Drug Susceptibility in HIV Infection After Viral Rebound in Patients Receiving Indinavir-Containing Regimens

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**Context** Loss of viral suppression in patients infected with human immunodeficiency virus (HIV), who are receiving potent antiretroviral therapy, has been attributed to outgrowth of drug-resistant virus; however, resistance patterns are not well characterized in patients whose protease inhibitor combination therapy fails after achieving viral suppression.

**Objective** To characterize drug susceptibility of virus from HIV-infected patients who are failing to sustain suppression while taking an indinavir-containing antiretroviral regimen.

**Design and Setting** Substudy of the AIDS Clinical Trials Group 343, a multicenter clinical research trial conducted between February 1997 and October 1998.

**Patients** Twenty-six subjects who experienced rebound (HIV RNA level ≥200 copies/mL) during indinavir monotherapy (n = 9) or triple-drug therapy (indinavir, lamivudine, and zidovudine; n = 17) after initially achieving suppression while receiving all 3 drugs, and 10 control subjects who had viral suppression while receiving triple-drug therapy.

**Main Outcome Measure** Drug susceptibility, determined by a phenotypic assay and genotypic evidence of resistance assessed by nucleotide sequencing of protease and reverse transcriptase, compared among the 3 patient groups.

**Results** Indinavir resistance was not detected in the 9 subjects with viral rebound during indinavir monotherapy or in the 17 subjects with rebound during triple-drug therapy, despite plasma HIV RNA levels ranging from 10^2 to 10^5 copies/mL. In contrast, lamivudine resistance was detected by phenotypic assay in rebound isolates from 14 of 17 subjects receiving triple-drug therapy, and genotypic analyses showed changes at codon 184 of reverse transcriptase in these 14 isolates. Mean random plasma indinavir concentrations in the 2 groups with rebound were similar to those of a control group with sustained viral suppression, although levels below 50 ng/mL were more frequent in the triple-drug group than in the control group (P = .03).

**Conclusions** Loss of viral suppression may be due to suboptimal antiviral potency, and selection of a predominantly indinavir-resistant virus population may be delayed for months even in the presence of ongoing indinavir therapy. The results suggest possible value in assessing strategies using drug components of failing regimens evaluated with resistance testing.

**See also pp 205 and 250.**

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ever, these patients’ regimens had not suppressed the virus fully, thus providing opportunity for selection of virus with resistance mutations. Resistance patterns in patients failing PI combination therapy following suppression are less well characterized.

We describe drug susceptibility in 26 trial participants achieving suppression with indinavir, zidovudine, and lamivudine followed by loss of suppression. Nine patients were receiving only indinavir when rebound was observed.

**METHODS**

**Subjects**

Subjects were a subset of the AIDS Clinical Trials Group 343 (ACTG 343) participants (for whom eligibility criteria were CD4 cells ≥ 200 × 10^6/L, HIV RNA levels ≥ 1000 copies/mL, limited treatment [<7 days] with PIs, and no prior treatment with lamivudine or abacavir). The goal for ACTG 343 was to assess whether suppression achieved by potent triple-drug therapy could be sustained with less intensive therapy. Subjects (n = 309) were prescribed 6 months of open-label induction therapy with indinavir, 800 mg every 8 hours, lamivudine, 150 mg twice daily, and zidovudine, 300 mg twice daily. Levels of HIV RNA were assayed at 4-week intervals. Treatment discontinuation was recorded but detailed adherence studies were not performed. Subjects with HIV RNA levels less than 200 copies/mL after 16, 20, and 24 weeks of induction therapy were randomized (blinded) in the maintenance phase to receive indinavir, triple-drug, and control groups as previously reported. Drug susceptibility was quantified by determining the 50% inhibitory concentration (IC_{50}) of drug assayed in vitro of a recombinant test strain incorporating protease and reverse transcriptase gene segments from patient isolates in the presence of protease and reverse transcriptase inhibitors compared with a control (NL4-3) strain. The IC_{50} values greater than 2.5-fold those of the drug-susceptible reference strain indicated reduced susceptibility based on assay validation studies.

**Phenotypic Resistance Testing**

Resistance was evaluated using a phenotypic assay for drug susceptibility (PhenoSense, ViroLogic Inc, San Francisco, Calif) on baseline and follow-up plasma samples from all patients in the indinavir, triple-drug, and control groups as previously reported. Drug susceptibility was quantified by determining the 50% inhibitory concentration (IC_{50}) of drug assayed in vitro of a recombinant test strain incorporating protease and reverse transcriptase gene segments from patient isolates in the presence of protease and reverse transcriptase inhibitors compared with a control (NL4-3) strain. The IC_{50} values greater than 2.5-fold those of the drug-susceptible reference strain indicated reduced susceptibility based on assay validation studies.

