Title Page

Peginesatide Clearance, Distribution, Metabolism, and Excretion in Monkeys Following Intravenous Administration

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Running Title Page:

Peginesatide Monkey ADME

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CKD, chronic kidney disease; EPO, erythropoietin; EPOr, erythropoietin receptor; ESA, erythropoiesis stimulating agent; EMH, extramedullary hematopoiesis; LSC, liquid scintillation counting; MARG, Microautoradiography; PRCA, pure red cell aplasia; QWBA, quantitative whole body autoradiography; rHuEPO, recombinant human erythropoietin.
Abstract

Peginesatide, a PEGylated peptide-based erythropoiesis stimulating agent (ESA), stimulates the erythropoietin (EPO) receptor dimer that governs erythropoiesis. Studies were designed to determine the erythropoietic response, pharmacokinetics (PK), tissue distribution, metabolism, and excretion of peginesatide in nonhuman primates following a single intravenous (IV) dose. The PK profile of peginesatide (0.1 to 5 mg/kg) is characterized by low, dose-dependent plasma clearance; small volume of distribution; and long half-life. The peginesatide PK profile following a single IV dose is consistent with the sustained erythropoiesis. Biodistribution quantitative whole body autoradiography (QWBA) demonstrated high peginesatide levels in bone marrow (i.e., primary hematopoietic site) as well as other known hematopoietic sites, persisting through at least 3 weeks at 2.1 mg/kg. Microautoradiography (MARG) analysis at 48 hours post-dose revealed uniform and high distribution of radioactivity in the bone marrow and splenic red pulp with less extensive distribution in the renal cortex (glomeruli, associated ducts, interstitial cells). Radioactivity in the kidney was most prominent in the outer medullary and papillary interstitium. At 2 weeks after dosing, cumulative radioactivity recovery in the urine and feces was 60 and 7% of the administered dose, respectively, with most of the radioactivity associated with the parent molecule. In conclusion, the PK characteristics are consistent with a PEGylated peptide of a 45 kDa molecular weight, specifically low volume of distribution and long half-life. Drug was localized principally to hematopoietic sites and non-specific tissue retention was not observed. The nonhuman primate data indicate that peginesatide is metabolically stable and primarily excreted in the urine.
Introduction

Erythropoietin is a glycoprotein hormone synthesized by the kidney in response to hypoxia. The hormone activates the EPO receptor (EPOr) on bone marrow erythroid cell precursors supporting their proliferation, growth, and differentiation, which leads to reticulocytosis and subsequent red blood cell maturation. Anemia in chronic kidney disease (CKD) patients occurs as a result of damage to the renal cells that are responsible for EPO production (Maxwell et al, 1997). Benefits of anemia treatment in CKD patients include decreased morbidity, hospitalization, mortality, and transfusion avoidance (Silverberg, 2003; Li et al., 2004; Vanrenterghem et al., 2002). Currently in the United States, management of anemia secondary to CKD relies on recombinant human erythropoietin (rHuEPO, epoetin alfa, Procrit®, Epogen®) or darbepoetin alfa (Aranesp®), which are typically administered up to three times weekly or every one to two weeks, respectively.

Peginesatide is a PEGylated, peptide-based ESA that is approved in the US for the treatment of anemia due to CKD in adult patients on dialysis. Peginesatide stimulates the EPOr, but has no sequence homology to rHuEPO (Woodburn et al., 2011). Peginesatide, by virtue of its lack of immunological cross-reactivity (Fan et al., 2006), has been shown to correct anemia in rats with anti-EPO antibody-mediated pure red cell aplasia (PRCA) (Woodburn et al, 2007) as well as increase hemoglobin levels and reduce the need for transfusions in CKD patients with PRCA caused by anti-EPO antibodies (Macdougall et al., 2009).
The peginesatide peptide sequence was identified by peptide screening against the human EPOr, followed by synthetic chemical optimization (Fan et al., 2006). The screening methodology allows the generation of peptide alternatives to endogenous proteins with amino acid sequences unrelated to the natural ligand or any other human sequence (Cwirla et al., 1997). The peginesatide peptide was PEGylated in an effort to prolong systemic circulation, increase solubility, and decrease the peptide’s immunogenic potential by masking epitopes (Calcieti and Veronese, 2003; Harris and Chess 2003).

Studies conducted in the rat characterizing the absorption, distribution, metabolism, and excretion (ADME) of peginesatide after IV administration and correlating the ADME properties with the pharmacological activity have been reported (Woodburn et al, 2012). The toxicologic assessment of peginesatide was also performed in both the rat (Woodburn et al., 2009) and the monkey (Woodburn et al, 2008a and b). The monkey and the rat are appropriate species for the nonclinical assessment of peginesatide based on pharmacological, toxicological, and PK considerations. Peginesatide has been shown to be pharmacologically active in both rats and monkeys. In addition, the red blood cell (RBC) life span is 52 to 128 days in the monkey and 45 to 60 days in the rat (Moore, 2000) compared to 120 days in normal adult humans and 45 to 85 days in patients with renal failure (Kruse et al., 2008). Unlike the rat, humans and monkeys undergo little or no extramedullary hematopoiesis (EMH) in the spleen and liver under normal conditions, whereas rodents commonly exhibit a fairly robust EMH response throughout their life (Greaves and Faccini, 1992). The erythropoietic response in monkeys, therefore, more
closely approximates the response in humans when compared to the rats, which allows a more direct translation of the data obtained in monkeys to human clinical use.

Extensive nonclinical studies have been conducted in nonhuman primates to support clinical development and approval of peginesatide. The results of studies designed to determine the erythropoietic response, pharmacokinetics, tissue distribution, and major routes of elimination of peginesatide following a single IV dose in Cynomolgus monkeys are described.
Materials and Methods

Chemicals

Peginesatide is a synthetic, dimeric peptide (approximate MW 4,900 amu). The molecule is comprised of two identical 21-amino acid chains covalently bonded via a linker to a single lysine-branched bis-PEG chain (approximate MW 40,000 amu), yielding a total molecular weight of approximately 45,000 amu (Figure 1). The linker is derived from iminodiacetic and β-alanine.

