patients with moderate to severe Alzheimer's disease (diagnosed according to DSM-IV and NINCDS-ADRDA criteria, with Mini-Mental State Examination scores  $\geq 5$  and  $\leq 14$ ) were randomized to memantine hydrochloride or placebo. Seventy-



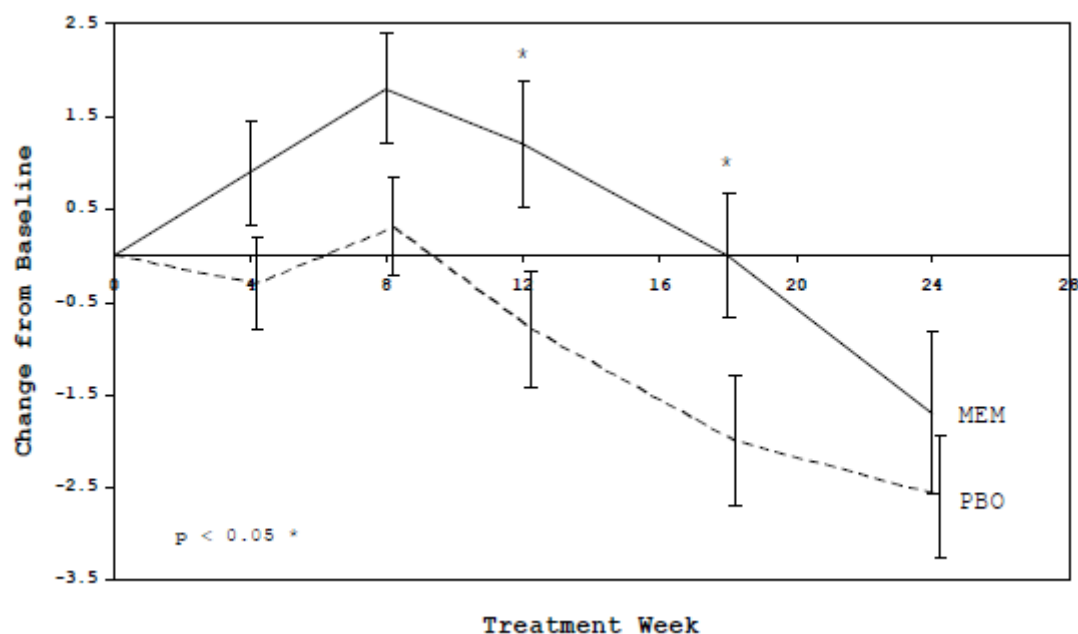
three percent and 75% of patients randomized to placebo and memantine hydrochloride, respectively, completed the study. The two primary efficacy endpoints were the mean change from baseline to endpoint (Week 24 LOCF) on the ADCS-ADL<sub>sev</sub> and SIB. Differences between treatment groups on the two primary endpoints were not statistically significant based on the primary analysis of efficacy.

At endpoint (Week 24 LOCF), the mean change from baseline in the ADCS-ADL<sub>sev</sub> score was numerically less for the memantine hydrochloride -treated patients compared to the patients on placebo (treatment difference of 0.7 units [Figure 5]).



**Figure 5:** Time course of the change from baseline in ADCS-ADL<sub>sev</sub> score at 24 weeks-LOCF (ITT Population)

At study endpoint (Week 24 LOCF) the mean difference in the SIB change scores was numerically less for the memantine hydrochloride-treated patients compared to the patients on placebo (treatment difference of 0.6 units).



**Figure 6:** Time course of the change from baseline in SIB score at 24 weeks-LOCF (ITT Population)

A *post-hoc* nonparametric re-analysis of the primary efficacy endpoint data showed that at study endpoint (Week 24 LOCF) the mean difference in the SIB change scores was statistically significantly less for the memantine hydrochloride- treated patients compared to the patients on placebo ( $p = 0.031$ ).

## INDICATION AND CLINICAL USE

pms-MEMANTINE (memantine hydrochloride) may be useful as monotherapy or as adjunctive therapy with cholinesterase inhibitors<sup>1</sup> for the symptomatic treatment of patients with moderate to severe dementia of the Alzheimer's type.

pms-MEMANTINE tablets should only be prescribed by (or following consultation with) clinicians who are experienced in the diagnosis and management of Alzheimer's disease.

In a 28-week placebo controlled monotherapy trial, patients with moderate to severe Alzheimer's disease showed stabilization or less worsening of functional and cognitive symptoms and of global assessment when treated with memantine hydrochloride compared to placebo.

In a 24 week "add-on" placebo controlled trial in which patients were treated with either memantine hydrochloride or placebo as add-on to ongoing donepezil therapy, stabilization or less worsening of functional and cognitive symptoms and of global assessment was observed in patients with moderate to severe Alzheimer's disease when treated with memantine hydrochloride compared to placebo.

<sup>1</sup> Cholinesterase inhibitors refers to only those which are approved in Canada for the symptomatic treatment of Alzheimer's disease.

Memantine hydrochloride has not been studied in controlled clinical trials for the symptomatic treatment of moderate to severe Alzheimer's disease for more than 6 months.

## CONTRAINDICATIONS

pms-MEMANTINE (memantine hydrochloride) is contraindicated in patients with known hypersensitivity to memantine hydrochloride or to any excipients used in the formulation.

## WARNINGS

### **Neurological Conditions**

**Seizures:** Memantine hydrochloride has not been systematically evaluated in patients with a seizure disorder. These patients were excluded from clinical studies during the premarketing testing of memantine hydrochloride. In clinical trials, seizures occurred in 0.3% of patients treated with memantine hydrochloride and 0.4% of patients treated with placebo. Seizure activity may be a manifestation of Alzheimer's disease. The risk/benefit of memantine treatment for patients with a history of seizure disorder or predisposing factors for epilepsy must, therefore, be carefully evaluated.

### **Genitourinary Conditions**

Conditions that raise urine pH may reduce the urinary elimination of memantine by a factor of 7 to 9, resulting in increased plasma levels of memantine (see ACTIONS AND CLINICAL PHARMACOLOGY). These conditions include drastic changes in diet, e.g. from a carnivore to a vegetarian diet, or a massive ingestion of alkalinising gastric buffers (see Drugs Which Makes Urine Alkaline, PRECAUTIONS). Also, urine pH may be elevated by states of renal tubular acidosis (RTA) or severe infections of the urinary tract with *Proteus bacteria*.

### **Cardiovascular Conditions**

In most clinical trials, patients with recent myocardial infarction, uncompensated congestive heart failure (NYHA III-IV), and uncontrolled hypertension were excluded. However, patients such as those with controlled hypertension (DBP < 105 mm/Hg), right bundle branch blockage and pacemaker were included. Although cardiovascular adverse events occurred at low frequencies in the two placebo-controlled clinical trials involving patient with moderate to severe Alzheimer's disease, there were increased frequencies of hypertension, chest pain, bradycardia and cardiac failure adverse events in patients who were treated with memantine hydrochloride compared to placebo in these trials. Consequently, caution should be observed when memantine is initiated in patients with cardiovascular conditions.

