Retrospective cohort study monitoring PEG-asparaginase activity in acute lymphoblastic leukemia patients with and without premedication [version 1; peer review: 1 approved with reservations]

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Abstract

Background: PEG-L-asparaginase (pegasparaginase) is a critical component of therapy for children and adults with acute lymphoblastic leukemia (ALL). Allergic reactions, which may occur in up to one third of patients, are the major cause for discontinuation. One study reported lower rates of allergic reactions with premedication. Besides allergy, an unknown number of patients develop silent neutralizing antibodies not associated with allergic reactions. The purpose of this retrospective cohort study was to determine the incidence of silent inactivation of pegasparaginase and compare incidence of allergic reactions with and without premedication.

Methods: Using a commercial assay, asparaginase activity was monitored following pegaspargase (2500 units/m²) in newly diagnosed children and young adults with B- and T-cell ALL from February 2013 to May 2017. The incidence of allergic reactions before and after initiation of premedication in May 2015 was compared.

Results: One patient out of 59 (1.7%) had silent inactivation after the second dose. No patient had silent inactivation after the first pegaspargase dose and no standard risk B-cell ALL patients, who received only two pegaspargase doses in combination with oral dexamethasone, had silent inactivation. The incidence of grade 3 or 4 allergic reactions was 3.7% per dose with premedication (methylprednisolone, acetaminophen and diphenhydramine) versus 5.2% without. The incidence per patient with premedication given for most of the doses was 8.3% versus 17% without. These values are not statistically significant. Premedication did not affect pegaspargase activity.

Conclusions: Due to the low incidence of silent inactivation with intravenous pegaspargase and the unlikely event patients receiving only two doses of pegasparaginase would receive erwinase for this possible transient silent inactivation, we recommend routine monitoring of pegaspargase activity only in patients scheduled to receive more than two doses.
Keywords
Pegasparginase Activity, Premedication, Silent Inactivation, Allergy, Anaphylaxis

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Author roles: Losasso M: Data Curation, Investigation, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; Bostrom B: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; Messinger Y: Conceptualization, Methodology, Project Administration, Resources, Supervision, Visualization, Writing – Review & Editing

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Introduction

PEG-L-asparaginase (pegaspargase) is a critical component of therapy for children and adults with acute lymphoblastic leukemia (ALL). Its use is hampered by many issues including allergic reactions, silent inactivation, thrombosis, hyperbilirubinemia and pancreatitis. Other common toxicities, such as hyperglycemia and hypertriglyceridemia, may be mitigated with the use of metformin and omega-3, respectively. There is also ongoing interest in the use of carnitine to treat, and possibly prevent, hepatic toxicity, manifested by a severe increase in direct bilirubin, among other findings.

The optimal dose, dose interval and target asparaginase level for pegaspargase is not completely established. In pediatrics, a dose of 2500 units/m² is the norm, whereas for adult patients, doses are often reduced due to increased toxicity at the pediatric dose. Some investigators have suggested using a pharmacokinetic driven model to individualize pegaspargase dosing.

The use of premedication (acetaminophen, diphenhydramine and a corticosteroid) has been suggested as a possible means of reducing allergic reactions. In a multi-center study testing the use of pediatric-based regimens in young adults, the rate of grade 3 or 4 allergic reactions was reduced from 10% to 4% after premedication was mandated. A study in adults with ALL reported allergic reactions in 7.2% of patients when pegaspargase was given concurrently with, or followed by, one week of prednisone. Using a novel mouse model of asparaginase hypersensitivity, pretreatment with seven days of oral dexamethasone was the only agent capable of mitigating the severity of hypersensitivity and partially restoring asparaginase activity. Dexamethasone given at the time of, or for one week following, asparaginase was not as effective.

