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Pharmacokinetics and Pharmacodynamics of Remifentanil in Volunteer Subjects with Severe Liver Disease

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Background: **Remifentanil, a new μ-opioid agonist with an extremely short duration of action, is metabolized by circulating and tissue esterases; therefore, its clearance should be relatively unaffected by changes in hepatic or renal function. This study was designed to determine whether severe hepatic disease affects the pharmacokinetics or pharmacodynamics of remifentanil.**

Methods: **Ten volunteers with chronic, stable, severe hepatic disease and awaiting liver transplantation and ten matched controls were enrolled. Each subject was given a 4-h infusion of remifentanil. The first five pairs received 0.0125 $\mu g \cdot kg^{-1} \cdot min^{-1}$ for 1 h followed by 0.025 $\mu g \cdot kg^{-1} \cdot min^{-1}$ for 3 h; the second five pairs received double these infusion rates. During and after the infusion, arterial blood was obtained for pharmacokinetic analyses, and the ventilatory response to a hypercarbic challenge was assessed. Simultaneous pharmacokinetic and pharmacodynamic analyses were performed. The pharmacokinetics were described using a one-compartment intravenous infusion model, and ventilatory depression was modelled using the inhibitory E_{max} model. The pharmacokinetics of the metabolite GR90291 were determined using noncompartmental methods.**

Results: **There were no differences in any of the pharmacokinetic parameters for remifentanil or GR90291 between the two groups. The subjects with liver disease were more sensitive to the ventilatory depressant effects of remifentanil. The EC_{50} values (the remifentanil concentrations determined from simultaneous pharmacokinetic/pharmacodynamic analyses to depress carbon dioxide-stimulated minute ventilation by 50%) in the control and hepatic disease groups were 2.52 ng/ml (95% confidence interval 2.07–2.97 ng/ml) and 1.56 ng/ml (95% confidence interval 1.37–1.76 ng/ml), respectively.**

Conclusions: **The pharmacokinetics of remifentanil and GR90291 are unchanged in persons with severe, chronic liver disease. Such patients may be more sensitive to the ventilatory depressant effects of remifentanil, a finding of uncertain clinical significance, considering the extremely short duration of action of the drug. (Key words: Analgesics, opioids: GR90291; remifentanil. Anesthetics, intravenous: remifentanil. Liver: disease. Pharmacodynamics. Pharmacokinetics.)**

REMIFENTANIL is a new, selective μ-opioid agonist with an extremely short duration of action.[1–3] It contains a methyl-ester linkage, which renders it susceptible to metabolism by circulating and tissue esterases, a metabolic pathway analogous to that which occurs with esmolol. The resulting carboxylic acid metabolite, GR90291, has approximately 1/4,600 the potency of remifentanil as a μ-opioid agonist in anesthetized dogs.[4] In humans, GR90291 is eliminated primarily *via* renal excretion with a terminal half-life of approximately 1.5–2 h.[3]

In experimental pain studies in human volunteers, remifentanil was found to be approximately 20–30

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times more potent than alfentanil.[2] In the initial study of remifentanil as part of balanced anesthesia, the ED_{50} for the abolition of all responses to surgical stimuli was 0.52 $\mu g \cdot kg^{-1} \cdot min^{-1}$ in the presence of 67% N_2O. After discontinuation of remifentanil infusions ranging from 0.025 to 2 $\mu g \cdot kg^{-1} \cdot min^{-1}$ and lasting from 1.0 to 6.8 h, the mean times to spontaneous ventilation, responsiveness, and extubation ranged from 2.5 to 7.0 min. Emergence times were not related to the infusion rate of remifentanil.[5]

Fentanyl, sufentanil, and alfentanil undergo extensive hepatic metabolism. When fentanyl and sufentanil are given as single doses, the kinetics are unchanged in patients with cirrhosis.[6,7] Both opioids, however, are substantially bound to plasma proteins, and patients with liver disease of even moderate severity often have decreased blood concentrations of such proteins, thereby altering the unbound fraction of drug available for metabolism. In contrast, alfentanil has reduced clearance, and recovery may be prolonged when alfentanil is administered by infusion to patients with impaired hepatic function.[8] Esmolol has been studied in patients with cirrhosis, and its pharmacokinetics were not altered by the presence of hepatic impairment.[9] We predicted that the pharmacokinetics of remifentanil would be unchanged in persons with impaired hepatic function. The purpose of this study was to examine this hypothesis in patients with severe liver disease and very little hepatic reserve. We also determined whether such persons have altered sensitivity to the opioid agonist effects of remifentanil.