## PRECAUTIONS

### **Ophthalmic Conditions**

In an open label study where memantine hydrochloride was administered to 10 elderly patients at a

dose of 20 mg per day for approximately 48 months, memantine concentrations in lacrimal fluid were about 3 fold higher than in plasma and did not show ophthalmologic effects. In another 6-month placebo-controlled trial, no major treatment differences were reported for ocular effects but worsening of the corneal condition was reported for slightly more patients treated with memantine hydrochloride than placebo (5.4% memantine vs. 3.3% placebo). Repeat-dose toxicology studies demonstrated corneal and lens histopathological changes in rodents treated with memantine hydrochloride. Therefore, periodic monitoring of the patient's ophthalmic condition is recommended.

## **Hypersensitivity**

### **Skin Hypersensitivity Reactions:**

Serious skin reactions (Stevens Johnson syndrome and acute generalized exanthematous pustulosis), and other less serious skin reactions (e.g., erythema multiforme), have been reported in patients receiving memantine hydrochloride (see ADVERSE REACTIONS, Post-Market Adverse Drug Reactions). Patients or caregivers should be instructed to inform their health care provider of any skin reactions that occur during treatment with memantine hydrochloride. It is recommended that treatment should be discontinued at the first appearance of skin rash.

## **Concomitant Use With Other Drugs**

### **Use with compounds chemically related to N-methyl-D-aspartate (NMDA) antagonists:**

As these compounds act at the same receptor system as memantine, adverse drug reactions (mainly CNS-related) may be more frequent or pronounced. Pharmacotoxic psychosis has been reported in the literature in two Parkinson's disease patients who were treated concomitantly with memantine, amantadine, L-dopa and terguride (see PRECAUTIONS, Drug Interactions, Other agents). The combined use of memantine hydrochloride with other compounds chemically related to NMDA antagonists such as amantadine, ketamine or dextromethorphan has not been systematically evaluated and is therefore not recommended.

## **Conditions That Make Urine Alkaline**

The clearance of memantine was reduced by about 80% under alkaline urine conditions at pH 8. Therefore, alterations of urine pH towards the alkaline condition may lead to an accumulation of the drug with a possible increase in adverse effects. Urine pH is altered by diet, drugs (e.g. carbonic anhydrase inhibitors, sodium bicarbonate) and clinical state of the patient (e.g. renal tubular acidosis or severe infections of the urinary tract). Hence, memantine should be used with caution under these conditions (see PHARMACOKINETICS and WARNINGS).

## **Special Populations**

### **Hepatic Impairment:**

Memantine hydrochloride undergoes minimal hepatic metabolism and is excreted primarily in its unchanged form by the kidneys. The pharmacokinetics of memantine have been studied in subjects with moderate hepatic impairment (see PHARMACOKINETICS). In patients with mild or moderate hepatic impaired function (Child-Pugh A and Child-Pugh B) no dose adjustment is needed. There are no data available for use of memantine in patients with severe hepatic impairment. Therefore,

administration of memantine hydrochloride is not recommended in patients with severe hepatic impairment.

**Renal Impairment:**

In patients with mildly impaired renal function (creatinine clearance 50 - 80 mL/min) no dosage adjustment is required. In patients with moderate renal impairment (creatinine clearance 30 - 49 mL/min) the daily dose should be 10 mg per day. If well tolerated after at least 7 days of treatment, and based on clinical response, the dose may be increased up to 20 mg/day according to the standard titration scheme. In patients with severe renal impairment (creatinine clearance 15 - 29 mL/min) the daily dosage should be 10 mg per day (see PHARMACOKINETICS and DOSAGE AND ADMINISTRATION).

**Use in Patients  $\geq$  85 Years Old:**

In placebo-controlled clinical studies, the number of patients aged 85 years or older who received memantine at the therapeutic dose of 20 mg/day was 40. There is limited safety information for memantine hydrochloride in this patient population.

**Use in Patients with Serious Co-Morbid Conditions:**

There is limited information on the safety of memantine treatment in patients with moderate to severe Alzheimer's disease with serious co-morbidities, as these patients were excluded from clinical trials. The use of memantine hydrochloride in Alzheimer's disease patients with chronic illnesses common among the geriatric population should be considered only after a proper risk/benefit assessment. Dose escalation in this patient population should proceed with caution.

**Pregnancy:**

Oral treatment of female rats with memantine once daily during organogenesis produced mild maternal toxicity at doses of 6-18 mg/kg/day (3-9 times the Maximum Recommended Human Dose [MRHD] on a mg/m<sup>2</sup> basis); however, memantine was not teratogenic at doses up to 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis), the highest dose tested. In a rat reproduction and fertility study, reduced growth and a developmental delay were observed at 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis).

Memantine doses of 0, 3, 10 and 30 mg/kg/day were orally administered to pregnant rabbits during the period of organogenesis. At 30 mg/kg/day (30 times the MRHD on a mg/m<sup>2</sup> basis) maternal toxicity and a slight increase in post-implantation loss were observed. No teratogenic effects were observed in rabbits administered memantine 30 mg/kg/day (30 times the MRHD on a mg/m<sup>2</sup> basis). The maternal and fetal no observed effect level (NOEL) was 10 mg/kg/day (10 times the MRHD on a mg/m<sup>2</sup> basis).

In a peri and postnatal study, memantine was orally administered to rats at up to 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis). At 18 mg/kg/day pups showed reduced mean body weights but there was no effect on their development or behaviour. Animal studies showed no indication of an adverse effect of memantine on labour and delivery.

There are no adequate and well-controlled studies of memantine in pregnant women to establish the safe use of memantine hydrochloride for this population. Therefore, memantine hydrochloride

should not be used in women of childbearing potential, unless, in the opinion of the physician, the expected benefits to the patient markedly outweigh the possible hazards to the foetus.

**Nursing Mothers:**

It is not known whether memantine is excreted in human breast milk. Therefore memantine hydrochloride should not be used in nursing mothers.

**Pediatric Use:**

The safety and effectiveness of memantine hydrochloride in any illness occurring in pediatric patients have not been established. Therefore, memantine hydrochloride is not recommended for use in children.

## **DRUG INTERACTIONS**

**Compounds Chemically Related to N-Methyl-D-Aspartate (NMDA) Antagonists:**

The combined use of memantine hydrochloride with other compounds chemically related to NMDA antagonists such as amantadine, ketamine or dextromethorphan has not been systematically evaluated and is therefore not recommended (see PRECAUTIONS, Concomitant Use With Other Drugs).