The presence of antibodies against asparaginase may be found, from as early as the end of induction therapy. The presence of asparaginase antibodies is a highly specific finding that is predictive of future allergic reactions but does not have the sensitivity to suggest modifications to therapy should be made. The presence of asparaginase antibodies at end of induction did not appear to alter prognosis in a large multi-center study. This suggests that measuring asparaginase activity is more useful than looking for the presence of antibodies.

Silent inactivation of pegaspargase activity by anti-asparaginase antibodies or other immune-mediated mechanisms are potentially of greater concern than allergic reactions, as patients with allergic reactions to pegaspargase will be switched to erwinase, which theoretically will improve outcome. The true incidence of silent inactivation is unknown, as there are no reports of a comprehensive screening program for silent inactivation in a large multi-institutional trial. The largest published study found silent inactivation in 7/89 (8%) of patients. However, these patients received induction with native Escherichia coli asparaginase before switching to pegaspargase, which is not current practice. The authors also report in the same group of patients that silent antibodies may spontaneously resolve with continued pegaspargase. Prudence suggests that patients who receive premedications should have pegaspargase activity monitored after every dose, due to the possible but unproven concern that premedication will mask allergic reactions and silent inactivation. In fact, a consensus panel of experts recommends screening for silent inactivation in all patients undergoing therapy for ALL with asparaginase.

Methods

Ethical statement

As the use of premedications and measurement of pegaspargase activity was considered by the leukemia provider group at Children’s Minnesota to be necessary for optimal care, no informed consent was obtained. Parents/adult patients were not informed of results unless intervention was indicated, which did not occur. This retrospective review study was approved by the institutional review board of Children’s Minnesota (IRB# 1606-062).

Patients

This retrospective study occurred in a large pediatric oncology center that diagnoses and treats approximately 40 new cases of ALL yearly in children and young adults up to age 30. If there are open studies, the patients are enrolled on Children’s Oncology Group protocols. Otherwise, patients are treated according to the most recent risk adapted protocols for standard risk B, high risk B and T-ALL. In order to reduce acquisition bias, charts of every patient who received pegaspargase from December 2013 to September 2016 were abstracted (N=99). As this was a pilot study and the expected reduction of grade 3 or 4 allergic reactions with premedication was unknown at the time, sample size calculations could not be calculated. Data from all 99 patients were used to estimate the incidence of grade 3 or 4 allergic reactions by patient and by dose. For the detailed pharmacokinetic analysis, we used a subgroup of all patients from May 2014 to September 2016 (N=46) who had pegaspargase levels drawn. This number was sufficient to define the confidence intervals of the pegaspargase activity.

Pegasparagase administration

A total of 112 blood samples from these 46 patients were collected from a central venous portacath in conjunction with scheduled clinical visits from 3 to 12 days following pegaspargase administration at the standard dose of 2500 mg/m². Pegaspargase was given by intramuscular injection or intravenously per Children’s Oncology Group protocols on an intermittent schedule starting with induction and completed prior to starting maintenance therapy. Because the distribution of the collection days clustered in ranges from day 3–5, 6–8 and 10–12, for analyses, pegaspargase activity was grouped in these categories. To better estimate the incidence of silent inactivation, pegaspargase levels lower than 0.01 units/ml were looked for in the data from an additional 13 patients, making a total of 59 evaluated. No evidence of silent inactivation was found in these 13 patients.

These patients were all treated according to Children’s Oncology Group protocols, using either intramuscular or intravenous
Pegasparagase as the only form of asparaginase. Intramuscular asparaginase was the standard of care until 2010 when intravenous administration became the new standard of care based on the Children’s Oncology Group AALL0932 protocol. A comprehensive review of published studies concluded that the risk of grade 3 or 4 allergic reactions is independent of the pegasparagase route of administration.