**Genotypic Resistance Testing**

Sequence analysis of drug-resistance mutations in reverse transcriptase and protease genes was done using population-based sequence analysis (PE Biosystems, Foster City, Calif) on all resistance test vector plasmid pools evaluated for evidence of resistance by phenotypic assay. Amino acid substitutions identified via comparison with NL4-3 were reported. As with the PhenoSense assay, the sequencing results represent the majority species of the HIV RNA amplified from plasma, except in 1 case involving 1 subject. In a prior study evaluating the sensitivity of this method for detecting mixtures of virus pools with 5 HIV polymerase gene polymorphisms, we found that the majority population was readily detectable. Minority species may not be uniformly detected by this method. Resistance mutations were classified as primary or secondary based on recent consensus guidelines.

**Indinavir Concentrations**

Indinavir concentrations were measured in a central laboratory using high-pressure liquid chromatography on plasma from 29 subjects with available banked plasma samples from time points coinciding with ACTG 343 protocol visits. After extracting indinavir with ethyl t-butyl ether, indinavir and an internal standard were back-extracted from the organic layer following acidification. Repeat extraction of indinavir and the internal standard with methyl t-butyl ether was performed after basification and the final organic was decanted and evaporated. The residue was dissolved with a phosphate buffer and acetonitrile mixture, and the extract was analyzed using high-pressure liquid chromatography with column switching. Chromatograph peaks were monitored by assessing absorbance at 210 nm.

The standard curve range for the indinavir assay ranged from 5 to 500 ng/mL. Precision and accuracy were 5.0% and 5.8%, respectively, at the low standard, and 1.6% and 0.7% at the high standard. The indinavir concentration was weighted by number of indinavir measures (range, 4-8) for each subject. Mean and median of indinavir values for each subject were used to generate weighted mean and median indinavir concentrations for each group. These values were compared using Kruskall-Wallis analysis of variance. The proportion of subjects with at least 1 indinavir value of less than 50 ng/mL was compared among the 3 groups using Fisher exact test.
(mean baseline HIV RNA level, 46 109 copies/mL). Four subjects had HIV RNA levels of less than 50 copies/mL by 8 weeks, 2 by 12 weeks, and 3 by 16 weeks. Rebound was detected 2 to 8 weeks after subjects switched to maintenance therapy. Peak HIV RNA levels during rebound ranged from 10^9 to 10^10 copies/mL.

Viral isolates were assayed for drug susceptibility and drug-resistance mutations 3 to 14 weeks after the switch to indinavir monotherapy, and for 3 subjects were assessed at 2 sequential time points (Table 1). Levels of HIV RNA ranged from 10^2 to 10^6 copies/mL in the samples collected at the same time points used for drug susceptibility testing. Viral isolates at baseline and during rebound showed no reduction in susceptibility to indinavir or to PIs nel-finavir, ritonavir, and saquinavir.

Nucleotide sequencing detected no primary mutations known to be associated with indinavir resistance (codons 46 and 82). Changes at codons 10, 20, 24, 32, 54, 63, 71, 73, and 90 were reported in patients with indinavir resistance and classified as secondary mutations. Persons infected with HIV may have changes at these codons prior to therapy initiation. Only those substitutions present during rebound but not at baseline are shown here.

There were no primary indinavir-resistance mutations with substitutions at codons 46 and 82. Changes at codons 10, 20, 24, 32, 54, 63, 71, 73, and 90 were reported in patients with indinavir resistance and classified as secondary mutations. Persons infected with HIV may have changes at these codons prior to therapy initiation. Only those substitutions present during rebound but not at baseline are shown here.

Drug Susceptibility
With Triple-Drug Therapy
No significant changes in indinavir susceptibility were detected during rebound in the 17 patients receiving triple-drug therapy despite peak HIV RNA levels during rebound of 1864 to 138,989 copies/mL (Table 2) (a representative subject’s experience is illustrated in the figure). The primary indinavir-resistance mutation M46L was identified in subject 24 at week 35 but not week 41. Antiretroviral therapy interruption with reduction of selective pressure shortly after the week 35 visit may explain the reappearance of wild-type virus at week 41. Secondary-resistance mutations were present at baseline at codon 63 (9 subjects), codon 10 (5 subjects), and codon 71 (2 subjects), but no new secondary indinavir-resistance mutations appeared in any rebound isolate. Duration of observation during rebound (mean, 6 months; range, 1-12 months) was longer in patients failing triple-drug therapy vs those with rebound when receiving indinavir maintenance therapy (mean, 1 month; range, 0.5-2.5). Although encouraged to switch to alternative antiretroviral regimens, patients chose to continue taking this triple-drug therapy due in part to the limited number of other regimens available at that time.