**Effects of Memantine Hydrochloride on Substrates of Microsomal Enzymes:**

*In vitro* studies conducted with marker substrates of CYP450 enzymes (CYP1A2, -2A6, -2C9, -2D6, -2E1, -3A4) revealed minimal inhibition of these enzymes by memantine. No pharmacokinetic interactions with drugs metabolized by these enzymes are expected.

**Effects of Inhibitors and/or Substrates of Microsomal Enzymes on Memantine Hydrochloride:**

Memantine is predominantly renally eliminated, and drugs that are substrates and/or inhibitors of the CYP450 system are not expected to alter the metabolism of memantine.

**Acetylcholinesterase (AChE) Inhibitors:**

*In vitro* studies have shown that memantine does not affect the reversible inhibition of acetylcholinesterase by donepezil or galantamine. In young healthy adult subjects (n=19, age range 18-35 years) under steady-state conditions of the AChE inhibitor donepezil hydrochloride (10 mg/day), co-administration of a single 10 mg oral dose of memantine did not affect the pharmacokinetics of either drug and did not affect donepezil-mediated AChE inhibition. In a 24-week study of patients with moderate to severe Alzheimer's disease the adverse event profiles were similar for patients treated with a combination of memantine and donepezil or placebo and donepezil.

In a pharmacokinetic study in healthy adult subjects (n=15, age range 21-55 years), coadministration of memantine (10 mg b.i.d.) did not significantly affect the steady state pharmacokinetics of galantamine (16 mg/day). The effect of galantamine on memantine pharmacokinetics was not evaluated. The safety of co-administering memantine and galantamine in patients with Alzheimer's disease has not been evaluated in clinical trials.

**Drugs Eliminated Via Renal Mechanisms:**

Co-administration of drugs that use the same renal cationic transport system as memantine, such as cimetidine, ranitidine, quinidine, hydrochlorothiazide (HCTZ), triamterene (TA), and nicotine could potentially alter the plasma levels of both agents. Co-administration of memantine hydrochloride and hydrochlorothiazide/triamterene (HCTZ/TA) did not affect the bioavailability of either memantine or triamterene, and the bioavailability of HCTZ decreased by 20%. The pharmacokinetics of memantine is similar in smokers and non-smokers, suggesting that nicotine may not affect the disposition of memantine. The potential for compromised renal function in elderly patients should be considered when memantine will be used concomitantly with other drugs eliminated via renal mechanisms (see PRECAUTIONS, DOSAGE AND ADMINISTRATION).

**Drugs Highly Bound to Plasma Proteins:**

Because the plasma protein binding of memantine is low (45%), an interaction with drugs that are highly bound to plasma proteins, such as warfarin and digoxin, is unlikely.

**Oral Anticoagulants:**

In post marketing experience isolated cases of international normalized ratio (INR) increases have been reported in patients treated concomitantly with memantine and warfarin. Although no causal relationship has been established, close monitoring of prothrombin time or INR is advised for patients treated concomitantly with memantine and oral anticoagulants.

**Antihyperglycemic Drugs:**

In young healthy adult subjects (n=21, age range 19-35 years), co-administration of a single 20 mg oral dose of memantine under steady state conditions of glyburide/metformin (1.25 mg glyburide/250 mg metformin) did not affect the pharmacokinetics of memantine, glyburide or metformin. The renal excretion of metformin and memantine, and potential for compromised renal function in elderly patients should be considered when memantine and metformin will be used concomitantly (see PRECAUTIONS, DOSAGE AND ADMINISTRATION).

**Other Agents:**

Since the effects of L-dopa, dopaminergic agonists, and anticholinergics may be enhanced by concomitant treatment with memantine hydrochloride, dosage adjustment of these other agents may be necessary.

**Carcinogenesis, Mutagenesis and Impairment of Fertility**

There was no evidence of carcinogenicity in a 113-week oral study in mice for either sex at doses up to 40 mg/kg/day (10 times the maximum recommended human dose [MRHD] on a mg/m<sup>2</sup> basis). There was also no evidence of carcinogenicity in rats orally dosed at up to 40 mg/kg/day for 71 weeks followed by 20 mg/kg/day (19 and 10 times the MRHD on a mg/m<sup>2</sup> basis, respectively) through 128 weeks.

Memantine did not show any genotoxic potential in assays for gene mutation (bacterial and mammalian cells *in vitro*) or in clastogenicity assays (human lymphocytes *in vitro* and mouse bone marrow *in vivo*).

No impairment of fertility or reproductive performance was seen in rats administered up to 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis) orally from 14 days prior to mating through gestation and lactation in females, or for 60 days prior to mating in males.

## ADVERSE EVENTS

A total of 916 patients were treated with memantine in double-blind, placebo-controlled dementia studies. Of these patients, 726 (79%) completed the studies. Patients were treated with memantine for a mean of 148.5 days. Approximately 61% of patients received memantine for at least 24 weeks.

### **Adverse Events Leading to Discontinuation of Treatment**

In placebo-controlled trials in which dementia patients received doses of memantine hydrochloride up to 20 mg/day, 11.1 % (102/916) of the memantine hydrochloride-treated patients discontinued treatment due to an adverse event. The discontinuation rate in the placebo-treated patients was 11.6% (109/893). The most frequent adverse event leading to discontinuation was agitation with an observed frequency among patients who discontinued treatment of 1.0% in patients receiving memantine vs. 1.8% in patients administered placebo. None of the other adverse events leading to discontinuation met the criteria for most common adverse events, defined as those occurring at a frequency of at least 2% and at twice the incidence seen in placebo patients.

### **Adverse Events Reported in Placebo-Controlled Dementia Trials**

**Table 1** lists treatment emergent signs and symptoms that were reported in at least 2% of patients in placebo-controlled dementia trials and for which the rate of occurrence was greater for patients treated with memantine hydrochloride than for those treated with placebo. The prescriber should be aware that these figures cannot be used to predict the incidence of adverse events in the course of usual medical practice where patient characteristics and other factors differ from those that prevailed in the clinical trials. Similarly, the cited frequencies cannot be compared with figures obtained from other clinical investigations involving different treatments, uses, and investigators. The cited figures, however, do provide the prescribing physician with some basis for estimating the relative contribution of drug and non-drug factors to the adverse event incidence rate in the population studied.