Methods

This was an open-label, parallel design study of ten volunteer subjects with hepatic disease awaiting liver transplantation and ten matched controls with normal liver function. Each control subject was matched for gender, race, age (±7 yr) and weight (±15%) with his or her counterpart with hepatic disease. The study was approved by the Subcommittee on Human Studies of the Massachusetts General Hospital, and each volunteer gave written, informed consent.

Each subject with liver disease had a history of chronic, stable hepatic disease (hepatitis B, hepatitis C, or primary biliary cirrhosis), and all were recruited from the list of patients awaiting liver transplantation. The primary determinant of the magnitude of hepatic impairment for inclusion in the study was hypoalbuminemia (≤3.2 g/dl). Most subjects with liver disease also had a prolonged prothrombin time and clinical features indicative of cirrhosis. All had evidence of portal hypertension, but none had encephalopathy or elevated blood ammonia concentrations at the time of their participation. Subjects were excluded if they had a history of anesthesia or opioid use within 8 weeks of the study, current or recent history of ethanol or other substance abuse, or current use of psychotropic medications.

The pharmacodynamic indicator of μ-opioid effect used was a decreased ventilatory response to a hypercarbic challenge. When each subject came for the screening visit, within 14 days of his or her participation in the study, two measurements of ventilatory drive were made to determine whether the subject could tolerate the hypercarbic challenge. At that time, each also had a neurologic examination to exclude encephalopathy, and blood tests of hepatic function were performed.

On the day of the study, each subject had the neurologic evaluation repeated. Intravenous and radial arterial catheters were inserted, and electrocardiogram and pulse oximetry were monitored continuously. Two baseline determinations of ventilatory drive were made, an infusion of remifentanil was begun, and during the 4-h infusion, six additional determinations of ventilatory drive were made. After stopping the infusion, ventilatory drive was measured until it had returned to baseline. Immediately after each ventilatory drive measurement, an arterial blood sample was obtained for determination of remifentanil and GR90291 concentrations, and the subject performed two psychomotor tests using pen and paper and completed several visual analog scales.

For safety reasons, very low doses of remifentanil were used in the first five pairs of subjects: The initial infusion rate of remifentanil was 0.0125 $\mu g \cdot kg^{-1} \cdot min^{-1}$, and it was maintained for 1 h. The infusion rate was then doubled and continued for an additional 3 h (low-dose group). In the second five pairs of subjects, the initial and final remifentanil infusion rates were doubled to 0.025 and 0.05 $\mu g \cdot kg^{-1} \cdot min^{-1}$, respectively (high-dose group). The largest dose was chosen on the basis of prior studies in volunteers. This dose was less than the lowest dose at which significant oxyhemoglobin desaturation occurred in a dose-escalation study in normal volunteers breathing room air (0.075 $\mu g \cdot kg^{-1} \cdot min^{-1}$).

For determination of ventilatory drive, the subjects were fitted with an airtight mask equipped with a tur-

Table 1. Models and Parameters

Model	Parameters
Full model	V_d, k_{10}, E_0, EC_{50}, γ
Reduced model with $\gamma = 1$	V_d, k_{10}, E_0, EC_{50}
Reduced model with fixed E_0	V_d, k_{10}, EC_{50}, γ
Simple model with $\gamma = 1$ and fixed E_0	V_d, k_{10}, EC_{50}

bine to measure expired volume (Interface Associates VMM-2) and a side port for measurement of carbon dioxide by infrared spectroscopy (Datex PB253). Two one-way valves were used to maintain an open system in which the subject breathed a defined gas mixture (7.5% CO_2, 50% O_2, balance nitrogen) and exhaled into the environment. For each determination of ventilatory drive, the subject breathed room air for 5 min, baseline minute ventilation was recorded, and then he or she breathed the carbon dioxide mixture for 5 min. Minute ventilation measured during the last min of each 5-min period was used in all calculations.

The analog outputs from the ventilation monitor and the capnometer were fed simultaneously to a paper chart recorder and an analog-to-digital converter board installed in a PC-class computer. Using software previously described in detail,[10,11] we obtained breath-by-breath analysis of minute ventilation.

To prevent blood esterases from metabolizing remifentanil in blood once it had been drawn, we processed arterial blood samples immediately by mixing with acetonitrile to inactivate esterase activity. Remifentanil was extracted by the addition of methylene chloride. The organic and aqueous phases were separated and stored at −70°C. Determination of remifentanil[12] and GR90291[13] concentrations was by high-resolution gas chromatographic mass spectrometry. The detection limits of remifentanil and GR90291 in blood were 0.1 ng/ml and 1 ng/ml, respectively.