Premedication administration
We became aware of an abstract showing a decrease in grade 3 or 4 allergic reactions in a multi-institutional study employing pegasparagase in young adults with ALL. This prompted us to institute in May 2015 premedication with acetaminophen (10–15 mg/kg orally), diphenhydramine (1 mg/kg orally or intravenously), and methylprednisolone (1 mg/kg intravenously), within the hour prior to administering pegasparagase. Every subsequent patient was to receive with all three of the premedication drugs without exception. The numbers with and without premedication are listed in Table 2 (per pegasparagase dose) and Table 3 (per patient).

Assessment of allergic reactions
Allergic reactions to were graded per CTC 4.0 toxicity scales. We compared the incidence of grade 3 or 4 allergic reaction in patients with and without premedication, both per pegasparagase dose and per patient.

Pharmacokinetic analysis
Routine monitoring of pegasparagase activity in patients with ALL was initiated in 2013 after the ‘asparaginase activity analysis’ test approved by Clinical Laboratory Improvement Amendments was introduced by AlBiotec, Richmond, VA 23225 US. Subsequent to the introduction in 2015 of a quantitatively identical test by Next Molecular Analytics, Chester, VA, samples were exclusively sent there.

Statistical analyses
SPSS version 23 was used for graphing and analyses. Grouped data were displayed with box graphs depicting the 1st, 25th, 50th (median), 75th and 99th percentiles. The comparison of pegasparagase activity with and without premedication was done by independent sample t-test. The comparison of grade 3 or 4 allergic reactions by patient and pegasparagase dose with and without the use of premedication was done by Chi-squared analysis. As some premedication doses were missed due to omission by the treating physician, an additional analysis of the incidences of those who received premedication after every dose or most doses were compared to those who received no premedication before any dose. Missed pegasparagase activity samples were omitted from analysis (Table 1).

Results
Pharmacokinetic analyses were done on 112 specimens from 46 patients. The 46 patients included 12 standard risk B-cell

Table 1. Percent of pegasparagase activity specimens collected following doses one to nine.

<table>
<thead>
<tr>
<th></th>
<th>One</th>
<th>Two</th>
<th>Three</th>
<th>Four</th>
<th>Five</th>
<th>Six</th>
<th>Seven</th>
<th>Eight</th>
<th>Nine</th>
<th>Total</th>
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<tr>
<td>Collected</td>
<td>8</td>
<td>33</td>
<td>18</td>
<td>19</td>
<td>18</td>
<td>6</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>112</td>
</tr>
<tr>
<td>Missed</td>
<td>38</td>
<td>12</td>
<td>16</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>96</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>45</td>
<td>34</td>
<td>29</td>
<td>25</td>
<td>12</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>208</td>
</tr>
<tr>
<td>% Collected</td>
<td>17%</td>
<td>73%</td>
<td>53%</td>
<td>66%</td>
<td>72%</td>
<td>50%</td>
<td>70%</td>
<td>40%</td>
<td>50%</td>
<td>54%</td>
</tr>
</tbody>
</table>

Table 2. Grade 3-4 allergic reactions by use of premedication per dose of pegasparagase.

<table>
<thead>
<tr>
<th>Grade 3-4 allergic reactions</th>
<th>None (83%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No premedication</td>
<td>7 (17%)</td>
<td>35</td>
</tr>
<tr>
<td>Some premedication</td>
<td>4 (6%)</td>
<td>58</td>
</tr>
<tr>
<td>Every dose premedication</td>
<td>4 (12%)</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 3. Grade 3-4 allergic reactions by use of premedication per patient.

<table>
<thead>
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<th>Grade 3-4 allergic reactions</th>
<th>None (83%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Every dose premedication</td>
<td>4 (12%)</td>
<td>30</td>
</tr>
</tbody>
</table>
patients, 21 high risk B-cell ALL patients, and 13 T-cell ALL patients. There were 25 males and 21 females. The ages ranged from one to 29 years with a median of 8.3 years. The number of specimens and missed specimens per pegaspargase dose number are shown in Table 1. First dose specimens were frequently missed, whereas specimens on doses two to seven were collected at least half the time.