**Table 1:** Adverse Events Reported in Controlled Clinical Trials in at Least 2% of Patients Receiving Memantine Hydrochloride and at a Higher Frequency than Placebo-treated Patients

Body System	Placebo (N = 893)	Memantine HCl (N = 916)
Adverse Event	%	%
Body as a Whole		
Pain	0.8	2.0
Cardiovascular System		
Hypertension	1.9	2.6
Central and Peripheral Nervous System		
Dizziness	3.7	5.5



Body System	Placebo (N = 893)	Memantine HCl (N = 916)
Adverse Event	%	%
Headache	2.9	4.5
Gastrointestinal System		
Constipation	2.8	4.8
Diarrhoea	2.8	3.4
Nausea	1.8	2.3
Vomiting	1.7	2.3
Musculoskeletal System		
Back pain	1.9	2.2
Psychiatric Disorders		
Anxiety	0.7	2.1
Confusion	4.3	4.6
Hallucinations	1.0	2.1
Somnolence	1.8	2.3
Respiratory System		
Coughing	3.2	3.4

Other adverse events occurring with an incidence of at least 2% in memantine hydrochloride - treated patients but at an equal or lower rate than placebo were agitation, arthralgia, bronchitis, cataract, depression, fall, gait abnormal, inflicted injury, influenza-like symptoms, insomnia, urinary incontinence and urinary tract infection.

#### **Vital Sign Changes:**

Memantine hydrochloride and placebo groups were compared with respect to (1) mean change from baseline in vital signs (pulse, systolic blood pressure, and diastolic blood pressure) and (2) the incidence of patients meeting criteria for potentially clinically significant changes from baseline in these variables. These analyses did not reveal any clinically important changes in vital signs associated with memantine hydrochloride treatment.

#### **Laboratory Changes:**

Memantine hydrochloride and placebo groups were compared with respect to (1) mean change from baseline in various serum chemistry, hematology, and urinalysis variables and (2) the incidence of patients meeting criteria for potentially clinically significant changes from baseline in these variables. These analyses revealed no clinically important changes in laboratory test parameters associated with memantine hydrochloride treatment.

#### **ECG Changes:**

Memantine hydrochloride and placebo groups were compared with respect to (1) mean change from baseline in various ECG parameters and (2) the incidence of patients meeting criteria for potentially clinically significant changes from baseline in these variables. These analyses revealed no clinically important changes in ECG parameters associated with memantine hydrochloride treatment.

### **Adverse Events Observed In Placebo-Controlled Trial in Patients Previously Treated with Donepezil**

In an additional double-blind, placebo-controlled study, 202 patients who had been treated with donepezil for at least 6 months and who had been on stable doses of donepezil for 3 months prior to randomization were treated with memantine for a period of 24 weeks while still receiving donepezil. Of these patients, 172 (85%) completed the study. In this clinical trial, a total of 14.9% (30/202) of the memantine/donepezil patients discontinued the study compared to 25.4% (51/201) of the placebo/donepezil patients. The most frequent reason for discontinuation was adverse events and included 12% of placebo/donepezil patients and 7% of memantine/donepezil patients.

Overall, the safety profile of the memantine/donepezil treated patients was similar to the one observed for the placebo-controlled dementia trials. The adverse events leading to discontinuation of the treatment, and for which the incidence was greater in the memantine/donepezil than in the placebo/donepezil group were: asthenia (memantine 1.0%; placebo 0%), dehydration (memantine 1.5%; placebo 0%) and confusion (memantine 2.0 %; placebo 1.5%).

**Table 2** lists treatment emergent signs and symptoms that were reported in at least 2% of patients in placebo-controlled dementia trials and for which the rate of occurrence was greater for patients treated with memantine hydrochloride /donepezil than for those treated with placebo/donepezil.

**Table 2:** Adverse Events Reported in Controlled Clinical Trials in at Least 2% of Patients Receiving memantine hydrochloride /donepezil and at a Higher Frequency than Placebo/donepezil-treated Patients

Body System Adverse Event	Placebo/ donepezil (N = 201)  %	Memantine hydrochloride / donepezil (N = 202)  %
Body as a Whole		
Chest pain	0.0	2.5
Fall	7.0	7.4
Fever	0.5	2.0
Oedema peripheral	4.0	5.0
Pain	0.5	3.0
Cardiovascular System		
Hypertension	1.5	4.5
Central and Peripheral Nervous System		
Gait abnormal	1.0	3.0
Headache	2.5	6.4
Gastrointestinal System		
Constipation	1.5	3.0
Vomiting	3.0	3.5
Metabolic and nutritional disorders		
Weight increase	0.0	2.5
Musculo-skeletal System		
Arthralgia	1.5	2.5
Psychiatric Disorders		
Confusion	2.0	7.9
Depression	3.0	4.0
Red blood cell disorder		

Body System Adverse Event	Placebo/ donepezil (N = 201)  %	Memantine hydrochloride / donepezil (N = 202)  %
Anemia	0.5	2.0
Reproductive disorders, male		
Prostatic disorder	0.0	4.1
Respiratory System		
Coughing	1.0	3.0
Influenza-like symptoms	6.5	7.4
Skin and appendages disorders		
Rash	1.5	2.5
Urinary system disorders		
Urinary tract infection	5.0	5.9
Urinary incontinence	3.0	5.4
Micturition frequency	0.5	2.0

Treatment emergent signs and symptoms that were reported in at least 2% of memantine hydrochloride /donepezil treated patients (but less than 9%) and at an equal or lower rate than placebo/donepezil treated patients were abdominal pain, agitation, anorexy, anxiety, asthenia, back pain, bronchitis, dehydration, diarrhea, dizziness, fatigue, fecal incontinence, hallucinations, inflicted injury, insomnia, personality disorder, somnolence, syncope, tremor, upper respiratory tract infection.

#### **Other Adverse Events Observed During Clinical Trials**

Memantine hydrochloride has been administered to approximately 1333 patients with dementia, of whom more than 1200 received the maximum recommended dose of 20 mg/day. Approximately 830 patients received memantine hydrochloride for at least 6 months of treatment and 387 patients were treated for approximately a year or more.

All adverse events occurring in at least two patients are included, except for those already listed in **Tables 1** and **2**, WHO terms too general to be informative, or events unlikely to be caused by the drug. Also included are the adverse events observed in the placebo-controlled trial in patients who had been previously treated with donepezil prior to memantine hydrochloride treatment. Events are classified by body system and listed using the following definitions: *frequent* – those occurring on one or more occasions in at least 1/100 patients; *infrequent*– those occurring in less than 1/100 patients but at least in 1/1000 patients. These adverse events are not necessarily related to memantine hydrochloride treatment and in most cases were observed at a similar frequency in placebo-treated patients in the controlled studies.

**Autonomic Nervous System:** *Infrequent:* sweating increased, mouth dry.

**Body as a Whole:** *Frequent:* asthenia, fatigue, oedema, leg pain, malaise, sepsis, syncope. *Infrequent:* abscess, allergic reaction, allergy, chest pain precordial, choking, condition aggravated, ESR increased, flushing, hernia NOS, hot flushes, hypothermia, infection, infection fungal, infection viral, moniliasis, oedema peripheral, pallor, rigors, sudden death.