To study whether opioid-induced encephalopathy had occurred, the subjects were evaluated after each determination of ventilatory drive by the use of two psychomotor tests, the Trieger dot and Halstead trail-making tests, and several visual analog scores, as previously described.[14] The Trieger dot test was scored as the number of dots missed, and the Halstead trail-making test was scored as the number of lines correctly connected. The visual analog scale was scored as a value from 0 to 100. Each subject was admitted to the hospital for the night following the study, and serial blood samples for the analysis of remifentanil and GR90291 were collected for 20 h after the end of the remifentanil infusion.

The pharmacokinetic/pharmacodynamic relationship of remifentanil was evaluated using nonlinear regression analysis (PCNONLIN version 4.2). A model was developed whereby the pharmacokinetics and pharmacodynamics were fit simultaneously. In addition, independent analyses of the pharmacokinetics were performed for each subject. The pharmacokinetics were described using a one-compartment intravenous infusion model, and the pharmacodynamics (minute ventilation) were modelled using the inhibitory E_{max} model:

$$MV = E_0 - \frac{E_{max} \cdot C^{\gamma}}{EC_{50}{}^{\gamma} + C^{\gamma}},$$

where E_0 is baseline minute ventilation, C is the remifentanil blood concentration, EC_{50} is the concentration at which 50% of the maximum response occurs, and γ is a dimensionless parameter describing the shape of the sigmoid curve. At very high blood remifentanil concentrations ($C >> EC_{50}$), the equation above simplifies to:

$$MV = E_0 - E_{max}.$$

Because the maximum response to remifentanil would be apnea (minute ventilation 0), E_{max} was fixed to equal E_0.

Table 2. Subject Characteristics

Group	Gender (M/F)	Age (yr)	Weight (kg)	[Albumin] (mg/dl)	PT Prolongation (s)
Low-dose, liver disease	4/1	43.2 ± 3.6 (37–55)	80.8 ± 10.4 (60–114)	2.7 ± 0.2 (2.3–3.2)	1.7 ± 0.5 (0.5–2.9)
Low-dose, control	4/1	38.4 ± 3.4 (31–49)	81.8 ± 7.7 (66–107)	4.1 ± 0.2 (3.8–4.5)	−0.1 ± 0.3 (−0.9–0.6)
High-dose, liver disease	4/1	49.2 ± 3.7 (41–60)	81.8 ± 7.6 (64–102)	3.0 ± 0.2 (2.5–3.6)	1.7 ± 0.6 (0.2–2.8)
High-dose, control	4/1	50.4 ± 5.0 (41–64)	82.2 ± 7.5 (71–105)	3.8 ± 0.1 (3.5–4.0)	−0.5 ± 0.2 (−0.9–−0.1)

Values are demographics for the subjects with liver disease and their matched controls. Values are means ± SEM (with range in parentheses). The values for serum albumin and prothrombin time were those recorded on the day of the study.

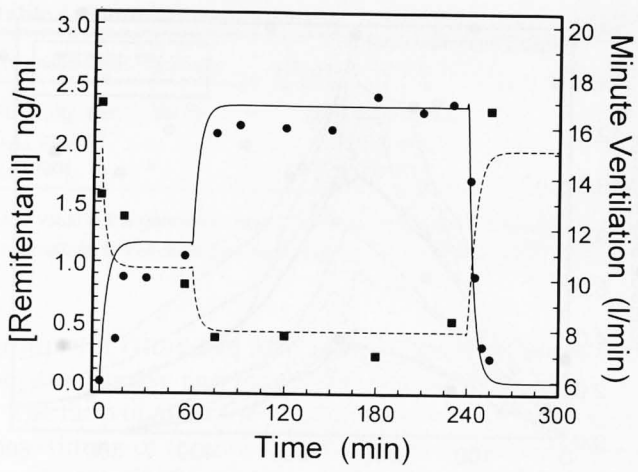


Fig. 1. Pharmacokinetic and pharmacodynamic data for subject 12. Closed circles represent the remifentanil concentrations, and closed squares represent the minute ventilation values. The solid line is the model of the blood concentration data, and the dashed line is the model of the minute ventilation data. During the first hour of the infusion at 0.025 $\mu g \cdot kg^{-1} \cdot min^{-1}$, the concentration of remifentanil reached a plateau and the infusion rate was doubled and maintained for an additional 3 h. At the initial infusion rate, minute ventilation was depressed 31%, increasing to 48% depression at the final infusion rate.

The modeling procedure was assessed using $1/Y$ or $1/Y^2$ weighting or no weighting, as appropriate, where Y is the predicted value for concentration or minute ventilation. Four pharmacodynamic models were assessed as shown in table 1. Using the weighted sums of squares, the Akaike information criterion[15] was calculated to determine which of the models provided the best fit.