Figure 1 is a box and whisker graph of pegaspargase activity on days 3–5, 6–8 and 10–12. The mean, standard error of the mean and standard deviation are: 1.37, 0.21 and 0.76 units/mL, respectively, for day 3–5; 0.89, 0.05 and 0.42 units/mL for day 6–8; and 0.89, 0.06 and 0.28 units/mL for day 10–12. These values are similar to those previously reported in pediatric patients with ALL.\(^{18,19}\)

Figure 2 is box and whisker graph of the pegaspargase activity on day 6–8, following doses with or without premedication. This time ranged was used for the comparison as it is the most common time for checking asparaginase activity. The mean and standard deviation for the no premedication group is 0.79 and 0.34 units/mL (N=14 samples), respectively, and for the premedication group is 0.92 and 0.41 units/mL (N=52 samples). These were not found to be significantly different by the independent sample t-test.

Only one patient had silent inactivation with the following activity levels by dose number and day following pegaspargase activity was checked: dose 1, day 24 - 0.11 units/mL; dose 2, day 8 - 0.05 units/mL; dose 3 day 6 - 0.01 units/mL; dose 4 day 8 - 0.33 units/mL; dose 5, day 8 - 0.82 units/mL; and dose 6, day 10 - 0.62 units/mL. The low values after doses 2 and 3 were not reviewed due to a clerical error until after dose 4, which showed adequate activity, so pegaspargase was continued until the end of treatment.

For the analysis of the role of premedication in preventing grade 3-4 allergic reactions, the data was analyzed per pegaspargase dose and per patient. In the analysis per pegaspargase dose, premedication did not significantly reduce grade 3-4 allergic reactions. With premedication, 7/185 (3.7%) had grade 3-4 allergic reactions compared to 8/155 (5.2%) without premedication, p=0.5 (Table 2).

Table 3 shows the incidence of grade 3-4 allergic reactions per patient. Without premedication, 7/42 (17%) had grade 3-4 allergic reactions. When premedication was given most of the time (usually the first dose was missed), 4/62 (6%) had grade 3-4 allergic reactions. When premedication was given for every dose, 4/32 (12%) had allergic reactions. There was no significant effect of premedication on grade 3-4 allergic reactions.

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**Figure 1.** Box plot of pegaspargase (PEG) activity following 2500 units/m\(^2\) on day 3-5, 6-8 and 10-12. Data points outside of the whiskers of the 1st and 99th percentiles are represented by a circle (outlier more than 1.5 times the interquartile range) or star (extreme outlier more than three times the interquartile range). The attached number is a data point and not a value.
reactions by dose when the premedication group (8/96; 8.3%) was compared to the no premedication group (7/42; 17%) (chi square = 2.09; p = 0.15) (Table 3). There was no difference in the distribution of patients who did or did not receive premedication by risk group.

Discussion

Compared with historical controls that received similar therapy, premedication did not significantly reduce the incidence of grade 3 or 4 allergic reactions when measured per patient or per dose of pegaspargase. However, there was a downward trend in the incidence per patient when any use of premedication was compared to no premedication. As premedication does not negatively affect pegaspargase activity levels, and other studies using historical comparisons have suggested premedication may reduce allergic reactions, we are continuing the practice. The interesting observation by Tong et al. that asparaginase antibodies generated after native E. coli asparaginase may resolve while on pegaspargase continuation therapy needs to be confirmed in patients who receive only pegaspargase during induction and beyond. We noted a transient decrease in pegaspargase activity, likely due to silent inactivating antibodies in 1/59 patients (1.7%). This decrease of pegaspargase activity occurred after the second dose in a high-risk B-cell ALL patient and resolved with continuation of pegaspargase dosing.

No decrease in pegaspargase activity was seen in standard risk patients who received only two doses of pegaspargase in combination with oral dexamethasone.