**Cardiovascular System:** *Frequent:* angina pectoris, bradycardia, cardiac failure, cardiac failure left, heart murmur, oedema dependent. *Infrequent:* aneurysm, arrhythmia, cardiac arrest, embolism pulmonary, fibrillation atrial, heart block, heart disorder, hypertension aggravated, hypotension,

hypotension postural, myocardial infarction, palpitation, phlebitis, pulmonary oedema, tachycardia, thrombophlebitis, thrombophlebitis deep, vascular disorder.

**Central and Peripheral Nervous System:** *Frequent:* aphasia, ataxia, cerebrovascular disorder, hypokinesia, transient ischemic attack, vertigo. *Infrequent:* absences, cerebral hemorrhage, coma, convulsions, coordination abnormal, extrapyramidal disorder, hemiparesis, hemiplegia, hyperkinesia, hypertonia, hypoesthesia, muscle contractions involuntary, neuralgia, neuropathy, paralysis, paresthesia, ptosis, speech disorder, stupor, tremor.

**Gastrointestinal System:** *Frequent:* abdominal pain, dyspepsia, fecal incontinence, hemorrhoids, tooth disorder. *Infrequent:* diverticulitis, dysphagia, esophageal ulceration, esophagitis, flatulence, gastroenteritis, gastroesophageal reflux, gastrointestinal disorder NOS, GI hemorrhage, gingivitis, hemorrhage rectum, melena, mucositis NOS, oesophagitis, saliva altered, saliva increased, stomatitis ulcerative, tooth ache, tooth caries.

**Hemic and Lymphatic Disorders:** *Frequent:* purpura. *Infrequent:* epistaxis, hematoma, leukocytosis, leukopenia, polycythemia.

**Metabolic and Nutritional Disorders:** *Frequent:* hyperglycemia, hypernatremia, hypokalemia, phosphatase alkaline increased, weight decrease. *Infrequent:* bilirubinemia, BUN increased, dehydration, diabetes mellitus, diabetes mellitus aggravated, gamma-GT increased, gout, hepatic enzymes increased, hepatic function abnormal, hypercholesterolemia, hyperkalemia, hyperuricemia, hyponatremia, NPN increased, polydipsia, AST increased, ALT increased, thirst.

**Musculoskeletal System:** *Frequent:* arthritis, arthrosis, muscle weakness, myalgia. *Infrequent:* arthritis aggravated, arthritis rheumatoid, bursitis, skeletal pain.

**Neoplasms:** *Infrequent:* basal cell carcinoma, breast neoplasm benign (female), breast neoplasm malignant (female), carcinoma, neoplasm NOS, skin neoplasm malignant

**Psychiatric Disorders:** *Frequent:* aggressive reaction, anorexia, apathy, cognitive disorder, delusion, nervousness. *Infrequent:* amnesia, appetite increased, concentration impaired, crying abnormal, delirium, depersonalization, emotional lability, libido increased, neurosis, paranoid reaction, paroniria, personality disorder, psychosis, sleep disorder, suicide attempt, thinking abnormal.

**Reproductive Disorders, Female:** *Infrequent:* vaginal hemorrhage, moniliasis; **Male:** *Frequent:* moniliasis.

**Respiratory System:** *Frequent:* dyspnea, pharyngitis, pneumonia, upper respiratory tract infection, rhinitis. *Infrequent:* apnea, asthma, bronchospasm, hemoptysis, respiratory disorder, sinusitis.

**Skin and Appendages:** *Frequent:* bullous eruption, herpes zoster, skin disorder, skin ulceration. *Infrequent:* alopecia, blister, cellulitis, dermatitis, eczema, pruritus, rash erythematous, seborrhea, skin dry, skin erosion, skin reaction localized, toxic skin eruption, urticaria.

**Special Senses:** *Frequent:* cataract, eye abnormality, macula lutea degeneration, vision abnormal. *Infrequent:* blepharitis, blurred vision, conjunctival hemorrhage, conjunctivitis, corneal opacity, decreased visual acuity, diplopia, ear ache, ear disorder NOS, eye infection, eye pain, glaucoma, hearing decreased, lacrimation abnormal, myopia, xerophthalmia, retinal detachment, retinal disorder, retinal hemorrhage, tinnitus.

**Urinary System:** *Frequent:* cystitis, dysuria. *Infrequent:* hematuria, micturition disorder, polyuria, pyuria, renal function abnormal, urinary retention.

**Vascular Disorders:** *Infrequent:* venous thrombosis/ thromboembolism.

### **Post-Market Adverse Drug Reactions**

The following adverse events of possible importance, for which there are inadequate data to determine the causal relationship to memantine treatment have been reported to be temporally associated with memantine treatment and are not described elsewhere in labeling: acne, atrioventricular block, bone fracture, cerebral infarction, cholelithiasis, claudication, colitis, depressed level of consciousness (including loss of consciousness and coma), dyskinesia, encephalopathy, gastritis, grand mal convulsions, hepatic failure, hepatitis (including increased ALT and AST), hyperlipidemia, hypoglycemia, ileus, increased INR, intracranial hemorrhage, myoclonus, neuroleptic malignant syndrome, acute pancreatitis, aspiration pneumonia, acute renal failure, prolonged QT interval, psychotic reactions, restlessness, sepsis, supraventricular tachycardia, tardive dyskinesia, thrombocytopenia.

A search of postmarket data found cases of the following skin hypersensitivity reactions: Drug Eruption, Pemphigoid, Toxic Skin Eruption, Stevens-Johnson Syndrome, Skin Exfoliation, Blister, Erythema Multiforme, Dermatitis Bulous, Pemphigus, Acute Generalized Exanthematous Pustulosis.

Alzheimer's disease has been associated with depression, suicidal ideation and suicide. In post-marketing experience these events have been reported in patients treated with memantine hydrochloride.

## **SYMPTOMS AND TREATMENT OF OVERDOSAGE**

### **Symptoms**

Cases of accidental and intentional overdose have been reported with memantine. The highest ingested dose that has been reported in an overdose is 2000 mg. Reported signs and symptoms in this case were agitation, diplopia and coma followed by full recovery. Fatal overdoses have only been reported when memantine was taken with several other drugs by patients on polytherapy that included memantine. No fatal cases of overdose have been reported in which memantine was taken alone.

### **Treatment of Overdosage**

Because strategies for the management of overdose are continually evolving, it is advisable to contact a regional Poison Control Center for the latest recommendations for the management of a suspected overdose of any drug.

Establish and maintain an airway to ensure adequate ventilation and oxygenation. Gastric lavage and use of activated charcoal should be considered. Cardiac and vital sign monitoring are recommended, along with general symptomatic and supportive measures. There are no specific antidotes for memantine hydrochloride. Elimination of memantine can be enhanced by acidification of urine.

