Pharmacokinetics of Sodium Tungstate in Rat and Dog: A Population Approach

SOPHIE LE LAMER, PATRICK POUCHERET, GÉRARD CROS, RENAUD KIESGEN DE RICHTER, PIERRE-ANTOINE BONNET, and FRANÇOISE BRESSOLLE

Laboratoire de Pharmacocinétique Clinique (S.L.L., F.B.) and Laboratoire de Pharmacologie (P.P., G.C.), Faculté de Pharmacie, Montpellier, France; and Agence Française de Sécurité Sanitaire des Produits de Santé (R.K.d.R., P.-A.B.), Vendargues, France

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ABSTRACT

Sodium tungstate has been found to correct hyperglycemia in insulin- and noninsulin-dependent models of diabetes when administered in drinking fluid with a low degree of toxicity; thus, it provides a potential treatment for diabetes. In the present report, pharmacokinetic studies with sodium tungstate were carried out in the Sprague-Dawley rat and beagle dog. This drug was administered either i.v. (8.97 mg/kg in rat; 25 and 50 mg/kg in dog) or orally in the form of solution (35.9 and 107.7 mg/kg in rat; 25 and 50 mg/kg in dog). Tungsten was quantified using an inductively coupled plasma method. Pharmacokinetic parameters were estimated using a population approach. Sodium tungstate followed first order kinetics, and plasma concentration-versus-time data were adequately described by a two-compartment model. In rat, bioavailability was high (92%), whereas it was lower in dog (approximately 65%). The total volume of distribution expressed by unit of body weight was much higher when the animal was smaller (0.46 l/kg in rat versus 0.23 l/kg in dog). The total body clearance normalized by weight, 0.19 l/h/kg in rat versus 0.043 l/h/kg in dog, changed as for the volume of distribution. The elimination half-life was two times higher in dog (approximately 4 h) than in rat (approximately 1.7 h). In the range of 35.9 to 107.7 mg/kg after oral administration in rat and 25 to 50 mg/kg after oral and i.v. administration in dog, tungsten plasma concentrations increased in proportion to dose.

Transition metal derivatives have recently been found to possess antidiabetic activity. Vanadate was first described as able to lower blood glucose in insulin-deficient rats (Heyliger et al., 1988) and in animal models of insulin resistance (Briachard et al., 1989). However, vanadate treatment was associated with significant side effects, including digestive troubles, which might be explained by its low bioavailability (10–20%). The antidiabetic activities of other transition metal derivatives such as chromium, molybdate, or selenate (Fillat et al., 1992; Battell et al., 1998; Anderson, 2000) have also been demonstrated. However, their toxicity decreases their interest for clinical use. Recently, sodium tungstate was found to correct hyperglycemia in insulin- and noninsulin-dependent models of diabetes when administered at a dosage of 169 to 418 mg/kg/day in drinking fluid for 15 days with low degree of toxicity (Barbera et al., 1994, 1997) and should be tested clinically. A biokinetic model for systemic tungsten in humans was recently published by Leggett (1997). This model is based on experimental data on the biokinetics of radiotungsten in laboratory animals and information on the kinetics of molybdenum or other physiological analogs of tungsten in humans and laboratory animals. An elimination half-life ($t_{1/2}$ elim) of 12 to 14 h was reported by Mason et al. (1989) in sheep. Experimental results concerning the distribution of tungsten between plasma and red blood cells (RBCs) have been published. In beagle dogs receiving $^{185}$W as sodium tungstate, the ratio of concentration plasma to RBCs was approximately 3 during the first 24 h (Aamodt, 1973). Higher RBC-to-plasma ratios for radiotungsten have been determined in rodents than in larger animals (Kaye, 1968). In rats and mice, RBC-to-plasma ratios of approximately 9 and 14 were found at 3 to 4 days after administration. In sheep, $^{185}$W tungstate was not protein bound (Mason et al., 1989).

This study was conducted to determine the pharmacokinetic profile of sodium tungstate after i.v. and oral administration in two different species: rat and dog. Individual pharmacokinetic parameters were estimated using an empirical approach.