Limitations of the study include multiple missed activity levels that may have found addition patients with silent inactivation. The sample size also makes it difficult to estimate the true incidence of silent inactivation and if premedication reduces the incidence of grade 3 or 4 allergic reactions. Additional studies are needed to clarify this.

Contrary to the findings of a large multi-institutional trial, where the introduction of premedication significantly reduced the incidence of high-grade allergic reactions, our study did not show a statistically significant reduction with the use of premedication. Despite this, we continue to use premedication in all patients receiving pegasparginase. Due to the low incidence of silent inactivation we are only monitor asparaginase activity in patients who are planned to receive more than two doses of pegaspargase during their entire course of treatment (T-cell ALL and high-risk B-cell ALL).

Addendum

A recent publication by the pediatric oncology group at Johns Hopkins also reported significant reduction of infusion reactions and need for erwinase using premedication of H1 and H2 histamine antagonists. They also found a low incidence of silent
inactivation with intravenous pegaspargase in one of 68 patients (1.5%), similar to our finding of one in 59 patients (1.7%)\(^1\).

**Data availability**

**Underlying data**

Figshare: Data Set for Retrospective cohort study monitoring Pegaspargase activity in acute lymphoblastic leukemia patients with and without premedication Lossaso M, Messinger Y, Bostrom B. https://doi.org/10.6084/m9.figshare.8281826.v1\(^1\)

This project contains the following underlying data:

- PEG Data De-identified.xlsx (demographic, medical and treatment information for each patient)

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

**Grant information**

The author(s) declared that no grants were involved in supporting this work.

**Acknowledgements**

The authors would like to thank the Children’s Minnesota leukemia nurse case managers who did and continue to do an outstanding job to ensure PEG activity is collected on as many patients as possible.

**References**


Open Peer Review

Current Peer Review Status: 

Version 1

Reviewer Report 26 September 2019

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Bernard L. Marini

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Drs. Losasso, Bostrom, and Messinger should be applauded for their work in characterizing asparaginase activity levels in ALL patients. The results and research are clearly presented and accurately reported. The conclusions of the study are appropriate, and the limitations of this retrospective cohort study are well-described.

Some specific suggestions/comments/recommendations:

Abstract:

- I would include the n in the incidence of hypersensitivity reactions, or acknowledge that the study may not have been powered to assess this outcome. Readers who only look at the abstract may wrongly conclude pre-medication is not effective, when the analysis may have been underpowered to detect a statistically significant difference in hypersensitivity reactions in the pre-medication vs. no pre-medication group.

- The paper, methods, and title are focused on the impact of pre-medication on activity levels; however, the conclusion primarily talks about the low incidence of silent inactivation with two doses; thus monitoring only being necessary in patients that receive >2 doses. I would consider a sentence re: pre-medication here as well.

Intro:

- Not essential, but could consider mentioning fibrates in the treatment of hypertriglyceridemia, which is another first line option.


- I would be careful with stating asparaginase antibodies are always predictive of future allergic reactions, as not all antibodies inactivate asparaginase or lead to clinical hypersensitivity reactions (ex: CCG01961). Consider rewording to soften this language.

- In paragraph 5, the statement is made that silent inactivation is of greater concern than allergic reactions. However, one could argue that allergic reactions are more common than silent inactivation with asparaginase (~1%), and monitoring activity levels in the setting of grade 1-2 allergic reactions is essential to determine which patients with clinical hypersensitivity reactions are having true antibody mediated reactions vs. other, non-antibody mediated (possibly ammonia vs. other immune-mediated) allergic reactions that would not warrant a switch to another asparaginase preparation.

- Other large scale studies assessing the rate of silent inactivation and finding the rate to be <8% could also be included in this discussion (or cited). These include, AALL07P4, Schore, et al. Leuk Lymph 2019^3, CCG1962, and Park JH, et al. Blood. 2016;128:1629^4.