For management of a suspected drug overdose, contact your regional  
Poison Control Centre immediately.

### **DOSAGE AND ADMINISTRATION**

pms-MEMANTINE (memantine hydrochloride) should only be prescribed by (or following consultation with) clinicians who are experienced in the diagnosis and management of Alzheimer's disease. Therapy should only be started if a caregiver is available who will regularly monitor drug intake by the patient. Diagnosis should be made according to current guidelines. The tolerance and dosing of memantine should be reassessed on a regular basis, preferably within three months after start of treatment. Thereafter, the clinical benefit of memantine and the patient's tolerance of treatment should be reassessed on a regular basis according to current clinical guidelines. Discontinuation of memantine should be considered when evidence of a therapeutic effect is no longer present or if the patient does not tolerate treatment.

#### **Adults**

The recommended maintenance dose for memantine is 20 mg/day. In order to reduce the risk of side effects the maintenance dose is achieved by upward titration as follows: the usual starting dose is 5 mg/day. The dose should then be increased in 5 mg increments to 10 mg/day (5 mg twice a day), 15 mg/day (10 mg and 5 mg as separate doses), and 20 mg/day (10 mg twice a day), depending on the patient's response and tolerability. The minimum recommended interval between dose increases is one week. The recommended dose titration is summarized in the following table.

	AM	PM
week 1	1 x 5 mg tablet	none
week 2	1 x 5 mg tablet	1 x 5 mg tablet
week 3	1 x 10 mg tablet	1 x 5 mg tablet
week 4 and beyond	1 x 10 mg tablet	1 x 10 mg tablet

The tablets can be taken with or without food. They should be swallowed whole with some water.

If a dose is missed, the patient should be instructed to take the next dose as scheduled. There is no need to make up the missed dose.

### **Special Populations**

#### **Elderly:**

On the basis of the clinical studies the recommended dose for patients over the age of 65 years is 20 mg per day (10 mg twice a day) as described above (see PHARMACOKINETICS).

#### **Renal Impairment:**

In patients with mildly impaired renal function (creatinine clearance 50 – 80 mL/min) no dosage adjustment is required. In patients with moderate renal impairment (creatinine clearance 30 - 49 mL/min) the daily dose should be 10 mg per day. If well tolerated after at least 7 days of treatment, and based on clinical response, the dose may be increased up to 20 mg/day according to the standard titration scheme. In patients with severe renal impairment (creatinine clearance 15 - 29 mL/min) the daily dosage should be 10 mg per day. (see PHARMACOKINETICS and PRECAUTIONS).

#### **Hepatic Impairment:**

In patients with mild or moderate hepatic impaired function (Child-Pugh A and Child-Pugh B) no dose adjustment is needed (see PHARMACOKINETICS). There are no data available for use of memantine in patients with severe hepatic impairment. Therefore, administration of memantine hydrochloride is not recommended in patients with severe hepatic impairment.

## PHARMACEUTICAL INFORMATION

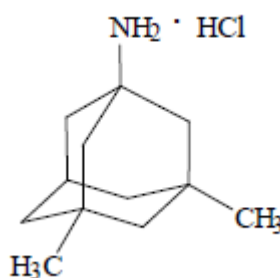
### DRUG SUBSTANCE

**Common Name:** Memantine hydrochloride

**Code Name:** MEM3; D145; MRZ 2/145

**Chemical Name:** 1-amino-3,5-dimethyladamantane hydrochloride

**Structural Formula:**



**Molecular Formula:**  $\text{C}_{12}\text{H}_{22}\text{Cl N}$

**Molecular Weight:** 215.77 g/mol (hydrochloride)  
179.31 g/mol (base)

**Description:** White, crystalline, practically odourless powder

**pH:** 5.5 – 6.0

**pKa:** 10.27

**Solubility:** water, hydrochloridic acid, methanol, n-hexane (soluble), methylene chloride, chloroform (freely soluble), ethylacetate (practically insoluble)



## DRUG PRODUCT

### Composition

pms-MEMANTINE tablets contain 5 mg or 10 mg of memantine hydrochloride and the following non-medicinal ingredients: Colloidal Silicon Dioxide, Crospovidone, Hydroxypropyl Methylcellulose, Lactose Monohydrate, Magnesium Stearate, Microcrystalline Cellulose, Polyethylene Glycol, Polysorbate 80, Titanium Dioxide.

### Stability and Storage Recommendations:

pms-MEMANTINE tablets should be stored in a dry place at room temperature between 15° and 30°C. Protect from moisture.

## AVAILABILITY OF DOSAGE FORMS

### 5 mg tablets:

White to off-white oblong, coated tablets, debossed with “MT” on one side and “5” on the other side. Available in HDPE bottle of 100.

### 10 mg tablets:

White to off-white, oblong, biconvex, scored tablet, debossed with "MT" divided by the score on one side and "10" divided by the score on the other side. Available in HDPE bottle packages of 100 tablets. and in blister packages of 30 tablets

## PHARMACOLOGY

Persistent activation of the central nervous system N-methyl-D-aspartate (NMDA) receptors by the excitatory amino acid glutamate has been hypothesized to be involved in the pathogenesis of Alzheimer's disease. Memantine, a low to moderate affinity uncompetitive (open channel) NMDA receptor antagonist, binds preferentially to the NMDA receptor-operated cation channels. It blocks the effects of pathologically elevated tonic levels of glutamate that may lead to neuronal dysfunction.

*In vitro* electrophysiological studies suggest that memantine inhibits NMDA receptor-mediated currents in a use-dependent [i.e., it blocks the receptor channel in the presence of an agonist, e.g., glutamate] and voltage-dependent manner, with rapid receptor-unblocking kinetics. Because of these attributes, memantine can selectively antagonize pathological activation of NMDA receptors without affecting the physiological functioning of the receptor. Physiological activation of NMDA receptors is known to play a critical role in synaptic plasticity processes such as cognition.

(+) MK-801 (dizocilpine) is the prototypical NMDA uncompetitive receptor antagonist. Memantine binds to the MK-801 recognition site in the NMDA channel with a  $K_i$  of 0.5 mM and antagonises NMDA receptor-mediated inward currents *in vitro* with an  $IC_{50}$  of 1-3 mM. The  $K_i$ -value of memantine at the phencyclidine (PCP) binding site of the NMDA receptor is 0.5 mM in human frontal cortex (0.1 ppm).

In several *in vitro* and *in vivo* studies, memantine has been shown to protect neurons from cell death due to excitotoxicity. For example, memantine protects rat cortical and hippocampal cells from the neurotoxic effects of glutamate. In addition, memantine attenuates  $\beta$ -amyloid ( $A\beta$ )-induced hippocampal cell death (apoptosis) in rats *in vivo*, and protects cholinergic neurons of the rat nucleus basalis magnocellularis from NMDA-induced neurotoxicity.