Both unlabeled and radiolabeled peginesatide were used in the studies. Radiolabeled peginesatide, with the 14C-radiolabel on the lysine linker between the peptide dimer and the two 20 kDa PEG chains (Figure 1) was used for the QWBA biodistribution and for the excretion/metabolism studies. Radiolabeled [14C]peginesatide, with activity ranging from 5.5 to 5.7 µCi/mg and a radiochemical purity of approximately 90%, was synthesized by GE Healthcare (Buckinghamshire, UK). The process to prepare the labeled material used a synthetic route that resulted in a mono-PEGylated 14C-labeled species at a level of approximately 10%, in addition to radiolabeled parent compound. The mono-PEG is a specific impurity formed during radiolabel chemical synthesis and has not been identified in any unlabeled lots. The mono-PEG species results from incomplete PEGylation (i.e., attachment of only one of the two 20 kDa PEG chains) and likely represents PEGylation of either the alpha or epsilon amine of lysine. The level of mono-PEG present in the formulation was not deducted from the total radioactivity measured in plasma and tissues.
Animal Studies

Animals were maintained at each of the study facilities in accordance with the Guidelines for Care and Use of Laboratory Animals.

Pharmacology

Dimeric peptide

Male non-naïve Cynomolgus monkeys (n=3 per group; 3 kg) were administered an IV injection of dimeric peptide (i.e., peginesatide minus PEGylation) at 0.1 or 1 mg/kg (1 mL/kg) on Day 1. Blood samples for complete blood counts (CBCs), including reticulocyte counts, were collected prior to dosing and on Days 4, 6, 10, 14, 19, and 29 post-dose.

Peginesatide

Male non-naïve Cynomolgus monkeys (n=4 per group; 3-5 years old) were administered an IV injection of vehicle (10 mmol/L acetic acid in isotonic saline, pH 5.5) or 0.02, 0.1, or 0.5 mg/kg peginesatide at 0.5 mL/kg on Day 1. Blood samples for CBCs, including reticulocyte counts, were collected prior to and 4, 7, 14, 21, 28, 35, 42, 49, 56, and 63 days following administration.

The RBC and reticulocyte data following administration of the dimeric peptide or peginesatide are expressed as mean ± standard deviation. Comparisons of hematologic
parameters were performed using a one-way analysis of variance followed by a post hoc Dunnett’s test. A p value less than 0.05 was considered statistically significant.

**Pharmacokinetics**

The PK and linearity of the PK profile were evaluated following single IV doses of peginesatide. Male non-naïve Cynomolgus monkeys (n=4 per group; 4 years old, 4.2-4.4 kg) were administered single escalating IV doses of 0.1, 0.5, and 5 mg/kg peginesatide at 0.5 mL/kg with a 42-day wash out period between doses. The vehicle was isotonic saline. Blood samples for PK analysis were collected from animals pre-dose and at 0.25, 1, 6, 24, 48, 72, 120, 168, 240, 336, 408, and 504 hours post-dose. Plasma was obtained and analyzed for peginesatide by a validated competition enzyme linked immunosorbent assay (ELISA) in monkey plasma with a lower limit of quantification (LLOQ) of 40 ng/mL (Fan et al., 2006; Woodburn et al., 2007).

The PK parameters were calculated using WinNonlin® software (version 5.0.1, Pharsight, Mountain View, CA, US). Area under the plasma concentration – time curve (AUC) and area under the first-moment curve of the plasma concentration-time curve (AUMC) were calculated by the linear trapezoidal rule. Clearance (CL) was calculated as dose/AUC, mean residence time (MRT) as AUMC/AUC, and volume of distribution at steady state (Vss) as CL*MRT. The Cmax was designated as the measured value at the earliest sampling time point of 0.25 hours post-dose.
Tissue Distribution

Tissue distribution and localization were investigated using QWBA and MARG. Male naïve Cynomolgus monkeys (n=4; 2 years old, 1.9-2.0 kg) were given an IV bolus dose of [14C]peginesatide at 2.1 mg/kg (7.14 μCi/mg). Three monkeys were sacrificed for QWBA analysis 48 hours or 1 or 3 weeks after dosing. One monkey was sacrificed for MARG analysis at 48 hours after dosing. Blood samples for CBCs, including reticulocyte counts, were collected pre-dose; 48 and 120 hours post-dose; and at 1, 2, and 3 weeks after dosing. Blood samples for PK determination were collected pre-dose; at 1, 24, 48, 72, and 120 hours post-dose; and at 1, 2, and 3 weeks after dosing.

The RBC and reticulocyte data were expressed and analyzed as previously described. Total radioactivity in whole blood samples was determined by combustion then liquid scintillation counting (LSC) analyses and plasma samples by LSC analyses. The PK parameters were calculated as previously described.

Quantitative Whole-body Autoradiography (QWBA) Preparation

Carcasses from animals euthanized at 48 hours, 1 week, and 3 weeks after dosing were immediately frozen in a hexane-dry ice bath for approximately 1 hour. Following embedding, the carcasses were cut into sagittal sections (40 μm thick) using a CM3600 cryomicrotome (Leica, Nussloch, Germany) and then mounted on cardboard backing. A set of sections from each animal were exposed to 14C-sensitive phosphor imaging plates (Fuji Biomedical, Stamford, CT) for a 4-day exposure period. Tissue radioactivity concentrations were quantified from the whole-body autoradiograms using a validated
image analysis system (Typhoon 9410™ image acquisition system [GE Healthcare/Molecular Dynamics, Sunnyvale, CA, USA] and MCID™ image analysis software [v. 6.0 and 7.0, GE Healthcare/Imaging Research, Inc., St. Catherines, Ontario, Canada]). A set of ^14^C-blood calibration standards (range was approximately 0.0007 to 6.5 μCi/g), applied to ^14^C-sensitive phosphor imaging plates (Fuji Biomedical, Stamford, CT), was used as the calibration standard.

**Microautoradiography (MARG) Preparation**

Liver, spleen, thymus, mesenteric lymph nodes, axillary lymph nodes, sternum, bone marrow (femur), kidney cortex, kidney medulla, and kidney papilla were immediately removed from one of the animals euthanized at 48 hours post-dose and were prepared for MARG analysis. Tissues were cut into blocks of approximately 0.5 cm². Each block was mounted on a cryosectioning stage and quick-frozen in isopentane cooled to the temperature of liquid nitrogen. Cryosections were collected (5 μm in thickness, chamber temperature approximately -25°C) and thaw-mounted under darkroom conditions onto slides previously coated with nuclear photographic emulsion (Kodak®, NTB). Slides were exposed and then developed in Kodak® D19 developer and fixed with Kodak® fixer. Slides were co-stained with hematoxylin and eosin for geographic orientation.