In 14 of the 17 subjects, lamivudine resistance was detected with the phenotypic assay in viral isolates obtained during rebound. Sequencing confirmed that the methionine to valine substitution at codon 184 of reverse transcriptase, known to confer high-level resistance to lamivudine, was present in all 14 isolates. In 13 of the 14 subjects with lamivudine resistance, lamivudine susceptibility decreased by more than 100-fold at rebound vs the control isolate. In 1 of the 14 subjects, a mixture of isolates with methionine and valine were present, and susceptibility to lamivudine was 7-fold less than that in the control group. Rebound isolates were sensitive to lamivudine in 3 subjects. In analyses from a separate pharmacokinetic study (J.-P.S., unpublished data, 1999), indinavir concentrations were undetectable at weeks 12, 20, and 35 in subject 24, who had no resistance to lamivudine, suggesting prescribed medications were not taken.

Random Indinavir Levels
Detectable indinavir concentrations were present in 98% of samples from the indinavir group, 72% from the triple-drug group, and 82% from the control group. At least 4 samples per patient were assessed (mean, 5.4 per patient). Indinavir levels were obtained both during suppression and rebound in 7 patients in the triple-therapy group and 2 patients in

**Table 1.** Drug Susceptibility in Subjects With Viral Rebound Receiving Indinavir Maintenance Therapy

<table>
<thead>
<tr>
<th>Subject</th>
<th>HIV RNA, copies/mL</th>
<th>Weeks of Indinavir Maintenance at Assay</th>
<th>Secondary Indinavir-Resistance Mutations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>168 035</td>
<td>2386</td>
<td>4, 12</td>
</tr>
<tr>
<td>2</td>
<td>4570</td>
<td>37 607</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>58 586</td>
<td>155 000</td>
<td>8, 14</td>
</tr>
<tr>
<td>4</td>
<td>8491</td>
<td>13 411</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>9065</td>
<td>1107</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>3956</td>
<td>1852</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>28 870</td>
<td>16 545</td>
<td>3, 8</td>
</tr>
<tr>
<td>8</td>
<td>44 513</td>
<td>62 012</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>65 582</td>
<td>2430</td>
<td>3</td>
</tr>
</tbody>
</table>

*There were no primary indinavir-resistance mutations with substitutions at codons 46 and 82.
†Peak level of human immunodeficiency virus (HIV) RNA during rebound when the viral isolates were assayed for drug susceptibility.
‡Each isolate assayed at these time points was sensitive for indinavir susceptibility. Sensitive was defined by 50% inhibitory concentration (IC50) of drug assayed in vitro less than or equal to 2.5-fold that of control isolate; resistance was defined as IC50 greater than 2.5-fold those of control.
§Substitutions at the following codons have been associated with indinavir resistance: 10, 20, 24, 32, 54, 63, 71, 73, and 90. Some patients had polymorphisms at these codons prior to therapy initiation. Only those substitutions present during rebound but not at baseline are shown here.
This isolate had a 7-fold reduction in susceptibility vs all the other resistant isolates (which had‡). There were no primary or secondary indinavir-resistance mutations except for subject 24, who had a primary mutation at M46L.

Subject defined as 50% inhibitory concentration (IC50) of drug assayed in vitro less than twice that of control isolate; resistance defined as IC50 2.5-fold greater than that of control.