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ABBREVIATIONS: $t_{1/2}$ elim, elimination half-life; RBC, red blood cell; E step, expectation step; M step, maximization step; CL, total clearance; V, initial volume of distribution; $V_{ss}$, steady-state volume of distribution; $k_{21}$, $k_{12}$, transfer rate constants; $k_{el}$, elimination rate constant; $k_{a}$, absorption rate constant; $t_{lag}$, lag time; $F$, bioavailability; $C_{exp}$, observed concentrations; $C_{obs}$, expected concentrations; SCPE, standardized concentrations; $C_{max}$, maximum plasma concentration; $t_{max}$, time of $C_{max}$; $C_{0}$, observed concentrations; SCPE, standardized concentrations; prediction error; CV, coefficient of variation.
Bayes’ methodology. The linearity of the kinetics was also investigated for different doses administered i.v. or orally. Our results indicate that after oral administration of 35.9 to 107.7 mg/kg sodium tungstate in rat and after oral and i.v. administration of 25 to 50 mg/kg sodium tungstate in dog, tungsten plasma concentrations increased in proportion to dose and that the bioavailability of sodium tungstate was relatively high (65% in dog and 92% in rat).

Materials and Methods

Compound. Sodium tungstate was obtained from Carlo Erba (Val de Reuil, France). Tungsten as the sodium salt was administered to animals in an aqueous solution containing 0.9% sodium chloride for the i.v. route and in distilled water for the oral route.

Animals. This study was conducted in male Sprague-Dawley rats and in male beagle dogs.

Rats. Two hundred sixteen Sprague-Dawley rats weighing 316 to 532 g (IFFA CREDO, L’Arbresle Cedex, France) at age 10 weeks were used (one animal per time point). Animals underwent an acclimatization of a minimum of 2 weeks before treatment. They were group housed in stainless steel cages with suspended wire-mesh floors (maximum of three rats per cage). The rats were fed a standard laboratory rodent diet (UAR sterile feed, Usine d’Alimentation Rationnelle, Villemoisson, Epinay s/Orge, France) and allowed free access to drinking water. Rats were fasted overnight (12 h) before drug administration and then weighed.

Dogs. Six male beagle dogs (Harlan, Grannat, France) weighing 11.5 ± 0.24 kg were housed individually during the study in metabolism stainless steel cages with access to pelleted food (400 g/day/animal; Usine d’Alimentation Rationnelle). Tap water was distributed ad libitum. The animals underwent an acclimatization period of 10 days before the experiment.

For all animals, the housing rooms had controlled environmental conditions with temperature and relative humidity of approximately 18–21°C and 40 to 70%, respectively, and artificial lighting, alternating on a 12-h light/dark cycle.

Drug Administration. Single i.v. (8.97 mg/kg) and oral (35.9 and 107.7 mg/kg) doses of sodium tungstate were administered to each rat. For which, three different solutions of sodium tungstate were prepared on the day of administration: one solution in 0.9% sterile isotonic saline (4.5 mg/ml) for i.v. administration and two solutions in distilled water (3.6 and 10.8 mg/ml) for oral administration. These solutions were used to treat animals, under the administered volume of 2 ml/kg (i.v.) and 10 ml/kg (oral).

Dogs received four different treatments: two i.v. doses (25 and 50 mg/kg) and two oral doses (25 and 50 mg/kg) of sodium tungstate. The vehicles used were 0.9% sterile isotonic saline (0.1 ml/kg b.wt.) for i.v. administration and double distilled water (1 ml/kg b.wt.) for oral administration.

For i.v. administration, the dose was administered over 1 min into the tail vein in the rat and the cephalic vein in the dog. For oral administrations, the drug was given by gavage through stomach tubing using a polypropylene catheter.

Blood Sampling. In rat, blood samples were collected (one sample per rat) at the following time points (six animals per time point): 5, 10, 15, and 30 min and 1, 2, 4, 8, 12, 16, and 24 h after drug administration. Untreated animals were used for basal tungsten level determination. Two minutes before sampling, rats were anesthetized with diethylether and then sacrificed by section of the carotid artery. Total blood was collected in heparinized polypropylene tubes (0.1 ml sodium heparinate per tube).

In dog, blood samples (8 ml) were collected from a superficial vein of the forelimbs into polypropylene tubes coated with sodium heparinate before the oral and i.v. doses; after 5, 10, 15, 30, 45, and 60 min and 2, 4, 8, 12, 16, 24, and 36 h for the i.v. route; and after 10, 20, 40, and 60 min and 2, 4, 8, 12, 16, 24, and 36 h for the oral route.

Fig. 1. Mean tungsten plasma concentration-versus-time curve after i.v. (8.97 mg/kg) and oral (35.9 and 107.7 mg/kg) administrations of sodium tungstate in rat.