**Metabolism and Excretion**

The metabolism and excretion of peginesatide was evaluated in male non-naïve Cynomolgus monkeys (n=4; 4 years old, 3.6-4.3 kg) following a single IV administration of 5 mg/kg radiolabeled[^14^C]peginesatide (28 μCi/kg body weight). Blood
samples for the analysis of PK parameters and metabolite profiling were also obtained at 0.25, 1, 6, 24, 48, 72, 96, 120, 144, 168, 240, and 336 hours post-dose.

The total plasma concentration of radioactivity was measured by a direct method (LSC). Quantitative metabolite profiling was performed using pooled plasma samples prepared from combining each respective time point. Samples were extracted and subjected to high performance liquid chromatography (HPLC) separation and fractionation as subsequently described. Radioactivity concentrations in the various fractions were measured by LSC. Unlabeled standards, including the non-PEGylated peptide monomer, non-PEGylated peptide dimer and a mono-PEG, were used for identification of potential metabolites. The un-identified minor peaks were combined as “Others”. The PK parameters were analyzed for peginesatide and metabolites as follows. The $C_{\text{max}}$ was obtained from the actual values measured at the earliest time point (i.e., 0.25 hours). The $t_{1/2}$ and AUC were calculated by the WinNonlin non-compartmental model (Ver. 4.1, Pharsight Corporation, Mountain View, CA, US). Clearance was calculated as dose/AUC. The AUC of metabolites designated as “Others” was calculated by the subtraction of the AUC of the identified components from the AUC of total radioactivity in the plasma.

Urine and fecal samples were collected every 24 hours up to 14 days after dosing. Radioactivity in the urine samples was measured using the direct method. Radioactivity in fecal homogenates was measured using the combustion followed by direct LSC methods. Cumulative excretion ratio was calculated and expressed as percent of administered dose.
For quantitative metabolite profiling, two aliquots (i.e., 0-168 and 168-336 hours post-dose) of each biological matrix were obtained by combining pooled samples from the 4 animals at respective 24 hour collection intervals. The samples were subsequently extracted and analyzed by HPLC fractionation and radioactivity was measured by a direct method (LSC) for plasma and urine and by a combustion method for the fecal homogenate.

**HPLC for Metabolite Profiling**

The radioactive HPLC fraction eluents were identified as peginesatide or mono-PEG (peginesatide with one PEG chain), with the remaining radioactivity designated as “Other”. The classification of Other is considered likely to encompass smaller PEGylated-peptides and peptide/amino acid components.

**Sample preparation**

Plasma, urine, and fecal homogenates were extracted with 5 volumes of methanol containing 0.1% of trifluoroacetic acid (TFA). The homogenate samples were then mixed and centrifuged at 1,500 × g at 4°C for 10 minutes to obtain supernatant. A portion of the supernatant was counted by LSC to estimate the extraction ratio of [14C]peginesatide and its related compounds in the biological samples. Extraction efficiencies for plasma and urine were above 95 and 97%, respectively.
DMD #48033

The rest of the supernatant was evaporated to dryness under a nitrogen gas stream. The residue was dissolved in a small volume of mobile phase A and B (MP(A):MP(B) = 1:1 by volume). A mixture of 0.1% TFA aqueous solution and 0.1% TFA in methanol solution were used for MP(A) and MP(B), respectively. The samples were injected into the HPLC, which consisted of an LC-10ADvp pump, a CTO-10ACvp column oven, an SPD-10Avp UV detector, and an SCL-10Avp system controller. The HPLC separation was achieved at 40°C with a Zorbax 300SB-C8 column (150 mm × 2.1 mm i.d., 5 µm, Agilent Technologies Japan, Ltd. Kyoto, Japan). The flow rate was 0.5 mL/min, and the peaks were monitored by a UV absorption detector at 215 nm and a radioisotope detector. The gradient elution involved increasing MP(B) from 50% to 80% and from 80% to 83% over a period of 2 to 10 minutes and 10 to 20 minutes, respectively. The concentration of MP(B) was continuously increased to 90% by 20.1 minutes and was held at 90% for 10 minutes, then cycled back to the initial condition (50%) yielding a total run time of 40 minutes. Under these conditions unchanged peginesatide and mono-PEG eluted at 18 and 17 minutes, respectively.

Results

Pharmacology

The pharmacological activity of the dimeric peptide is enhanced by PEGylation. Dimeric peptide doses of 0.1 and 1 mg/kg did not induce increases in RBCs in male Cynomolgus monkeys following a single IV administration (not shown). The lowest peginesatide dose tested of 0.02 mg/kg, which contains approximately 0.0022 mg/kg of the dimeric peptide,
on a weight basis, produced a statistically significant \((p < 0.05)\) increase in RBCs, compared to the concurrent vehicle control (Figure 2).

Peginesatide induced an initial, generally dose-dependent increase in percent reticulocytes. At peak response on Day 5, however, a notable difference between the response at 0.1 and 0.5 mg/kg was not observed, suggesting that the magnitude of the peak response plateaus at a given dose. The increase in reticulocytes subsequently resulted in a dose-dependent increase in RBC parameters. By Day 21, reticulocyte values were similar or lower than baseline values across all doses. A decrease below baseline values likely represents negative feedback mechanisms secondary to the peginesatide-induced polycythemia. The duration of the increase in both reticulocytes and RBC parameters was also dose-dependent.

On Day 14, mean RBC counts were \(5.83 \pm 0.513\), \(6.17 \pm 0.533\), and \(6.72 \pm 0.316 \times 10^6/\mu L\) at 0.02, 0.1, and 0.5 mg/kg, respectively, compared to concurrent vehicle control levels of \(5.48 \pm 0.384 \times 10^6/\mu L\). The increase in RBCs, which reached statistical significance at doses of 0.1 and 0.5 mg/kg, corresponded to Hgb increases of \(0.50 \pm 0.424\), \(1.40 \pm 0.408\), and \(2.95 \pm 1.25\) g/dL at 0.02, 0.1, and 0.5 mg/kg, respectively, compared with pre-dose levels. The increase from pre-dose levels in RBCs on Day 21 were \(0.025 \pm 0.114\), \(0.330 \pm 0.075\), and \(0.855 \pm 0.166 \times 10^6/\mu L\) for 0.02, 0.1, and 0.5 mg peginesatide/kg, respectively, reaching statistical significance at all dose levels. By Day 35, RBC counts in the 0.1 and 0.5 mg/kg groups remained elevated. The increase, however, was statistically significant compared to the concurrent vehicle control group at
only the high dose of 0.5 mg/kg. A significant elevation in RBC counts persisted through Day 42 in the 0.05 mg/kg group, with increases over concurrent controls of 0.453 ± 0.389 \(10^6/\mu\text{L}\). By Day 63, values across all dose groups were similar to or approached the levels of the concurrent control group.