Memantine also improves learning and memory in animal studies. For example, memantine prevents ( $A\beta$ )-induced impairment in learning in rats, and reverses neurodegeneration and memory impairment in rats produced by the NMDA receptor agonist quinolinic acid. Memantine does not affect learning in normal (control) rats.

Memantine exhibits low to negligible affinity for other receptors (GABA, benzodiazepine, dopamine, adrenergic, noradrenergic, histamine and glycine) or voltage-dependent  $Ca^{2+}$ ,  $Na^+$  or  $K^+$  channels. In addition, it does not directly affect the acetylcholine receptor or cholinergic transmission, which have been implicated in the cholinomimetic side effects (e.g., increased gastric acid secretion, nausea and vomiting) seen with acetylcholinesterase inhibitors. Memantine showed antagonist effects at the  $5HT_3$  receptor with a potency similar to that for the NMDA receptor.

Standard safety pharmacology studies were conducted to evaluate memantine's effects on CNS, cardiovascular, gastrointestinal and renal functions. At doses higher than the pharmacologically relevant dose ( $\geq 30$  mg/kg), memantine produced considerable CNS side effects. Decreased awareness, motor activity and reflexes were observed at high doses (100 mg/kg). High doses of memantine ( $\geq 30$  mg/kg, intraduodenal) decreased cardiac minute output, stroke volume and systolic left ventricular pressure. Memantine inhibited intestinal motility in rats with an  $ED_{50}$  of 20 mg/kg,

and produced diuresis and saluresis in rats at high doses (40 mg/kg; p.o.).

## PHARMACOKINETICS

### Absorption

Memantine is relatively rapidly and completely absorbed after oral administration.

Approximate peak plasma memantine concentrations after single and repeated oral doses (gavage or capsule) in rat and baboon are given in the table below:

**Table 3: Peak plasma memantine concentrations**

Species	Treatment duration	Dose (mg/kg)	Peak plasma concentration (ppm)	
			males	females
Rat	Single dose	25	1.0	1.6
		50	2.4	2.4
		100	4.4	4.9
	5-week	10	0.4	0.8
		20	1.2	1.3
		40	1.5	3.0
	26-week	10	0.8	1.0
		20	1.5	2.1
		40	2.4	2.4
	52-week (diet)	20/15 (m/f)	0.2	0.3
		40/30	0.7	0.8
		70/50	3.2	2.1
Baboon	2-week	8	0.4	0.3
	13-week	2	0.0	0.0
		4	0.02	0.01
		8	0.10	0.05
	52 week	2	0.01	0.01
		4	0.02	0.02
		8	0.06	0.07

There was no systematic sex difference, female levels were 0.5 to 2 times male levels in various samples, with no discernible pattern (and  $t_{max}$  did not differ between the sexes).

### Distribution

Mean plasma binding of memantine in the rat is 41%, comparable to the 45% binding found in man.

Distribution studies with memantine have been carried out in rats and baboons. Oral bioavailability of memantine is virtually complete, and distribution to target, the brain, is rapid. Once in the body, memantine distributes preferentially to the organs of metabolism and excretion, liver and kidney, but also to the lung. Exceptionally high concentrations of memantine were found in bile and Harderian glands, and at lower concentrations in the central nervous system, consistent with its lipophilicity. High concentrations are also found in the uveal tract of pigmented animals. The localization of  $^{14}\text{C}$ -memantine and/or its labelled metabolites in the uveal tract (which includes choroid, ciliary body

and iris) of the eyes of pigmented animals (239 ppm vs. 13 ppm in albinos) suggests that the test substance has an affinity with melanin, which has also been demonstrated *in vitro*.

More pharmacologically oriented studies have focused on determining the concentration in extracellular fluid. Based on the assumption that concentrations measured in the cerebrospinal fluid (CSF) or microdialysate allow conclusions to be drawn about the concentration at the site of action, the following results are of interest. After *i.p.* administration of 20 mg memantine per kg to rats, about 0.3 ppm memantine was found in the microdialysate, taking the recovery into account. Under the same conditions 0.8 ppm total memantine (free and bound memantine) was found in the plasma. Similar results have been reported for humans, with a CSF/serum ratio for total memantine of about 0.4-0.6. Monitoring of the plasma concentration therefore provides information about the presumed concentration at the site of action across different species.

Following 7 days infusion of memantine (20 mg/kg/day) whole brain concentrations were 44-fold higher than free concentrations in serum. The free brain ECF concentration of memantine ( $0.83 \pm 0.05$  mM) corrected for *in vivo* recovery (39 %) was comparable to free serum and CSF concentrations.

### **Metabolism and Elimination**

Memantine metabolites are mainly derivatives hydroxylated on the methyl groups (-CH<sub>2</sub>OH or -COOH) or on the cage structure, with an intact or oxidised amino function (hydroxylamino, nitro derivatives). In addition, conjugated compounds were found as phase II metabolites but they seem to be of minor importance.

The following table shows the proportion (%) of these metabolites in urine after memantine administration:

**Table 4:**

**Metabolites in urine after memantine administration**

Metabolites	Mouse	Rat	Baboon	Man
Unmetabolised	68	28	9	68
Hydroxy derivatives*	46	65	41	17
N-oxidised**	4	1	43	10
Carboxy derivatives***	0	6	1	0
N-glucuronide****	5	<1	<1	6

\* Hydroxylated metabolites were MRZ 2/371, 2/373, 2/374, 2/525, 2/564, 2/677

\*\* N-oxidised (nitro, nitroso) metabolites were MRZ 2/523, 2/524, 2/529

\*\*\* MRZ 2/375

\*\*\*\* MRZ 2/325.

Other metabolites found were <1% in all species.

Memantine and its metabolites are excreted primarily via the kidney. After a single oral dose of <sup>14</sup>C-memantine, a minimum of 80-90% of the excreted radioactivity was excreted in the urine in rats, mice, rabbits, miniature pigs, dogs, baboons and humans.

In the baboon, a substantial portion of memantine radioactivity is associated with bile. Since excretion is predominantly renal, this indicates substantial enterohepatic circulation.

As for amantadine, memantine is partly excreted by tubular secretion.

Elimination half-life was approximately 4 hours in all species except man; there was no accumulation with repeat dosing. In baboon's 13 and 52 week oral toxicity studies, followed by a 4 week recovery period, no detectable memantine was present at the end of the recovery period in any tissue except the eye; concentrations in the eyes fell from 8 to 0.4 ppm during recovery in the 13 week study, and from 15 to 1 ppm in the 52 week study.