Table 1. Population pharmacokinetic parameters of sodium tungstate in rat

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Distribution</th>
<th>Mean</th>
<th>CV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL (l/h/kg)</td>
<td>Normal</td>
<td>0.186</td>
<td>27.4</td>
</tr>
<tr>
<td>V (l/kg)</td>
<td>Normal</td>
<td>0.210</td>
<td>30.0</td>
</tr>
<tr>
<td>k12 (h⁻¹)</td>
<td>Normal</td>
<td>1.30</td>
<td>41.9</td>
</tr>
<tr>
<td>k21 (h⁻¹)</td>
<td>Normal</td>
<td>1.51</td>
<td>41.5</td>
</tr>
<tr>
<td>ka (h⁻¹)</td>
<td>Normal</td>
<td>0.36</td>
<td>33.5</td>
</tr>
<tr>
<td>F</td>
<td>Normal</td>
<td>0.92</td>
<td>28.7</td>
</tr>
<tr>
<td>Sigma</td>
<td>Normal</td>
<td>0.235</td>
<td>437.7</td>
</tr>
</tbody>
</table>

ML, maximum likelihood.

The sigma value (random effect) is for all parameters.
Tubes containing blood samples were immediately and gently agitated to prevent coagulation and then centrifuged at 2000 g for 20 min. Plasma was removed, transferred into two polypropylene tubes, and then stored at −20°C until assay.

**Assay Method.** Concentrations were expressed in tungsten metal. Tungsten plasma concentrations were determined using an inductively coupled plasma emission spectrometric method at a wavelength of 207.91 nm (Poucheret et al., 2000). Samples (500 µl) were directly nebulized; each determination was performed in replicate (n = 5). Calibration curves were obtained in the range 134 to 1300 ng/ml. Precision ranged from 0.4 to 17%, and accuracy was between 89 and 105%. Dilution has no influence on the performance of the method, which could then be used to quantify plasma samples containing up to 90 µg/ml. The limit of quantification was 100 ng/ml, it was defined as the lowest drug concentration that can be determined with an accuracy of 100 ± 20% and a relative standard deviation of ±20% on a day-to-day basis. Using quality control samples at this level, the precision averaged 17%.

**Population Pharmacokinetic Analysis.** Individual pharmacokinetic parameters were estimated using an empirical Bayes’ methodology (Sheiner et al., 1972). In this analysis, population characteristics of the parameters to be estimated were used as prior information to estimate each individual pharmacokinetic parameter.

In rat, a preliminary analysis was carried out using the Pk-fit software (version 1.1.4, 1999; RDPP, Montpellier, France), to compute pharmacokinetic parameters from the average concentration values at each time points. Such an analysis allowed us to estimate the initial pharmacokinetic parameters that will be used in the population analysis and to choose the pharmacokinetic model. Individual pharmacokinetic parameters were then determined using a population approach and the baseline-corrected plasma concentrations.

In dog, plasma concentration-versus-time data were first analyzed using a noncompartmental approach (Pk-fit software). Such an analysis allowed us to verify that drug concentration increased in proportion to dose. Then, despite the few number of dogs, the data obtained in each dog from the whole treatment (i.v. plus oral administration) were analyzed using a population approach. Such an analysis 1) avoided a possible bias in the estimation of the t<sub>1/2 elim</sub> Indeed, at low doses, 36 h after administration, tungsten concentrations were below the limit of quantification of the analytical method in the majority of animals, so the t<sub>1/2 elim</sub> could not be estimated with the same accuracy at low and high doses. 2) It allowed us to use the same model after i.v. and oral routes (the distributive phase being poorly detectable after oral administration, so using a classic approach, this phase cannot be accurately fitted). 3) It allowed a better estimation of individual pharmacokinetic parameters, including bioavailability. Moreover, this ap-

![Graphs](https://example.com/graph.png)