The \([^{14}\text{C}]\)peginesatide-induced erythropoiesis following an intravenous dose of 2.1 mg/kg was characterized by an initial increase in reticulocytes and a subsequent time-dependent increase in RBCs (Figure 3). Twenty-one days following administration of radiolabeled peginesatide, there was an increase in RBCs of \(1.73 \times 10^6/\mu\text{L}\). The kinetics of the erythropoietic response, including magnitude of response, following administration of unlabeled 2 mg/kg peginesatide was similar to that obtained with radiolabeled material. Specifically, there was an increase in RBCs of \(1.67 \times 10^6/\mu\text{L}\) 21 days after the administration of unlabeled peginesatide (Woodburn et al., 2008b). The data support, therefore, that radiolabeling does not interfere with the pharmacologic activity of peginesatide.

**Pharmacokinetics**

Plasma concentrations of peginesatide were sustained for at least 72 hours post-dose following a single IV dose at 0.1 mg/kg, at least 168 hours post-dose at 0.5 mg/kg, and for at least 504 hours post-dose at 5 mg/kg (Figure 4). The PK parameters are provided in Table 1. The \(C_{\text{max}}\) values increased in a roughly dose-proportional manner between the doses of 0.1 and 5 mg/kg, while the increase in AUC\(_{0-\infty}\) was greater than dose-proportional. Following a 5-fold increase in dose from 0.1 to 0.5 mg/kg, there was
an approximately 8- to 9-fold increase in AUC. Following a 10-fold increase in dose from 0.5 to 5 mg/kg, there was an approximately 19- to 21-fold increase in AUC.

The clearance (CL) was typically low, was decreased from 1.22 to 0.435 mL/h/kg across the dose range of 0.1 to 5 mg/kg, and was only a fraction of the estimated monkey glomerular filtration rate (GFR) of 125 mL/h/kg (Davies & Morris, 1993). The half-life (t½) of peginesatide, consequently, increased as a function of dose. The volume of distribution (Vss), which was low and apparently independent of dose, ranged from 32.0 to 41.4 mL/kg over 0.1 to 5 mg/kg and approximated the plasma volume of 44.8 mL/kg described for monkeys (Davies & Morris, 1993). The volume of distribution, therefore, suggests that peginesatide is generally confined to the vascular compartment. Because the kinetics of peginesatide are non-linear, in the absence of any further data, CL values may have been in flux over the time course of the study (i.e., CL low at earlier time points characterized by high plasma concentrations and higher at later time points characterized by lower plasma concentrations of peginesatide). The CL values, therefore, may represent time- and concentration-dependent averaged values.

The plasma PK of [14C]peginesatide was evaluated in an excretion study and a QWBA study in male Cynomolgus monkeys following a single IV administration of 5 or 2.1 mg/kg, respectively. The PK parameters, including measured Cmax (i.e., measured at the first sampling time point), AUC, t½, CL, and Vss, for unlabeled peginesatide as determined by ELISA analysis were similar to the kinetics derived via quantitative radiometric (HPLC fractionation) profiling at a dose of 5 mg/kg (Table 1). The measured
C\textsubscript{max}, AUC, CL, and t\textsubscript{1/2} obtained in the QWBA study at 2.1 mg/kg (data not shown) were similar to the toxicokinetic values obtained at a dose of 2 mg/kg administered in a 9-month toxicology study in monkeys (Woodburn et al., 2008b). The data indicate that radiolabeling peginesatide does not alter the PK profile of the molecule and that the analytical methods yield comparable results at a given dose level.

The PK in the QWBA monkeys was characterized in both blood and plasma. Regardless of the biological matrix, clearance was low (0.885 and 0.520 mL/kg/h for blood and plasma, respectively) and half-life was prolonged (approximately 70 hours in blood or plasma). At all PK time points, radioactivity concentration was greater in plasma than blood. The blood to plasma ratios ranged from 0.466 to 0.622, indicating minimal association with blood cells and demonstrating that the majority of [\textsuperscript{14}C]peginesatide was confined to the plasma compartment.

**Quantitative Whole Body Autoradiography study-Tissue Distribution**

Representative whole-body autoradiograms from male Cynomolgus monkeys at 48 hours, 1 week, and 3 weeks post-dose following a single IV administration of [\textsuperscript{14}C]peginesatide at 2.1 mg/kg are depicted in Figure 5. Drug-derived radioactivity was widely distributed at 48 hours post-dose throughout the tissues with the exception of the central nervous system (CNS) separated from the vasculature by the blood-brain barrier. Tissue distribution, however, was slow as evidenced by tissue:plasma ratios generally < 1 through at least 48 to 72 hours post-dose. Based on the sustained blood and plasma levels
of $[^{14}\text{C}]$peginesatide ($t_{1/2}$ of approximately 70 hours), the tissue distribution demonstrated by QWBA analysis at 48 hours is considered likely to reflect the presence of drug within the vascular/lymphatic space of the individual tissues (e.g., confinement of radiolabel to the vascular compartment). Accumulation of radioactivity (tissue concentrations higher than blood) in spleen, lymph node, bone marrow, adrenal gland, and pituitary gland was observed 1 week following administration. Persistently high levels of radioactivity were also observed in the urine through 1 week following administration, supporting renal clearance as a major route of excretion (Table 2).

The highest concentrations of tissue radioactivity or measured $C_{\text{max}}$ (i.e., measured values at $\geq$ 48 hours ranging from approximately 6.5 to 29 $\mu$g equiv/g) were found, based on rank order from highest to lowest, to occur in the red pulp of the spleen, blood, lung, renal medulla, adrenal medulla and capsule, and the highly vascularized nasal turbinates. Tissues with the lowest exposure (i.e., $C_{\text{max}}$ at 48 hours < 1.0 $\mu$g equiv/g) included bone, skeletal muscle, small intestine contents, brain, and spinal cord. Concentrations in urine/bladder were notably higher than bile or intestinal contents at each time point throughout the study supporting renal excretion as a primary route of elimination.