## TOXICOLOGY

### **Acute Toxicity**

Acute oral and intravenous toxicity studies in rat and mouse demonstrated that memantine is moderately toxic. The lowest lethal oral dose is  $\geq 300$  mg/kg in both species. The results of standard LD<sub>50</sub> studies are as follows:

Route of administration	Species	LD <sub>50</sub> ( mg/kg)	
		male	female
Intravenous	Mouse	30	32
	Rat	38	38
Intraperitoneal	Rat	79	
Subcutaneous	Mouse	206	138
	Rat	436	386
Oral	Mouse	498	437
	Rat	370	328

Toxic symptoms were similar by all administration routes: ataxia, tremor, prone position and bradypnea. These motor effects at high doses are consistent with central nervous system blockade of glutamatergic transmission in neocortex and cortical projection fields. Recovery was relatively rapid in all cases, i.e. within hours after intravenous administration and within 1-2 days after intraperitoneal, subcutaneous or oral administration. No persistent clinical signs were seen in survivors 14 days after acute high dose memantine treatment.

### **Repeat-Dose and Long-Term Toxicity**

In subchronic and chronic studies the most prominent clinical signs in all species were related to the central nervous system and included ataxia, tremor, and/or unsteadiness and aggressiveness or hyperexcitability in rodents, incoordination, tremors and apathy or quietness in dogs and baboons, and convulsions in dogs. Reduced body weight, which was sometimes accompanied by a change in food consumption, was noted in all studies.

Pathological changes, such as accumulation of foamy macrophages in several tissues, renal papillary mineralization, tubulo-interstitial nephritis, vacuolization of defined cortical neurons, and corneal opacities were observed in repeat-dose toxicity studies in rodents. The neuronal vacuolation and corneal opacities occurred at dose levels that resulted in overt toxicity.

In rats, following repeat-dose administration of memantine for various durations, the accumulation of foamy macrophages was observed in several tissues including lungs, kidneys, liver Kupffer cells,

cornea, lymphoid organs, testes, epididymides and tongue muscle. Accumulation of foamy macrophages is a form of phospholipidosis. In most tissues, except for lungs, the accumulation of foamy macrophages occurred when blood concentrations were several-fold greater than the potential concentrations in humans at therapeutic doses. In lungs accumulations of foamy macrophages were observed when systemic exposure was less than 2-times the potential systemic exposure at human therapeutic dose levels.

Renal papillary mineralization or calcification of the collecting tubuli of the renal medulla was observed in male rats at doses of 20 mg/kg (or higher) and in female rats 15 mg/kg (or higher) following repeat-dose administration of memantine for 52-weeks or 2 years. The kidney lesions were observed at memantine blood concentrations that were less than 2-fold the potential systemic exposure in humans following repeated administration of 20 mg/day.

Cerebrocortical neurons in adult rodent brain are prone to injury (or lesions) by systemic administration of high affinity uncompetitive (or open channel) NMDA receptor antagonists, such as, (+) MK-801, PCP, and ketamine. To determine the potential of memantine to induce Olney-type lesions, studies were conducted in rats that indicated that single intraperitoneal doses of memantine of 20 mg/kg (or higher) or oral doses of 100 mg/kg (or higher) produced a dose related increase in the frequency and severity of Olney-type lesions. These experiments also indicated that vacuolization was reversible and that only a small portion of cells became necrotic. Repeated daily oral doses of 40 mg/kg/day memantine administered in a dose-escalation manner did not demonstrate evidence of neurotoxicity when examined after appropriate tissue fixation procedures. Although body weight was reduced in the mid and high dose groups, no ataxia, neuronal vacuolisation or necrosis was observed at any dose level.

Experiments in rats comparing the effect of duration of dosing (acute vs. subchronic) and route of administration (dietary vs. gavage) of memantine on the development of Olney-type lesions demonstrated that regardless of duration or route of administration, ataxia occurred at doses 2 to 4 times lower than vacuolization or necrosis.

Numerous repeated dose toxicology studies with memantine were performed without any significant observations regarding neuropathology. Re-examination with appropriate preparation techniques of the existing brain tissue slides from 13-week and 52-weeks dietary study in mice and rat, respectively, and examination of the newly prepared slides from the 52-week rat study revealed no neurodegenerative changes. Histopathological examination of brains from the 13-week mouse study also revealed vacuolization in brainstem and cerebellum of males, but not cingulate and retrosplenial cortex, at 320 mg/kg/day, a dose that produced profound systemic toxicity including death.

The ability of memantine to produce Olney-type lesions in baboons was also examined. The highest dose (8 mg/kg/day) from the 52-week study was administered to baboons for 2 weeks. While ptosis was observed in all treated animals, perfusion fixation prepared brain revealed no evidence of vacuolization or necrosis. These results are consistent with the actions of other NMDA antagonists in primates, which have demonstrated that primates are resistant to the development of Olney-type lesions. Similarly in humans subjected to high doses of a low affinity uncompetitive NMDA receptor antagonist or amantadine, no necrosis in posterior cingulate/retrosplenial cortex or elsewhere in the brain was found at autopsy.

### **Reproduction Studies**

Reproductive performance of rats was examined after treatment in all segments of the reproductive cycle in a series of three studies, all using the same doses: 2, 6 and 18 mg/kg/day. The doses were chosen on the basis of a range-finding gavage study with low doses of up to 12.5 mg/kg, and on previous repeat dose oral studies in rats showing dose-related weight loss at 15-30 mg/kg. Treatment of female rats with memantine orally once daily during organogenesis produced mild maternal toxicity at doses of 6-18 mg/kg/day (3-9 times the Maximum Recommended Human Dose [MRHD] on a mg/m<sup>2</sup> basis); however, memantine was not teratogenic at doses up to 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis), the highest dose tested. In a rat reproduction and fertility study, reduced growth and a developmental delay were observed in offspring of mothers administered 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis).

At 30 mg/kg/day (30 times the MRHD on mg/m<sup>2</sup> basis) maternal toxicity and slight increase in post-implantation loss were observed in rabbits administered memantine once daily during organogenesis. No teratogenic effects were observed at that dose level. The maternal and fetal no observed effect level (NOEL) was 10 mg/kg/day (10 times the MRHD on a mg/m<sup>2</sup> basis).

In a peri and postnatal study, memantine was orally administered in rats at up to 18 mg/kg/day (9 times the MRHD on a mg/m<sup>2</sup> basis). At 18 mg/kg/day pups showed reduced mean body weights but there was no effect on their development or behaviour. Animal studies showed no indication of an adverse effect of memantine on labor and delivery.

Considering memantine's molecular weight and its lipophilicity, it is likely that it will be present in the treated mother's milk during lactation (at unknown levels). In a peri and postnatal study there were dose-related increases in memantine levels in milk in lactating rats when memantine was administered from mating through postnatal day 4, although no toxic effects were seen in suckling offspring.