TABLE 2. Drug Susceptibility in Subjects Receiving Indinavir, Zidovudine, and Lamivudine With Viral Rebound*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Maximum Weeks of Viral Rebound at Assay</th>
<th>Peak HIV RNA Level During Viral Rebound, copies/mL</th>
<th>Weeks of Triple-Drug Therapy at Assay</th>
<th>Susceptibility† of Indinavir</th>
<th>Lamivudine</th>
<th>Genotype of Codon 184V of Reverse Transcriptase</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>12</td>
<td>32 962</td>
<td>32, 36, 44</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>11</td>
<td>17</td>
<td>22 426</td>
<td>24, 31</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>12</td>
<td>37</td>
<td>68 659</td>
<td>30, 36, 46, 61</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>13</td>
<td>22</td>
<td>10 320</td>
<td>16, 24, 38</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>14</td>
<td>25</td>
<td>62 220</td>
<td>20, 45</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>29 996</td>
<td>24, 36, 44</td>
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<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>18 64</td>
<td>16, 20</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>17</td>
<td>8</td>
<td>24 60</td>
<td>29, 38</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>18</td>
<td>19</td>
<td>39 67</td>
<td>24, 35</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>19</td>
<td>28</td>
<td>19 487</td>
<td>20, 48</td>
<td>Sensitive</td>
<td>Wild type</td>
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<tr>
<td>20</td>
<td>16</td>
<td>57 917</td>
<td>20, 28</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>21</td>
<td>36</td>
<td>10 061</td>
<td>26, 62</td>
<td>Sensitive</td>
<td>Wild type</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>29</td>
<td>62 40</td>
<td>49</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>23</td>
<td>46</td>
<td>11 493</td>
<td>66</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>24</td>
<td>25</td>
<td>49 697</td>
<td>35, 41</td>
<td>Sensitive</td>
<td>Wild type</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>24</td>
<td>138 989</td>
<td>24, 40</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
<tr>
<td>26</td>
<td>49</td>
<td>27 172</td>
<td>65</td>
<td>Sensitive</td>
<td>Resistant</td>
<td>M184V</td>
</tr>
</tbody>
</table>

*The baseline isolates contained polymorphisms considered secondary indinavir-resistance mutations in 16 subjects and are listed in the “Results” section. HIV indicates human immunodeficiency virus.

†Sensitivity defined as 50% inhibitory concentration (IC50) of drug assayed in vitro less than twice that of control isolate; resistance defined as IC50 2.5-fold greater than that of control.

‡There were no primary or secondary indinavir-resistance mutations except for subject 24, who had a primary mutation at M46L.

§This isolate had a 7-fold reduction in susceptibility vs all the other resistant isolates (which had >100-fold reductions).

The patients in this study had suppressed viral load to below 50 copies/mL while taking triple-drug therapy. Suppression was then lost either when continuing triple therapy or when switching to indinavir maintenance therapy. In both groups, indinavir levels were detectable in most samples tested and indinavir-sensitive virus was the predominant population identified during rebound. In most patients continuing to receive lamivudine as part of triple-drug therapy, virus was lamivudine-resistant phenotypically and genotypically at the time of rebound. Outgrowth of indinavir-sensitive, lamivudine-resistant HIV emerged rapidly. These observations and similar ones involving PI monotherapy led to the generally held assumption that when suppression failure occurs with a regimen containing a PI, PI-resistant virus accounts for HIV RNA rebound. Failure to detect resistance in some patients was attributed to regimen nonadherence. The results from this study and others challenge this view and suggest that suboptimal antiviral potency permits rebound, and that selection of a predominantly PI-resistant virus population may be delayed for months.

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resistant virus with continuing treatment pressure may be explained by viral fitness and antiviral potency.

By definition, the predominant virus replicating under a set of selective pressures is the most fit. For lamivudine or non–nucleoside reverse transcriptase inhibitors such as nevirapine or efavirenz, a single nucleotide change can confer a 20- to 1000-fold reduction in susceptibility.23-26 In the presence of drugs, the mutant virus is so much more fit that it will predominate. Clinical data confirm that when antiviral potency of a regimen containing one of these drugs is insufficient to suppress replication, drug-resistant virus rapidly emerges.27-29 Most patients failing triple therapy herein had lamivudine resistance. In a study of isolates from patients with rebound when taking an efavirenz and indinavir combination regimen, most isolates were resistant to efavirenz.30

Why did indinavir-sensitive virus appear in patients continuing therapy? Possible factors include impaired fitness of early indinavir–resistant mutant virus, reduced antiviral potency, and an increase in target cells. In contrast to lamivudine and non–nucleoside reverse transcriptase inhibitors, development of high-level resistance to PIs and zidovudine requires the accumulation of multiple mutations.9,10,31,32 For PIs, the first mutation confers only limited reduction in susceptibility, usually less than 10-fold.33 Also, the first mutations adversely affect protease function and virus replication.9,11,34 Thus, a virus with 1 or 2 mutations is less fit than wild type, even in the presence of drugs.