At 1 week post-dose, the concentrations of radioactivity were decreasing in the majority of the tissues except in the spleen, lymph node, bone marrow, and adrenal gland. In these tissues, radioactivity concentrations were increasing, which suggested partitioning of peginesatide. Concentrations of radioactivity increased through 3 weeks for the spleen and lymph node and pronounced levels persisted in the bone marrow and adrenal gland.
The bone marrow had sustained levels that remained fairly constant throughout the study ranging from 2.32 to 4.93 µg equiv/g, although values appeared to be decreasing by the final time point in the study at 3 weeks post-dose.

Elimination of the radioactivity was not complete by the end of the study, but tissue concentrations had generally declined at 3 weeks with the levels in most tissues < 1 µg equiv/g of tissue. The exceptions were the spleen, lymph node, bone marrow, adrenal gland, and pituitary gland. The radioactivity levels in the spleen and lymph nodes remained increased compared to 48 hours but were similar for Week 1 vs. Week 3. The radioactivity levels in the bone marrow, adrenal gland, and pituitary gland were approximately 53%, 36%, and 56% lower, respectively, at Week 3 compared to Week 1.

**Microautoradiography**

Microautoradiography analyses at 48 hours post-dose revealed uniform distribution of radioactivity in the bone marrow and liver. Radioactivity within the bone marrow extracted from the femur was uniform and relatively high (**Figure 6a**). There was no obvious cell-associated accumulation of radioactivity. Bone matrix did not contain radioactivity (not shown). Moderate distribution of radioactivity was seen throughout the marrow cells of the sternum. Similarly, the radioactivity in the liver (**Figure 6d**) and thymus (not shown) was scattered and light.
Microautoradiography demonstrated differential distribution in the spleen and, to a lesser extent, the lymph nodes. A notable differential distribution was observed between red and white pulp of the spleen (Figure 6b). The MARG results are consistent with the QWBA data (Table 2) that yielded red pulp:white pulp ratios of 2.56, 7.8, and 4.94 to 1 at 48 hours and 1 and 3 weeks, respectively. Radioactivity was diffusely distributed in the axillary and mesenteric lymph nodes, with only a slight accumulation at the blood/lymphatic vessels and no cell specific localization (Figure 6c).

In the kidney, comparable distribution was noted across the glomeruli, proximal and distal convoluted tubules, and collecting ducts, blood vessels, and interstitial cells of the renal cortex (Figure 7a). In the medulla, however, radioactivity was more obvious in the interstitium. There was less association of radioactivity with the lumen of the ducts compared to cells in the interstitium (Figure 7b). Similarly, radioactivity in the papilla was associated primarily with cells in the interstitium, while little was seen in the collecting ducts (Figure 7c).

Excretion

The major route of drug excretion following IV administration of 5 mg/kg [14C]peginesatide was in the urine with lesser amounts excreted in the feces. By 24 hours after administration [14C]peginesatide, the excretion ratios for urine and feces were 12.4 ± 2.4% and 0.2 ± 0.2% of the radioactive dose, respectively. The ratios of the radioactive dose excreted into the urine and feces at 96 hours after dosing were 34.3 ± 4.6% and 2.2 ± 1.6%, respectively. Excretion was not complete by 14 days.
post-dose with approximately 67% of the total radioactive dose excreted by the end of the collection period. Of the total radioactivity excreted by the end of the collections, approximately 60% was excreted in the urine and approximately 7% in the feces. Of the excreted radioactivity, a large proportion (approximately 34% of the radioactive dose) was excreted in the urine during the first 96 hours post-dose. During the remainder of the study (i.e., 96–366 hours post-dose), the total daily radioactivity excretion ranged from 1.5% to 5.6% of the administered dose. The extent of excretion and recovery of the dose administered are depicted in **Figure 8 and Table 3**.

**Plasma, Urine and Fecal Metabolite Profiles**

Quantitative metabolite profiling was performed using pooled plasma, urine, or fecal samples. The plasma concentration versus time profile is depicted in **Figure 9**. Peginesatide was the major component in plasma. At 0.25 hours post-dose, the plasma content of the parent and mono-PEG was essentially the same as the dose formulation. Specifically, peginesatide and mono-PEG accounted for approximately 90% and 10% of the total radioactivity, respectively, in both plasma and dose formulation. By 168 hours (Day 7) post-dose, [14C] peginesatide represented over 90% of the total radiolabel in the plasma. At 336 hours (Day 14), [14C] peginesatide remained the only major circulating drug-related component in plasma, with an 14C-AUC for the parent molecule accounting for 87.1% of the total 14C-AUC (**Table 4**). The disappearance of mono-PEG from plasma appeared to be faster than peginesatide, resulting in a relative exposure of 5.4% of total 14C-AUC and a half-life of 34.7 hours (**Table 4**). The rate of elimination of mono-PEG
vs. peginesatide provides further support that the mono-PEG in plasma comes from the impurity in the radiolabeled preparation, rather than being formed in vivo.

The major moiety in urine was also the parent molecule, peginesatide (Table 3). The cumulative recovery of radioactivity (i.e., at 336 hours post-dose) in the urine associated with peginesatide, mono-PEG, and unidentified components was 42.6%, 15.9%, and 1.2%, respectively, of the total radioactive dose. The urinary radioactivity of peginesatide, mono-PEG, and unidentified components comprised 71.4%, 26.6%, and 2.0%, respectively, of the cumulative excreted radioactive dose. The recovery of peginesatide and mono-PEG in the feces was below the limit of quantification (BLQ). Unidentified components (Other) represented 7% of the administered radioactive dose or 100 % of the fecal radioactivity.
Discussion

Erythropoietic activity of the dimeric peptide portion of peginesatide, discovered by screening against human EPOr (Fan et al., 2006), was enhanced by PEGylation with a 40 kDa branched PEG. PEGylation improves the PK of protein and peptide therapeutics by reducing renal clearance and protecting the molecule from enzymatic proteolysis or antibody neutralization (Calcieti & Veronese, 2003; Harris and Chess, 2003). Enhanced erythropoietic activity of PEGylated dimeric peptide (i.e., peginesatide) is considered largely a function of prolonged peginesatide plasma levels (Green et al., 2011).