**Methods:**

- While a sample size was not calculated a priori, could the authors conduct a sensitivity analysis on the data determined the detectable effect size at 80% power in the primary outcome of interest (rate of grade 3/4 allergic reactions?)?

- Were dose reductions in PEG ever conducted in this data set for toxicity/age/risk factors for hepatotoxicity?

- It is unclear how silent inactivation is defined in this data-set from the methods. It may also be clinically relevant to capture “accelerated clearance”, which also may be clinically relevant. Not all anti-asparaginase antibodies lead to full inactivation of the drug, but some lead to accelerated clearance and lower than expected values at early time points. A patient with silent inactivation would have a peak level that is undetectable, whereas a patient with accelerated clearance may clear the PEG by day ~7 when an expected duration of asparagine depletion is 21-28 days with a full pediatric dose.

- Were any levels obtained in patients with low-grade hypersensitivity reactions? If so, did any of these patients have accelerated clearance/“loud” inactivation?

- Were the activity levels normally distributed? If not, perhaps medians in the box plot and a Mann Whitney U for comparison would be more accurate. Similarly, if the values in the 2x2 contingency table are small, consider a Fisher’s exact test rather than chi-square for the incidence of hypersensitivity reaction comparison (although it likely won’t make a significant difference).

- Was there a protocol to say every patient should have a level with every dose, or were levels obtained at random/provider discretion? Could there then be a selection bias in the patients who have activity levels obtained since so many were missed? I’m assuming first dose levels were “missed” because the risk of inactivation with the first dose should theoretically be zero, so they were perhaps more accurately intentionally omitted.

**Results:**
- Is there any possibility that the level on day 6-8 of 2.8 was spurious? Were there any concomitant levels in this patient with this dose to make sense of such a high level?

- The one patient being described as having silent inactivation - I do not think I would characterize this as silent inactivation technically, since they had detectable activity levels at several time points, and no peak level is ever undetectable. I would consider this a transient accelerated clearance with dose 2 and 3. If silent inactivation was truly present, a patient should not have activity present for a full week and then have full activity with later doses. Patients with activity levels even as low as ~0.02 may still have asparagine depletion (AALL07p4).

- It may be interesting to graph levels over time in some of these patients with very low levels. Was there ever more than one level obtained per dose? Were repeat levels obtained to verify the low activity levels or follow the activity level trend over time (as is suggested in some guidelines?). This would help characterize the PK better in these patients.

- Was the choice to pre-medicate done at a strict, uniform point in time (i.e., was this a quasi-experimental design where a protocol to pre-medicate all patients was mandated?), or was pre-medication at the choice of the treating provider? If this was selected by the provider and not systematic, could there have been some slight selection bias where patients perceived to be at higher risk of hypersensitivity reactions were given pre-medication? This could have diminished the impact of pre-medication on reducing the rate of hypersensitivity reactions. Consider this in the discussion section if deemed relevant.

Discussion:
- I would more accurately call the silent inactivation here "accelerated clearance" as the patient had asparagine depletion for at least a week, even with the low level.

- Consider discussing the possible value of obtaining activity levels in patients with questionable allergic reactions (grade 1/2).

- Could add as a limitation that it appears patients only had one activity level obtained per dose, which makes it challenging to interpret PK, especially in patients with higher or lower than expected activity levels.

Overall, a very well-done paper with logical conclusions. Thank you for allowing me to review the manuscript and for your hard work in this research.

References


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Tallman MS, Douer D: A Pediatric-Inspired Regimen Containing Multiple Doses of Intravenous Pegylated Asparaginase Appears Safe and Effective in Newly Diagnosed Adult Patients with Ph-Negative Acute Lymphoblastic Leukemia in Adults up to Age 60: Results of a Multi-Center Phase II Clinical Trial. *Blood*. 2016; **128** (1629).

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

**Competing Interests:** Servier (consultant)

**Reviewer Expertise:** Asparaginase, leukemia treatment, therapeutic drug monitoring

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.