The pharmacokinetic parameters of GR90291 were determined using noncompartmental methods. The terminal rate constant was obtained using an algorithm contained within PCNONLIN and confirmed by visual inspection.

The pharmacokinetic parameters for remifentanil and GR90291 were log-transformed before statistical analysis. The following pharmacokinetic parameters for remifentanil were analyzed: volume of distribution (V_d), clearance (Cl), elimination rate constant (k_{10}), and half-life ($t_{1/2}$). For GR90291, the area under the concentration *versus* time curve (AUC), maximum blood concentration (C_{max}), and half-life ($t_{1/2}$) were determined. The pharmacodynamic parameters were analyzed without transformation. One-way analysis of variance was used to compare the dose groups and subject groups. Two-way analysis of variance was used to assess a dose*subject group interaction. A *P* value less than 0.05 was considered significant. Based on the data, the sample size of ten subjects per group (control *vs.* liver disease) would provide 80% power to detect a 26% difference in clearance, and five subjects per group (low-dose *vs.* high-dose) would provide 80% power to detect a 39% difference in clearance.

Results

The demographics of the subjects are listed in table 2. Ten subjects with chronic liver disease were enrolled in the study, eight with hepatitis C, one with hepatitis B, and one with primary biliary cirrhosis. Two of the ten were women. On the day of the study, the serum albumin level for subject 12 exceeded the inclusion criterion. Because he had had multiple serum albumin determinations in the recent past with values less than 3 mg/dl and because he had biopsy-proven cirrhosis, he underwent the experimental protocol. Serial albumin determinations in the days and weeks after the study were less than 3 mg/dl, so his data were included in the analyses. Several subjects had evidence of mild or moderate ascites, but none had difficulty completing the ventilatory measurements.

The simultaneous pharmacokinetic and pharmacodynamic results for a representative subject are shown in figure 1. As the blood remifentanil concentrations increased, minute ventilation decreased. The solid line depicts the predicted blood concentrations, and the dashed line depicts the minute ventilation values based on the model described in methods.

Table 3. Summary Pharmacokinetic Parameters for Remifentanil

Pharmacokinetic Parameter	Low-dose Hepatic Disease	High-dose Hepatic Disease	Low-dose Healthy Subjects	High-dose Healthy Subjects
Cl ($ml \cdot min^{-1} \cdot kg^{-1}$)	39.1 (33.2–46.0)	33.3 (23.0–48.3)	31.5 (23.8–41.6)	33.0 (28.5–38.1)
V_d (ml/kg)	264 (196–356)	272 (162–456)	208 (112–384)	205 (178–235)
$t_{1/2}$ (min)	4.7 (3.7–5.9)	5.7 (4.0–8.1)	4.6 (2.8–7.4)	4.3 (4.1–4.5)

Each value is the geometric mean. The 95% confidence intervals are in parentheses.

Figure 2 shows the remifentanil concentration *versus* time data for all subjects. The pharmacokinetic parameters for remifentanil are summarized in table 3. There were no significant differences in Cl, V_d, or $t_{1/2}$ between any of the groups. In addition, independent analysis of the pharmacokinetic parameters provided results consistent with those obtained from the simultaneous pharmacokinetic-pharmacodynamic modeling.

The concentration *versus* time data for GR90291 in the subjects are shown in figure 3, and the pharmacokinetic parameters are summarized in table 4. There were no significant differences in any of the pharmacokinetic parameters when the healthy subjects and the subjects with hepatic disease were compared within dosage groups. Subjects who received the higher dose of remifentanil had measurable concentrations of GR90291 for a longer period. There were significant differences noted between the low- and high-dose