Peginesatide plasma PK in monkeys demonstrated a profile consistent with concentration-dependent processes, exhibiting a Michaelis-Menten type saturable elimination. Population PK modeling, based on doses of 0.02 to 0.21 mg/kg, indicated that peginesatide kinetics in humans is also characterized by Michaelis-Menten elimination. The near dose-proportional increase in C\text{max} in monkeys suggests a dose-independent initial volume of distribution. A greater than dose-proportional increase in AUC (i.e., 143-fold increase) was related to reduced plasma clearance and increased half-life with increasing dose from 0.1 to 5 mg/kg (i.e., a 50-fold increase).

A V\text{ss} in the monkey approximating plasma volume (44.8 mL/kg, Davies and Morris, 1993) suggests peginesatide is generally confined to the vascular compartment. The initial widespread tissue radioactivity in the biodistribution study is considered primarily due to peginesatide-associated radiolabel confined to the vascular space. Based on size, peginesatide would not readily cross the tight inter-endothelial junctions and complete
basement membrane of the vasculature that results in a relatively effective barrier to molecules > 2 kDa (Porter et al., 2001).

A similar peginesatide PK profile was observed across species (i.e., mouse, rat, and monkey) following a single IV dose (Woodburn et al., 2011; Woodburn et al., 2012). Regardless of species, peginesatide plasma elimination was generally biphasic with a relatively rapid initial phase and prolonged elimination phase; CL was typically slow and less than the GFR; and $V_{ss}$ was low often approximating plasma volume. A generally dose-related decrease in clearance and increase in half-life generally translated into nonlinear kinetics. Half-life in the mouse at 0.1 to 10 mg/kg ranged from approximately 14 to 51 hours (Woodburn et al., 2011) and in rats at 0.1 to 5 mg/kg from approximately 18 to 32 hours (Woodburn et al., 2012).

A dose-dependent effect on clearance has also been reported for rHuEPO (Woo et al., 2007), with ESA clearance attributed to multiple mechanisms, both saturable and nonsaturable (Agoram et al., 2009). Nonsaturable clearance mechanisms may involve renal glomerular filtration (Kato et al., 1997). Peginesatide clearance via renal glomerular filtration is consistent with the excretion data in normal animals and the decrease in clearance of approximately 57% for 5/6 nephrectomized rats (Fan et al., 2006). Most of the excreted urine radioactivity in the monkey was associated with parent compound. Although branched PEG clearance may be facilitated by slow release of one of the two PEG lysine linked chains on the carbamate bond between the PEG chains and the linker
(Guiotto et al., 2004), the monkey data do not support that there is a similar degradation of peginesatide.

The nonlinear kinetics of rHuEPO has been attributed to saturable receptor-mediated endocytosis (RME) (Woo et al., 2007). Following ESA binding to EPOr, internalization or dissociation of the molecule from the receptor can occur. Once internalized, the ligand may be degraded or recycled intact to the cell surface and released. Peginesatide has been shown to have high affinity for the EPOr (Fan et al., 2006). Internalization, however, has not yet been shown.

Agoram et al. (2008) suggest that non-EPOr mediated pathways, including clearance in the interstitium or lymphatic system, may contribute to elimination and that non-EPOr mediated pathways may play a greater role than RME for hyperglycosylated and PEGylated ESAs. A 30 kDa PEGylated epoetin beta (Mircera®) does not appear to be internalized when incubated with EPO receptor bearing UT-7 cells, unlike epoietin beta (EMEA, 2010). The findings are consistent with the literature suggesting that PEGylation may lower RME (Webster et al., 2007) due to lower receptor affinity. A 64% decrease in clearance associated with a 50-fold increase in peginesatide was observed dose at higher doses in the normal monkey and may reflect saturation of receptor and non-receptor mediated mechanisms. The decrease in peginesatide clearance in the rat renal failure model may reflect saturation of receptor and non-receptor mediated mechanisms to a greater or lesser extent, in addition to decreased GFR.
Monkey distribution data should be interpreted and extrapolated to humans within the context of dose differences. While a 0.1 mg/kg dose in the monkey is 2.5-fold higher than the human starting dose of 0.04 mg/kg administered every 4 weeks, the 5 mg/kg dose is 125-fold higher than the human starting dose. The nonclinical doses were selected to obtain a recommended targeted radioactive dose of 16 to 300 µCi/kg (Solon, 2007) and based on the achievable specific activity of [14C]peginesatide. Administration of lower clinically relevant doses would not have delivered adequate radioactivity for the determination of tissue distribution using both QWBA and MARG analyses.

Radioactivity concentrations were decreasing in most tissues in the monkey at 1 week post-dose. The increased radioactivity concentration in spleen, lymph node, bone marrow, adrenal gland, and urine suggests a partitioning of peginesatide into these tissues or increased excretion (urine). The relatively high peginesatide-associated radioactivity levels in the lymphatic tissues may reflect the uptake or removal of the macromolecule, transport to the draining lymph nodes, and the potential processing and/or degradation of the molecule (Porter et al. 2001).

The ability to collect potentially meaningful quantitative tissue distribution data with peginesatide is in contrast to approved protein based ESAs. Radiolabeling of proteins, such as rHuEPO and darbepoetin alfa, with iodine-125 can lead to results confounded by label instability with cleavage and uptake of free label into various tissues by transporters (Solon, 2012). For peginesatide, 14C can be used to radiolabel the lysine linker between the peptide dimer and the two 20 kDa PEG chains.
Peginesatide biodistribution data may potentially provide insight into the biodistribution of ESAs and perhaps even EPOr sites. The data suggest that peginesatide is localized to known EPOr sites (bone marrow), sites that may have functional EPOr (e.g. splenic red pulp), and putative EPOr sites such as the renal medulla and papilla (Westenfelder et al. 1999). There is considerable controversy, however, with respect to not only EPOr distribution, but whether the EPOr is functional if expressed on cells other than hematopoietic progenitor cells.