**Fig. 2.** Mean tungsten plasma concentration-versus-time curve after i.v. (25 and 50 mg/kg) and oral (25 and 50 mg/kg) administrations of sodium tungstate in dog.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Route</th>
<th>Dose&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>t&lt;sub&gt;1/2 elim&lt;/sub&gt; (h)</td>
<td>i.v.</td>
<td>8.97</td>
<td>1.72</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>35.9</td>
<td>1.68</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>107.7</td>
<td>1.79</td>
<td>0.32</td>
</tr>
<tr>
<td>CL&lt;sup&gt;b&lt;/sup&gt; (l/h/kg)</td>
<td>i.v.</td>
<td>8.97</td>
<td>0.19</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>35.9</td>
<td>0.18</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>107.7</td>
<td>0.19</td>
<td>0.017</td>
</tr>
<tr>
<td>V&lt;sub&gt;p&lt;/sub&gt; (l/kg)</td>
<td>i.v.</td>
<td>8.97</td>
<td>0.21</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>35.9</td>
<td>0.20</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>107.7</td>
<td>0.21</td>
<td>0.016</td>
</tr>
<tr>
<td>V&lt;sub&gt;a&lt;/sub&gt; (l/kg)</td>
<td>i.v.</td>
<td>8.97</td>
<td>0.47</td>
<td>0.114</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>35.9</td>
<td>0.44</td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>107.7</td>
<td>0.47</td>
<td>0.055</td>
</tr>
<tr>
<td>t&lt;sub&gt;1/2 k&lt;sub&gt;a&lt;/sub&gt; (h)</td>
<td>Oral</td>
<td>35.9</td>
<td>1.89</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>107.7</td>
<td>2.05</td>
<td>0.37</td>
</tr>
<tr>
<td>F</td>
<td>Oral</td>
<td>35.9</td>
<td>0.95</td>
<td>0.093</td>
</tr>
<tr>
<td></td>
<td>Oral</td>
<td>107.7</td>
<td>0.88</td>
<td>0.132</td>
</tr>
</tbody>
</table>

<sup>a</sup> Expressed in sodium tungstate.

<sup>b</sup> After oral dosing, CL, V<sub>a</sub>, and V<sub>p</sub> were corrected from bioavailability.
On the basis of the examination of the objective function and of the characterized by a population mean and an interindividual variance. were then assumed to arise from a normal or log-normal distribution the residual distribution showed that the error variance was better heteroscedastic model were considered. For the two species studied, the residual and individual predicted-versus-observed concentration plots objective function (Gomeni et al., 1994). Inspection of weighted re- the fixed, random, and residual error variance parameters between individual parameters are estimated (bayesian estimate) given the the population analysis was performed using the P-PHARM com- ML, maximum likelihood. a The sigma value (random effect) is for all parameters. the plasma concentration-time curve (AUC), and the steady-state value of distribution (\( \bar{V} \)) were calculated as follows:
\[
t_{1/2 \text{ elim}} = \frac{0.693 \times 2}{(k_{12} + k_{21} + k_d) - \sqrt{(k_{12} + k_{21} + k_d)^2 - 4 \times k_{21} \times k_d}}
\]
From this model, the plasma concentration of tungsten at any time can be easily computed using the empirical Bayes' estimate of the pharmacokinetic parameters.

**Consistency Check of Pharmacokinetic Parameter Estimates.** To check the error model assumptions and the distribution on the estimated population pharmacokinetic parameters, P-PHARM estimates the expected concentrations (\( C_{exp} \)) for each individual in the population and computes appropriate statistical tests to evaluate the distribution properties of the differences between the expected and the observed data. For each concentration, a standardized concentration prediction error (SCPE) is calculated as follows:
\[
\text{SCPE} = \frac{C_{obs} - C_{exp}}{\text{S.D.}(C_{exp})}
\]

**Statistical Evaluation.** Results in the text are presented as mean ± S.D. In rat, differences in pharmacokinetic parameters (CL, \( V_d, t_{1/2 \text{ elim}} \)) were compared across the three treatment groups by using the Kruskal-Wallis test (Siegel and Castellan, 1988). The effect of the administered dose (35.9 versus 107.7 mg/kg sodium tungstate) was also assessed by comparing AUC.

In dog, a two-way ANOVA was performed to assess the effect of the administered dose on parameters determined by noncompart- mental approach (i.e., AUC after i.v. administration of 25 and 50 mg/kg sodium tungstate, and \( C_{max} \) and AUC after oral administration of 25 and 50 mg/kg sodium tungstate). Before the statistical analyses, CL, \( V_d, C_{max} \) and AUC were log-transformed; \( C_{max} \) and AUC were normalized to the same administered dose. A 5% level of statistical significance was used.