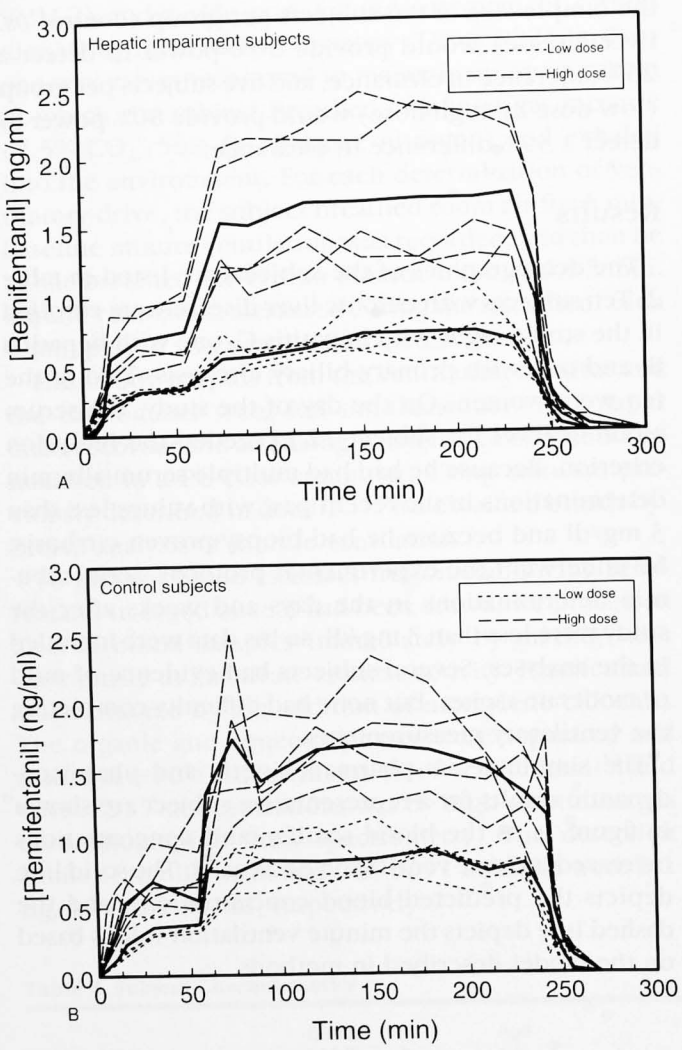


Fig. 2. The remifentanil blood concentration *versus* time data for the subjects with liver disease (*A*) and the control subjects (*B*). Each dashed line represents the data from one subject, and the heavy lines are the mean values. In all groups, a stable plateau was reached during the first hour, and another plateau was achieved during the next 3 h of the infusion. After termination of the infusion, the concentrations declined rapidly. There were no differences between the subjects with liver disease or the control subjects in the low- or high-dose groups.

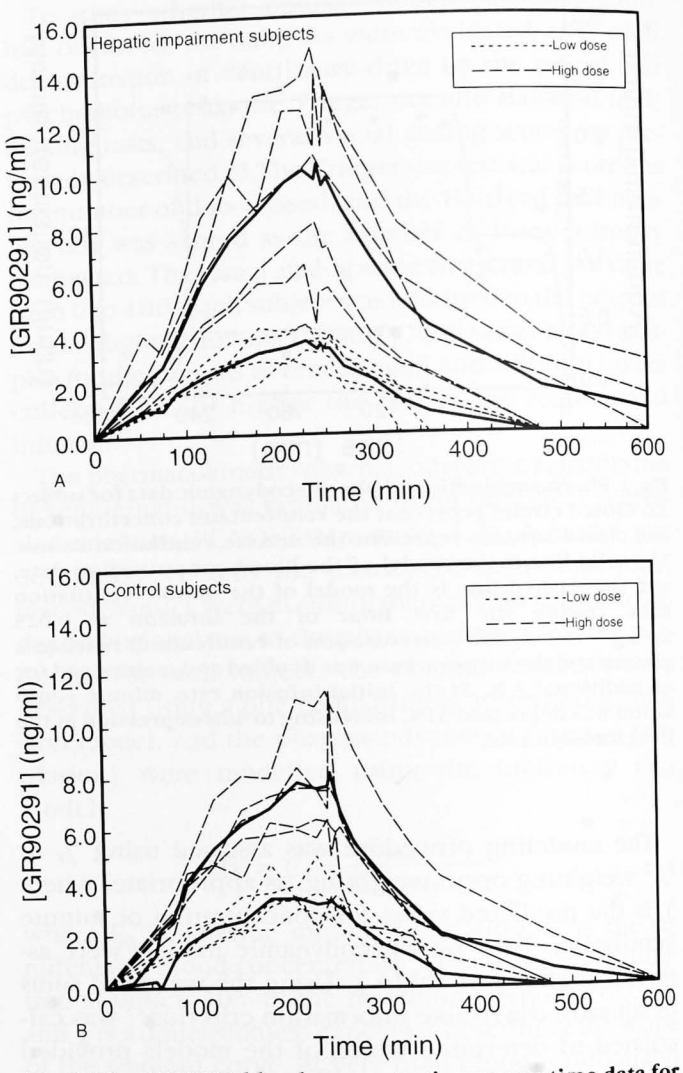


Fig. 3. The GR90291 blood concentration *versus* time data for the subjects with liver disease (*A*) and the control subjects (*B*). Each dashed line represents the data from one subject, and the heavy lines are the mean values. In all groups, the concentrations of GR90291 continued to increase during the 4-h infusion of remifentanil. After termination of the remifentanil infusion, the concentrations of GR90291 gradually declined. The apparently higher concentrations of GR90291 in the subjects with liver disease compared with the control subjects in the high-dose group were not statistically different.