The bone marrow is the primary hematopoietic site in monkeys. Unlike rodents, in which notable EMH occurs throughout the animal’s lifespan, EMH does not normally occur in nonhuman and human primates. (Greaves and Faccini, 1992; O’Malley et al. 2005). Furthermore, unlike rodents (Woodburn et al., 2009), EMH has not been shown to occur in monkeys administered peginesatide up to 20 mg/kg IV every 3 weeks for 9 months (Woodburn et al., 2008a and b). Under certain pathological conditions and in response to certain biological modifiers, EMH has been shown to occur in the spleen, lymph node, thymus, adrenal gland, pituitary, and kidney of monkeys (Okasaki et al., 2002; Starost et al., 2004; Welte et al., 1987) and in the spleen of humans (O’Malley et al., 2005). The EMH in rodents and, under certain conditions in primates, may involve the erythroid lineage, which suggests that EPOr occurs at these sites and may be or may become functional. The peginesatide data suggest that although drug may bind to splenic EPOr, the receptor was not functional, under the conditions of the study, since no erythropoietic effect was noted in the monkeys.
Following IV administration of peginesatide, the pronounced, sustained erythropoietic response increased with increasing dose and exposure across animal species and in normal healthy volunteers (Fan et al., 2006; Stead et al., 2006). A pharmacologically active IV peginesatide dose of 0.1 mg/kg resulted in an average maximum change in baseline Hgb of 1.36 g/dL in normal healthy volunteers (Stead et al., 2006) and of 1.4 g/dL in monkeys. The apparently more pronounced effect in rodents likely reflects the robust peginesatide-associated EMH response in the spleen and liver.

A greater erythropoietic response in 5/6 nephrectomized rats compared to normal animals is likely due to at least two factors, including altered PK (i.e., a 2-fold slower clearance and higher exposures) in the nephrectomized and diminished activity in nephrectomized rats of the negative feedback controls on erythropoiesis that would come into play following administration of peginesatide to normal animals (Fan et al., 2006). The nephrectomized rat findings are consistent with data in clinical trials of peginesatide showing an enhanced pharmacological response, decreased CL, and an increase in half-life in CRF patients compared to normal healthy volunteers.

The ADME and pharmacology of peginesatide have been extensively evaluated in monkeys. The similarity in PK and pharmacology parameters for monkeys and humans suggests that the monkey data can be extrapolated to humans and that the monkey is an appropriate species for evaluating peginesatide effects. The robust, sustained erythropoietic response in monkeys is consistent with the clinical data demonstrating that once monthly dosing of peginesatide maintains hemoglobin in dialysis patients.
DMD #48033

Authorship Contributions

Participated in research design: Woodburn, Tagawa, Moriya, Sloneker, Fong, and Wilson

Conducted experiments: Tagawa, Moriya, Sloneker, Solon, and Strzemienski

Performed data analysis: Woodburn, Tagawa, Moriya, Sloneker, Fong, Solon, Strzemienski

Wrote or contributed to the writing of the manuscript: Woodburn, Tagawa, Moriya, Sloneker, Fong, and Wilson
References


EMEA (European Medicines Agency) European Public Assessment Report (EPAR): MIRCERA- EPAR Summary for the Public Revision 7- Published 11/05/10


Footnotes

The work was supported by Affymax, Inc., and Takeda Pharmaceutical Company Ltd.
Figure Legends

Figure 1. Sites of radiolabel for [14C]peginesatide.

Figure 2: Time course for changes in percent reticulocytes and red blood cells (RBCs) increases, from predose levels, in Cynomolgus monkeys administered a single IV dose of peginesatide. Each point represents the mean ± standard deviation of 4 animals. Statistically significant (#, p<0.05; ##, p<0.01) when compared to the concurrent control group (0 mg/kg).

Figure 3. Mean percent reticulocytes and RBC counts ± SE following IV dosing in monkeys at 2.1 mg/kg [14C]peginesatide. Pre-dose and Day 2 data points represent 4 animals, Days 5 and 7 data points represent 2 animals, and Days 14 and 21 data points represent 1 animal.

Figure 4. Mean concentration of peginesatide in the plasma of male monkeys after single IV administration. Each point represents the mean ± standard deviation of 4 animals.

Figure 5: Whole-body autoradiograms of male Cynomolgus monkeys at 48 hours, 1 week, and 3 weeks following a single IV administration of [14C]peginesatide at 2.1 mg/kg.

Figure 6. Microautoradiographs of bone marrow (a), spleen (b), lymph node (c), and liver (d) from a male Cynomolgus monkey 48 hours post IV dosing with [14C]peginesatide at 2.1 mg/kg. BM = bone marrow cells; BV = blood vessel; RP = red pulp; C = cortical region; M = medullary region; KC = Kupffer cell. [14C]peginesatide associated biodistribution is represented by the dark brown granules overlaid on H&E staining.
Figure 7. Microautoradiographs of kidney sections from a male Cynomolgus monkey 48 hours post IV dosing with [14C]peginesatide at 2.1 mg/kg. G = glomerulus; P = proximal convoluted tubule; D = distal convoluted tubule; C = collecting duct; BV = blood vessel. [14C]peginesatide associated biodistribution is represented by the dark brown granules overlaid on H&E staining.

Figure 8. Cumulative recovery of [14C]peginesatide related radioactivity in urine and feces of male monkeys following IV administration at 5 mg/kg. Each value represents the mean ± SD for 4 animals.

Figure 9. Plasma Concentration versus time profile for total 14C-radioactivity, [14C]peginesatide and [14C]mono-PEG in monkey plasma following a single IV administration of 5 mg/kg [14C]peginesatide.
Tables

**Table 1.** Plasma pharmacokinetic parameters of peginesatide in male Cynomolgus monkeys after IV administration

<table>
<thead>
<tr>
<th>Dose (mg/kg)</th>
<th>Cmax † (μg/mL)</th>
<th>t1/2 (h)</th>
<th>AUC0-inf (μg·h/mL)</th>
<th>CL (mL/h/kg)</th>
<th>Vss mL/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>2.94 ± 0.30</td>
<td>19.0 ± 2.0</td>
<td>82.9 ± 11.8</td>
<td>1.22 ± 0.16</td>
<td>32.0 ± 2.3</td>
</tr>
<tr>
<td>0.5</td>
<td>13.2 ± 1.04</td>
<td>34.0 ± 5.9</td>
<td>646.2 ± 104</td>
<td>0.79 ± 0.13</td>
<td>37.9 ± 4.1</td>
</tr>
<tr>
<td>5</td>
<td>121 ± 15.6</td>
<td>99.0 ± 37.1</td>
<td>11892 ± 2372</td>
<td>0.435 ± 0.097</td>
<td>41.4 ± 5.7</td>
</tr>
<tr>
<td>5 [¹⁴C]−</td>
<td>140 ± 10.2</td>
<td>84.0 ± 9.56</td>
<td>11438 ± 1322</td>
<td>0.441 ± 0.46</td>
<td>47.6 ± 3.17</td>
</tr>
</tbody>
</table>

† Cmax was designated as the measured value at the earliest sampling time point of 0.25 hours post-dose.