**Results**

**Pharmacokinetics in Rat.** The mean endogenous tungsten concentration was 137 ng/ml. Semilogarithmic plots of the mean plasma concentration-time curve after i.v. bolus injection of 8.97 mg/kg and oral administrations of 35.9 and 107.7 mg/kg sodium tungstate are shown in Fig. 1. Data were

---

**TABLE 3**

Population pharmacokinetic parameters of sodium tungstate in dog

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Distribution</th>
<th>Mean value</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL (h/lb/kg)</td>
<td>Log-normal</td>
<td>0.0422</td>
<td>27.7</td>
</tr>
<tr>
<td>V (h/lb/kg)</td>
<td>Log-normal</td>
<td>0.171</td>
<td>38.3</td>
</tr>
<tr>
<td>( k_{12} ) (h⁻¹)</td>
<td>Normal</td>
<td>0.407</td>
<td>42.2</td>
</tr>
<tr>
<td>( k_{21} ) (h⁻¹)</td>
<td>Normal</td>
<td>1.44</td>
<td>19.1</td>
</tr>
<tr>
<td>( k_d ) (h⁻¹)</td>
<td>Normal</td>
<td>0.901</td>
<td>30.1</td>
</tr>
<tr>
<td>( t_{lag} ) (h)</td>
<td>Normal</td>
<td>0.053</td>
<td>73.0</td>
</tr>
<tr>
<td>( F )</td>
<td>Normal</td>
<td>0.86</td>
<td>12.1</td>
</tr>
<tr>
<td>Sigma</td>
<td>1.39</td>
<td>107.7</td>
<td></td>
</tr>
<tr>
<td>ML</td>
<td>-841.7</td>
<td>5</td>
<td>841.7</td>
</tr>
</tbody>
</table>

The posterior individual pharmacokinetic parameter estimates were then assessed to arise from a normal or log-normal distribution characterized by a population mean and an interindividual variance. On the basis of the examination of the objective function and of the inspection of weighted residuals and individual predicted-versus-observed concentration plots, results indicate that in rat, for all parameters, the probability distribution of the random effect parameters [\( \sigma(CL) \), \( \sigma(V) \), \( \sigma(k_{12}) \), \( \sigma(k_{21}) \), \( \sigma(k_d) \), \( \sigma(F) \)] was better described by normal distribution. In dog, for CL and V, the probability distribution of the random effect parameters was better described by log-normal rather than normal distribution; for the other parameters (\( k_{12}, k_{21}, k_a, t_{lag} \), and \( F \)), a normal distribution was used.

The \( t_{1/2 \text{ elim}} \) area under the plasma concentration-time curve (AUC), and the steady-state value of distribution (\( \bar{V} \)) were calculated as follows:
\[
t_{1/2 \text{ elim}} = \frac{0.693 \times 2}{(k_{12} + k_{21} + k_d) - \sqrt{(k_{12} + k_{21} + k_d)^2 - 4 \times k_{21} \times k_d}}
\]
consistent with a two-compartment model. Twelve hours after i.v. administration and 24 h after oral administration of 35.9 mg/kg, concentrations returned to baseline value (i.e., 137 ng/ml). After oral administration, absorption was rapid (approximately 2 h).

A total of 176 concentrations were used to compute population parameters (Table 1). From the population characteristics, it can be seen that CL was the parameter that exhibited the lowest coefficient of variation (CV = 27.4%) and $k_{12}$ was the parameter that exhibited the highest (CV = 41.9%). Bioavailability averaged 92%.

From the empirical Bayes’ estimate of the individual pharmacokinetic parameters, mean pharmacokinetic parameters, according to the three treatment groups, are given in Table 2. CL, $V_d$, and $t_{1/2 \text{elim}}$ did not differ statistically between treatments. No significant relationship was found between weight and CL or between weight and $V_d$. AUC averaged 26.5 $\pm$ 2.3 mg/l $\times$ h after i.v. administration of 8.97 mg/kg sodium tungstate and 111.2 $\pm$ 10.1 and 326.9 $\pm$ 31.0 mg/l $\times$ h after oral administration of 35.9 and 107.7 mg/kg sodium tungstate, respectively.

Bioavailability was 95% (CV = 9.5%) after oral administration of 35.9 mg/kg and 88% (CV = 14.8%) after oral administration of 107.7 mg/kg sodium tungstate, respectively. Bioavailability was 66% (57–74%).

**Pharmacokinetics in Dog**. The mean baseline tungsten concentration value was 129 ng/ml. After oral administration, the absorption was rapid ($t_{\text{max}}$, 1–2 h).