Table 4. Summary Pharmacokinetic Parameters for GR90291

Pharmacokinetic Parameter	Low-dose Hepatic Disease	High-dose Hepatic Disease*	Low-dose Healthy Subjects	High-dose Healthy Subjects*
AUC ($ng \cdot min^{-1} \cdot ml^{-1}$)	805 (620–1,047)	1,301 (740–2,288)	767 (536–1,098)	986 (743–1,308)
C_{max} (ng/ml)	3.7 (3.0–4.5)	5.1 (3.3–7.9)	3.9 (3.0–5.1)	4.2 (3.0–6.0)
$t_{1/2}$ (min)	71 (60–83)	115 (71–186)	69 (45–107)	112 (68–183)

Each value is the geometric mean. The 95% confidence intervals are in parentheses.

* Normalized to low-dose (*i.e.*, AUC and C_{max} were divided by two for comparison in this table).

groups for GR90291 AUC and $t_{1/2}$ in the subjects with hepatic disease and for $t_{1/2}$ in the control group.

The ratio of AUCs for GR90291 and remifentanil gives an estimate of the ratio of the blood concentrations at steady-state.[16] These ratios are listed in table 5 and range from 3.1 to 6.2. Within both the high- or low-dose groups, the ratio was not different in the control subjects and the subjects with liver disease.

Four models for the simultaneous modeling of the pharmacokinetics and pharmacodynamics were tested. The full model (five parameters) could not be adequately fit because of insufficient information to estimate all parameters simultaneously. One subject in the high-dose control group did not manifest ventilatory depression in response to remifentanil and was not included in the pharmacodynamic analyses. The results indicated that the simple model provided the best overall fit in 15 of the remaining 19 subjects. In three of the other four subjects, although the reduced models provided a better statistical fit than the simple model, there were no differences in the parameter estimates obtained. Thus, in only one subject did the reduced models provide a better statistical fit and different parameter estimates. The simple model was applied to the 19 subjects in whom pharmacodynamic calculations were performed.

The minute ventilation data as a function of time are shown in figure 4. In all four groups, there was a decrease in minute ventilation during the first hour of the infusion. A larger decrease occurred during the subsequent 3 h after the infusion rate had been doubled. Minute ventilation returned rapidly to baseline after termination of the infusion. The subjects with liver disease who were given the higher dose of remifentanil experienced a greater magnitude of ventilatory depression than the corresponding control group.

The values for EC_{50} are listed in table 5. The EC_{50} for the subjects with hepatic disease given the higher dose was significantly less than that of the comparable control subjects. Of the subjects given the smaller dose of remifentanil, only two of the ten manifested a 50% (or greater) decrease in minute ventilation. Because EC_{50} values in these subjects would represent extrapolations, they are not included.

Figure 5 shows the individual minute ventilation measurements as a function of the blood concentration of remifentanil. Fitting the pooled, individual data points to the inhibitory E_{max} model provides an alternative method for estimating EC_{50}. The EC_{50} values in the control subjects and the subjects with liver disease were 2.52 ng/ml (95% confidence interval 2.07–2.97 ng/ml) and 1.56 ng/ml (95% confidence interval 1.37–1.76 ng/ml), respectively. The EC_{50} values in the two groups were significantly different.

All subjects were able to complete the various psychomotor and visual analog scale measurements at all times. At baseline (*i.e.*, before remifentanil), there were no differences between groups in performance on either the Trieger or the Halstead tests. Most subjects in each group had impaired performance on ei-

Table 5. Summary AUC Ratio and EC_{50} Values

Parameter	Low-dose Hepatic Disease	High-dose Hepatic Disease	Low-dose Healthy Subjects	High-dose Healthy Subjects
$AUC_{GR90291}/AUC_{remifentanil}$	6.2 ± 1.4	4.5 ± 1.9	4.8 ± 1.4	3.1 ± 0.4
EC_{50} (ng/ml)	*	1.5 ± 0.5	*	3.4 ± 2.0†

Each value is the arithmetic mean ± standard deviation of the values determined for the individuals in the group.

* EC_{50} values in the low-dose groups are not estimated because most of the subjects did not manifest a 50% reduction in ventilation.

† Significantly different from the high-dose hepatic disease group ($P = 0.0276$).

ther or both tests, but there were no differences between groups in performance after remifentanil. Remifentanil produced dose-dependent sedation as measured by visual analog scale; however, there were no differences between the control group and the group with liver disease.