Data represent mean ± SD values; n=4.
Table 2. Radioactivity tissue concentrations greater than blood at 48 hours, 1 week, and 3 weeks after IV administration of 2.1 mg/kg [\(^{14}\text{C}\)]peginesatide in monkeys

<table>
<thead>
<tr>
<th>Tissue</th>
<th>48 hour Value (µg equiv/g)</th>
<th>1 week Value (µg equiv/g)</th>
<th>3 week Value (µg equiv/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood</td>
<td>11.0</td>
<td>3.87</td>
<td>BLQ</td>
</tr>
<tr>
<td>Adrenal gland (capsule)</td>
<td>6.68</td>
<td>6.04</td>
<td>3.84</td>
</tr>
<tr>
<td>Adrenal gland (medulla)</td>
<td>7.06</td>
<td>3.23</td>
<td>2.06</td>
</tr>
<tr>
<td>Pituitary gland</td>
<td>3.69</td>
<td>4.75</td>
<td>2.07</td>
</tr>
<tr>
<td>Bone marrow</td>
<td>3.22</td>
<td>4.93</td>
<td>2.32</td>
</tr>
<tr>
<td>Lymph node</td>
<td>2.64</td>
<td>3.90</td>
<td>4.52</td>
</tr>
<tr>
<td>Spleen, red pulp</td>
<td>7.77</td>
<td>29.1</td>
<td>23.4</td>
</tr>
<tr>
<td>Spleen, white pulp</td>
<td>3.04</td>
<td>3.71</td>
<td>4.74</td>
</tr>
<tr>
<td>Kidney (medulla)</td>
<td>7.96</td>
<td>3.17</td>
<td>0.622</td>
</tr>
<tr>
<td>Lung</td>
<td>9.60</td>
<td>2.66</td>
<td>0.264</td>
</tr>
<tr>
<td>Nasal turbinates</td>
<td>6.50</td>
<td>2.10</td>
<td>0.728</td>
</tr>
<tr>
<td>Urinary bladder (contents)</td>
<td>4.09</td>
<td>4.98</td>
<td>0.233</td>
</tr>
<tr>
<td>Bile</td>
<td>1.67</td>
<td>0.632</td>
<td>BLQ</td>
</tr>
<tr>
<td>Large intestine (contents)</td>
<td>1.81</td>
<td>0.365</td>
<td>BLQ</td>
</tr>
<tr>
<td>Small intestine (contents)</td>
<td>0.166</td>
<td>BLQ</td>
<td>BLQ</td>
</tr>
</tbody>
</table>

BLQ: below the lower limit of quantification; (i.e. 0.106 µg equiv/g of tissue).
Table 3. Percent dose excretion of [14C]peginesatide and associated radioactivity in monkey urine and feces after single IV administration of 5 mg/kg

<table>
<thead>
<tr>
<th>Compound</th>
<th>Urine</th>
<th>Feces</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-168 h</td>
<td>168-336 h</td>
</tr>
<tr>
<td>Total Radioactivity</td>
<td>47.7 (100)</td>
<td>12.0 (100)</td>
</tr>
<tr>
<td>Peginesatide</td>
<td>35.2 (70.8)</td>
<td>7.4 (61.7)</td>
</tr>
<tr>
<td>Mono-PEG</td>
<td>12.1 (28.3)</td>
<td>3.8 (31.7)</td>
</tr>
<tr>
<td>Other</td>
<td>0.4 (0.9)</td>
<td>0.8 (6.6)</td>
</tr>
</tbody>
</table>

Values in parentheses represent percent radioactivity for a given matrix at the specified time interval.

N=3. Dosing solution contained approximately 10% mono-PEG. BLQ: Below the lower limit of quantitation.
Table 4. Pharmacokinetic parameters of peginesatide and related compounds following a single IV dose of 5 mg/kg [14C]peginesatide to Cynomolgus monkeys

<table>
<thead>
<tr>
<th>Compound</th>
<th>C&lt;sub&gt;max&lt;/sub&gt; (µg equiv./mL)</th>
<th>AUC&lt;sub&gt;0-336 h&lt;/sub&gt; (µg equiv.·h/mL)</th>
<th>CL (mL/h/kg)</th>
<th>t&lt;sub&gt;1/2&lt;/sub&gt; (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total radioactivity</td>
<td>140</td>
<td>11,005 (100)</td>
<td>0.43</td>
<td>65.1</td>
</tr>
<tr>
<td>Peginesatide</td>
<td>118</td>
<td>9580 (87.1)</td>
<td>0.436</td>
<td>64.3</td>
</tr>
<tr>
<td>Mono-PEG</td>
<td>16.4</td>
<td>596 (5.4)</td>
<td>1.05</td>
<td>34.7</td>
</tr>
<tr>
<td>Other</td>
<td>ND</td>
<td>829 (7.5)</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND: not detected
Figure 1

2 x 21mer Cyclic peptide

Linker

PEG 2 x 20 kDa
Figure 3

The graph illustrates the change in reticulocytes (%) and RBCs ($10^6/\mu$L) over time post administration.

- **Reticulocytes (%)**:
  - Increases sharply from day 0 to day 6, peaking around day 8.
  - Thereafter, it decreases gradually.

- **RBCs ($10^6/\mu$L)**:
  - Starts at a lower level and increases to a peak around day 14.
  - Afterward, it decreases linearly.

The data points indicate a significant rise in reticulocytes followed by a gradual decline, while RBCs show an initial rise with a subsequent decrease.
Figure 8

![Graph showing the percent of dose against time after dosage (days). The graph includes data for urine, feces, and total dosage.](image-url)
Figure 9

- Total $^{14}$C-radioactivity
- $[^{14}\text{C} \text{peginesatide}}$
- $[^{14}\text{C} \text{mono-PEG}}$

Concentration (µg/mL) vs. Time after dosage (days)