In those receiving indinavir maintenance therapy, reduction in antiviral potency (ie, discontinuation of zidovudine and lamivudine) allowed increased viral replication. Because the wild-type virus had a fitness advantage over early mutant virus, it was the predominant population for months. Replication may also have been enhanced by an increase in target cells. In patients randomized to maintenance therapy in ACTG 343, loss of suppression was most likely in those with the greatest increment in CD4 cell number,6 supporting predator-prey models proposed to explain viral dynamics in patients receiving zidovudine.35 The models were later extended to induction-maintenance treatment strategies.5 In these models, increased numbers of target cells resulting from treatment provide better conditions for the virus when suppression is incomplete.

Based on prior studies of indinavir monotherapy, one would expect that had patients failing indinavir maintenance therapy not been switched back to more potent regimens, indinavir-resistant virus would have become the predominant population. Continuing growth of the breakthrough virus in the presence of drug select for an accumulation of mutations conferring both reduced susceptibility and compensation for the adverse impact of resistance mutations on protease function and virus replication. Compensatory mutations have been well characterized both in protease outside the substrate binding site and in protease cleavage sites in gag.36,37 The maximum period of observation of indinavir maintenance failures was 3 months. It is probable that selection of early indinavir-resistant mutant virus occurred, but that the prevalence remained below the limit of detection of the assay used to assess drug susceptibility.

In patients failing triple-drug therapy, diminished antiviral potency (as a result of suboptimal adherence or drug delivery) undoubtedly contributed to rebound. Although the specimen collection schedule was not designed to assess indinavir exposure, evaluation of random samples for indinavir levels suggested that patients taking triple-drug therapy that was failing had more dosing interruptions than the indinavir maintenance group (data not shown). Brief periods of low or undetectable drug levels may have allowed unabated replication and the fitness disadvantage of early indinavir-resistant mutant virus may have allowed sensitive virus to predominate for months.

In terms of alternative hypotheses to explain outgrowth of virus wild type in protease with indinavir, the presence of p7/p1 or p1/p6 gag cleavage-site mutations were ruled out by the sequencing, which also excluded the theoretical possibility of a gag–pol frameshift mutation resulting in increased expression of protease. Also, drug efflux transporters could have diminished indinavir’s effect and not been detected via measure of indinavir levels. This possibility is supported by the recent recognition of P glycoprotein transporters that can serve as protease efflux pumps in vitro.36,37

Our findings have several clinical implications. First, in patients failures suppressing antiretroviral combination regimens, the predominant virus population may be resistant to 1 (ie, lamivudine), but not all (ie, PI) components of the regimen. Second, not all drugs in a failing regimen (defined as a rebound in HIV RNA levels) may be lost options. Third, these data suggest that drug-resistance testing early after loss of suppression may be useful in identifying components of a failing regimen that might be useful in a new combination regimen. These results suggest value in assessing strategies using drug components of a failing combination evaluated by resistance testing.

Table 3. Random Plasma Indinavir Concentrations*

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Subjects</th>
<th>No. of Measures</th>
<th>Range, ng/mL</th>
<th>Indinavir Concentration, ng/mL</th>
<th>No. of Subjects With at Least 1 Indinavir Value &lt; 50 ng/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indinavir</td>
<td>9</td>
<td>51</td>
<td>114-4928</td>
<td>1486 (584)</td>
<td>522 (309)</td>
</tr>
<tr>
<td>Triple drug</td>
<td>10</td>
<td>55</td>
<td>22-3585</td>
<td>1429 (370)</td>
<td>1084 (492)</td>
</tr>
<tr>
<td>Control†</td>
<td>10</td>
<td>50</td>
<td>375-3047</td>
<td>1627 (300)</td>
<td>1585 (522)</td>
</tr>
</tbody>
</table>

*Indinavir levels were obtained both during suppression and viral rebound for 7 patients in the triple-therapy group and 2 patients in the indinavir group. For the other subjects, levels were obtained during suppression.
†Patients maintaining suppression who were receiving indinavir, zidovudine, and lamivudine.
‡The proportion of subjects with at least 1 indinavir value less than 50 ng/mL is significantly higher in the triple-drug group vs the control group (P = .03).

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However, systematic studies are needed to address concerns that retaining part of a regimen that appears sensitive on resistance testing could lead to selection of resistant minority species that may contribute to virologic failure of the new regimen and reduced treatment options. Finally, it must be acknowledged that PI-sensitive virus in patients taking a failing regimen is not necessarily evidence of nonadherence.

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