Discussion

The pharmacokinetics of remifentanil were not altered in subjects with severe hepatic disease awaiting liver transplantation. Hepatic function in the subjects was severely compromised; although none had encephalopathy, all had evidence of portal hypertension on physical examination. All had hypoalbuminemia, and most had a prolongation in prothrombin time. As shown in figure 2, there was no evidence of accumulation of remifentanil in these subjects after a 4-h infusion.

There were also no differences in the disposition of GR90291 between the control subjects and the subjects with liver disease. The ratio of AUC for GR90291 to remifentanil ranged from 3.1 to 6.2, providing an estimate of the ratio of the blood concentrations at steady-state. Profound analgesia during surgery under anesthesia with nitrous oxide and remifentanil is achieved with blood concentrations of remifentanil ranging from 10 to 35 ng/ml.[4] If we assume that 6 times as much metabolite might be present, steady-state blood concentrations of GR90291 as high as 210 ng/ml may occur during surgery. Because GR90291 is about 1/4,600th as potent in dogs as remifentanil as a μ-opioid agonist,[4] the blood concentration of GR90291 under such circumstances would be approximately equivalent to 0.05 ng/ml remifentanil, a concentration that does not produce detectable ventilatory depression, assuming a similar potency ratio in humans. The potency of GR90291 in humans is unknown.

Subjects who received the larger dose of remifentanil had detectable concentrations of GR90291 for a longer period, and therefore the estimate of AUC and $t_{1/2}$ is more accurate in the high-dose groups. This explains the differences in AUC and $t_{1/2}$ between the low- and high-dose groups. The ratio of AUC for GR90291 to remifentanil is less for both control subjects and subjects with liver disease in the high-dose groups; thus, the actual contribution of GR90291 to overall μ-opioid effect is likely to be less than the worst-case scenario assumed in the preceding paragraph.

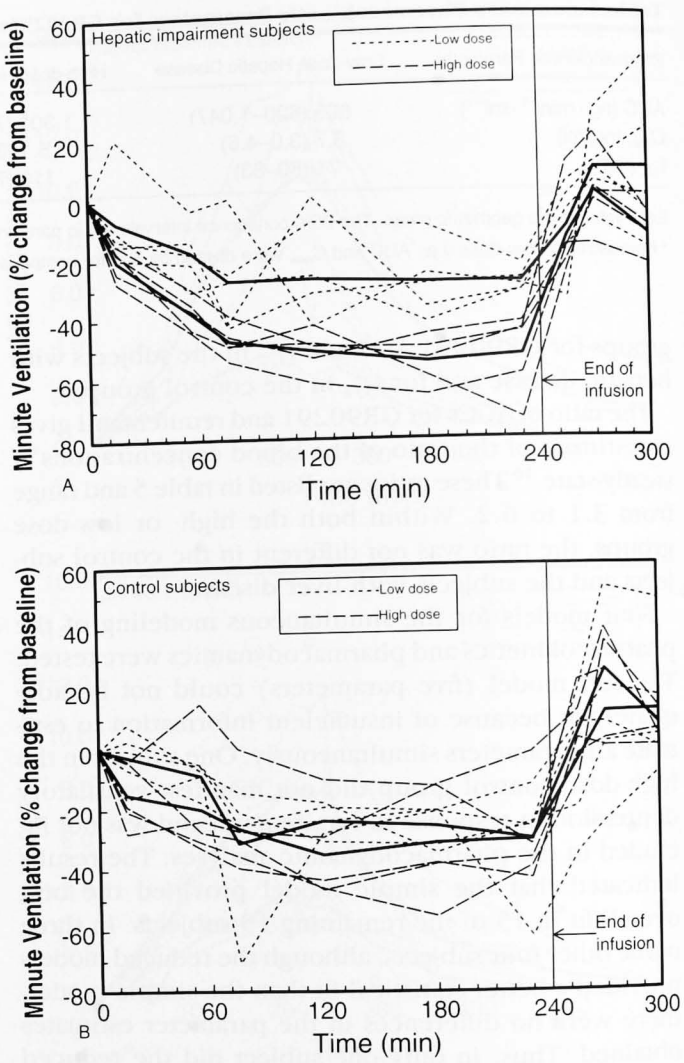
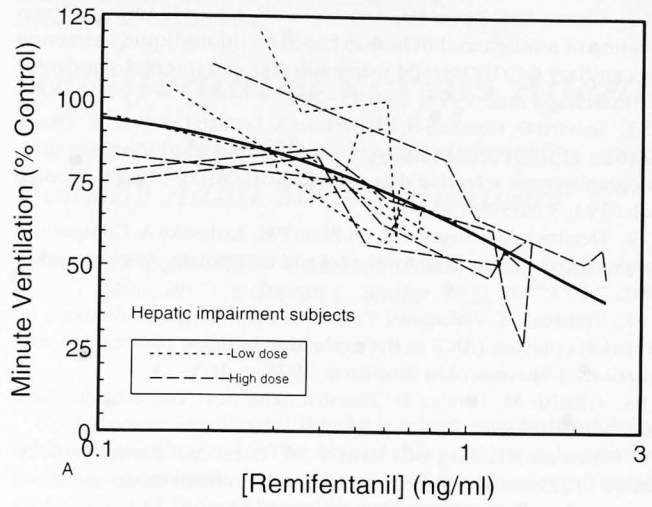