Semilogarithmic plots of the plasma concentration-time curve after i.v. bolus injections of 25 and 50 mg/kg sodium tungstate and oral administrations of the same doses are shown in Fig. 2.

Preliminary analysis performed by noncompartmental approach revealed that after i.v. and oral administrations, concentrations increased in proportion to dose. AUC averaged 297.2 $\pm$ 34.9 and 647.4 $\pm$ 70.7 mg/l $\times$ h after i.v. administration of 25 and 50 mg/kg, respectively; after oral administration of the same doses, they were 177.0 $\pm$ 53.3 and 431.0 $\pm$ 93.7 mg/l $\times$ h, respectively.

A total of 351 concentrations were used to compute population parameters.

The parameter estimates given by the model are summarized in Table 3. From the population characteristics, it can be seen that $k_{21}$ was the parameter that exhibited the lowest coefficient of variation (CV = 19.1%) and $t_{\text{lag}}$ was the parameter that exhibited the highest (CV = 73%). Mean bioavailability was 66% (57–74%).

Individual pharmacokinetic parameters are presented in Table 4.

A typical posterior individual fitting is illustrated in Fig. 3.
in the rat by a common transport system subject to competitive inhibition. In dog, the bioavailability averaged 65%. These results are higher than that of 25% reported by Aamodt (1975) after the intragastric administration of a weakly acidic aqueous suspension of tungstic oxide in beagle dog.

In both species, over the sampling times monitored, plasma concentration profiles versus time were compatible with a two-compartment model and first-order kinetics. These results were in accordance with those found by Leggett (1997). In rat, after oral administration of 107.7 mg/kg sodium tungstate, mean concentration-versus-time curve showed a double-peak phenomenon during the input process. However, further investigations carried out on rat after re-
peated administrations (data not shown) did not confirm such a result. The total volume of distribution ($V_d = 0.46$ l/kg in rat versus $0.23$ l/kg in dog) and the total body clearance (0.19 l/h/kg in rat versus 0.043 l/h/kg in dog) normalized by body weight were both much higher when the animal was smaller. No relationship occurred between weight and CL or $V_d$. The $t_{1/2}$ elim was two times higher in dog (approximately 4 h) than in rat (approximately 1.7 h). These results confirmed the findings of Leggett (1997) that rats appear to excrete tungsten at a much higher rate than do larger animals. This relatively high excretion rate could be related to the unusually low requirements of the rat for the chemically similar element molybdenum (Higgins et al., 1956). After oral administration of 35.9 to 107.7 mg/kg sodium tungstate in rat and after oral and i.v. administration of 25 to 50 mg/kg sodium tungstate in dog, tungsten plasma concentrations increased in proportion to dose.

These pharmacokinetic properties indicate that tungsten is relatively unique among pharmacologically active metals. Indeed, although tissue storage was not specifically studied in the present work, the short $t_{1/2}$ elim of sodium tungstate suggests a rather limited tissue accumulation. Moreover, a major difference between tungstate and vanadate is the bioavailability. Vanadate bioavailability is still a matter of debate; it was reported in rat to vary from 5% (Conklin et al., 1982; French and Jones, 1993; Nielsen, 1988) to a maximum of 30% (Bodgen et al., 1982; Setyawati et al., 1998; Wiegmann et al., 1982). This low bioavailability was associated with digestive side effects (e.g., cramps and diarrhea) in correlation with the pharmacological activity of the metal on the digestive tract (Goldfine et al., 1995; Soulé et al., 1996) and led to the development of organomineral compounds (Yuen et al., 1997). In this perspective, the high bioavailability of sodium tungstate will certainly constitute a major advantage.

In conclusion, this report represents valuable information about the pharmacokinetics of sodium tungstate in rat and dog. Because this study was conducted in healthy animals, it was not possible to correlate tungsten plasma levels to a pharmacological response. Future studies will explore pharmacodynamic/pharmacokinetic relationships in diabetic animals.

**Acknowledgment**

We gratefully acknowledge C. Ballongue (Agence Française de Sécurité Sanitaire des Produits de Santé, Vendargues, France) for technical support.

**References**


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**Fig. 5.** Frequency distribution of standardized residuals. A, rat. B, dog.

Send reprint requests to: Dr. Françoise Bressolle, Ph.D., Laboratoire de Pharmacocinétique Clinique, Faculté de Pharmacie, 34060 Montpellier Cedex 2, France. E-mail: Fbressolle@AOL.com