Fig. 4. The minute ventilation *versus* time data for the subjects with liver disease (*A*) and the control subjects (*B*). Each dashed line represents the data from one subject, and the heavy lines are the mean values. In all groups, minute ventilation declined during the first hour of the infusion, and a further decline occurred during the subsequent 3 h of the infusion after the infusion rate was doubled. Minute ventilation returned rapidly to baseline after the infusion was terminated.

The EC_{50} values were less in the subjects with hepatic disease, suggesting that they may be more sensitive to the ventilatory depressant effects of remifentanil. When remifentanil is used in such patients, the dose necessary to provide analgesia may be less than in a patient without liver disease. Because the drug is cleared so rapidly, regardless of the presence of liver disease, a twofold difference in dose is unlikely to produce any change in duration. The mechanism of the altered EC_{50} in the patients with liver disease is unknown. We do not know



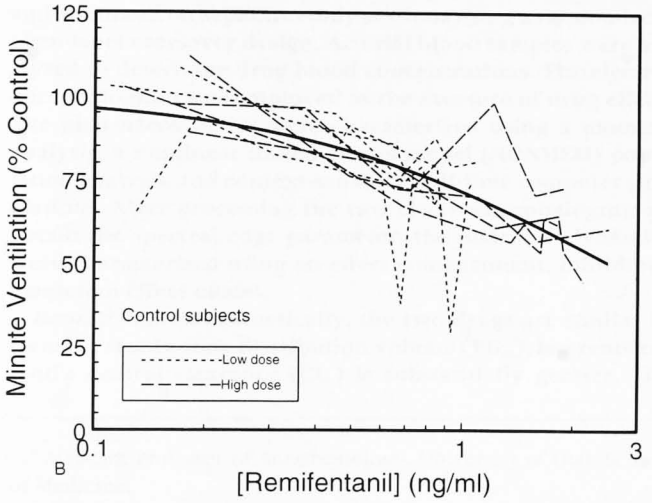


Fig. 5. The individual minute ventilation determinations as a function of blood remifentanil concentration in the subjects with liver disease (*A*) and the control subjects (*B*). Each dashed line represents the data from one subject, and the heavy lines represent the minute ventilation *versus* remifentanil curve predicted by the model. The subjects with liver disease had an EC_{50} value of 1.56 ng/ml (95% confidence interval 1.37–1.76 ng/ml). The control subjects had an EC_{50} value of 2.52 ng/ml (95% confidence interval 2.07–2.97 ng/ml).

the nature of remifentanil binding to piasma proteins. It is possible that, because of decreased hepatic synthesis of albumin and other proteins (*e.g.*, α_1-acid glycoprotein, to which alfentanil binds more avidly than to albumin), the unbound fraction of remifentanil may be higher in patients with hepatic impairment. Alternatively, the central nervous system may be more sensitive to the depressant effects of the drug.

For completeness, we must raise the possibility that the difference in sensitivity to remifentanil is due to unusually high values for EC_{50} in the control subjects in this study. In two prior studies of normal volunteers,†† the EC_{50} values in normal volunteers were similar to those obtained in our subjects with liver disease and less than in our control subjects. Figure 4 shows that the high-dose control subjects did not experience a greater response than the low-dose controls, so it is possible that individuals in the former group were relatively resistant to the ventilatory depressant effects of remifentanil. It is not surprising to observe this level of individual variability in the response to opioids.[17]

Our data allow us to conclude that remifentanil may be an appropriate opioid to use in patients with severe hepatic failure. Severe hepatic impairment does not alter the pharmacokinetics of remifentanil. Recovery from the effects of remifentanil is rapid, even when large doses are given, because of three factors: rapid disappearance from the circulation, rapid equilibration between blood and "effect" sites, and the relative inactivity of the metabolite. Furthermore, recovery is similar in normal individuals and in patients with severe liver disease. The apparent difference in sensitivity to the ventilatory depressant effect of remifentanil in subjects with hepatic disease, if real, is small and unlikely to cause meaningful changes in the safety of the drug in the recovery period.

†† Glaxo Inc: Unpublished data. 1992.

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Talmage D. Egan, M
Keith T. Muir, Ph.D.,

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