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Mitochondrial toxicity has been recently suggested to be the underlying mechanism of long-term linezolid-associated toxicity in patients with 16S rRNA genetic polymorphisms. Here, we report for the first time two cases of lactic acidosis due to long-term linezolid exposure in liver transplant recipients who presented an A2706G mitochondrial DNA polymorphism.

Linezolid was the first oxazolidinone to be approved for clinical use by the Food and Drug Administration in 2000. This antimicrobial inhibits bacterial protein synthesis by binding to the 23S rRNA of the 50S subunit. Linezolid is used to treat a variety of Gram-positive infections, including those due to methicillin-resistant Staphylococcus aureus and vancomycin-resistant enterococci. In addition, it has been used as a valid alternative in the management of Nocardia infections, multidrug-resistant tuberculosis, and other mycobacterial infections. Linezolid is generally well tolerated, and most reported adverse effects are mild, transient, and reversible upon the cessation of therapy. Among the most common side reactions are gastrointestinal disturbances, followed by headache and rash. However, long-term use of this antibiotic can lead to severe toxicity, particularly myelosuppression, peripheral or optic neuropathy, serotonin syndrome (1), and lactic acidosis (1–12).

There is evidence that mitochondrial toxicity is the underlying mechanism of lactic acidosis and peripheral and optic neuropathy (7, 10). Soriano et al. (10) reported that mitochondrial respiratory chain complex IV (synthesized by mitochondrial ribosomes) activity was lower in linezolid-treated patients than in nontreated patients, suggesting a relationship between linezolid-related toxicity and mitochondrial protein synthesis inhibition due to potential structural similarities between bacterial and mitochondrial ribosomes. In addition, De Vriese et al. also reported a decreased mitochondrial enzymatic activity in a patient treated with linezolid (6). Moreover, it has been recently described that the presence of A2706G and G3010A mitochondrial 16S rRNA polymorphisms could predispose to the development of linezolid-related lactic acidosis (4, 11). Here, we have studied the presence of 16S rRNA polymorphisms in two liver transplant patients who developed lactic acidosis while receiving linezolid therapy.

Case 1. A 72-year-old diabetic woman was diagnosed with disseminated nocardiosis (i.e., bone and central nervous system). She had received a liver transplant due to hepatitis C virus-associated cirrhosis. He started treatment with amoxicillin (2 g twice a day [b.i.d.]) and linezolid (600 mg b.i.d.). Clinical and radiological improvements were observed after 4 weeks of treatment. She was discharged with oral linezolid. Nine weeks later, she was readmitted to our hospital with hypoglycemic coma and lactic acidosis. At the admission date, arterial blood gas data were as follows: pH 7.25; lactate, 3.20 mmol/liter; and HCO₃, 15.60 mmol/liter. Other causes of hyperlactatemia were excluded. No evidence of graft dysfunction was observed. Even though the bicarbonate rate improved with fluid solution, the lactate increased to 4.80 mmol/liter, and she continued with diarrhea and vomiting. Linezolid was stopped and doxycycline was started. Thiamine infusion was administered. The patient was discharged without gastrointestinal symptoms and normalization of lactic acid levels. She successfully completed 1 year of treatment with doxycycline (100 mg/day). She has no signs of nocardiosis up to date (i.e., 7 years after nocardiosis diagnosis).

Case 2. A 43-year-old man was diagnosed with lung tuberculosis. Three years before he had received a liver transplant due to hepatitis C virus-associated cirrhosis. He started treatment with ethambutol (Myambutol; 400 mg t.i.d.), pyrazinamide (20 mg/kg of body weight),isoniazid (300 mg), and levofloxacin (500 mg) per day. He developed severe myalgias, so levofloxacin and pyrazinamide were stopped and linezolid (600 mg b.i.d.) was orally started. The patient was admitted in our hospital 8 weeks after beginning with linezolid because of nausea, asthenia, and diarrhea. The arterial blood gas data were as follows: pH 7.29; lactate, 7.20 mmol/liter; HCO₃, 15.60 mmol/liter. He suffered an acute renal failure with a creatinine clearance of 30 ml/min (creatinine of 2.5 mg/dl) and pancytopenia. Linezolid was stopped and fluid resuscitation with bicarbonate was started. Other causes of hyperlactatemia were excluded, including sepsis, liver failure, and expo-
sure to medications generally known to cause it. No evidence of
graft dysfunction was observed. Thiamine infusion was adminis-
tered. The patient improved and lactic acid decreased to normal
values. The antituberculous drugs were changed and ethambutol
was reintroduced, continuing with isoniazid with adequate tolerance
to the treatment. He completed 1 year of treatment and has no
signs of tuberculosis up to date (i.e., 1 year after finishing treat-
ment).

Screening for polymorphisms in mitochondrial 16S rRNA was
performed as previously reported (7) following both restriction
enzyme digestion and sequencing of PCR fragments amplified
from blood DNA. A total of 200 ng of genomic DNA isolated from
peripheral blood lymphocytes (Lymphohemat-H protocol; Cedar-
lane) was used for the PCR. PCR conditions, using the GoTaq
Flexi DNA polymerase (Promega), were as follows: (i) 95°C for 2
min; (ii) 30 cycles at 95°C for 30 s, 57°C for 30 s, and 72°C for 40 s;
and (iii) 1 cycle at 72°C for 7 min. PCR was amplified in a 2720
Thermal Cycler apparatus (Applied Biosystems), and DNA se-
quencing of the PCR products was performed using the BigDye
Terminator 3.1 kit and the ABI PRISM 3120 XL apparatus (Ap-
plied Biosystems). To identify the A2706G polymorphism, we em-
ployed the restriction enzyme NlaIII (New England Biolabs),
which recognizes the 5'-CATG-3' sequence and digests a 237-bp
PCR product (amplified with the following primers: forward, 5'
-ACCGTGCAAAGGTAGCATAA-3'; and reverse, 5'-GCCCCAA
CCGAATTTTTTA-3') in 3 bands (121 and 116 bp) for the se-
quenches containing the A2706G polymorphism but did not cut
the wild-type fragment. On the other hand, to identify the G3010A
polymorphism, we employed the restriction enzyme Bcl (New
England BioLabs), which recognizes the 5'-CCATC-3' sequence and
digests a 1,074-bp PCR product (amplified with the following primers:
forward, 5'-ACCTCTCACACCCAATTGGA-3'; and reverse, 5'
-GGAGGTTGGCCATGGGTATG-3') in 2 bands (121 and 116 bp) for the se-
quenches containing the G3010A polymorphism. The digestion products were run in a 2.5% agarose gel
and visualized in a GELDOC EQ PC system (Bio-Rad).

The analysis of mitochondrial 16S rRNA revealed that both
patients possessed the A2706G polymorphism. As expected for
this polymorphism, the digestion of the PCR product (237 bp)
with the restriction enzyme NlaIII produced two fragments of 121
and 116 bp (Fig. 1A), being the sequence confirmed by sequencing the undigested fragment (B).

FIG 1 Analysis of mitochondrial 16S rRNA. PCR product (237 bp) digestion
with the restriction enzyme NlaIII produced 2 fragments of 121 and 116 bp
(A), being the sequence confirmed by sequencing the undigested fragment (B).
reported mitochondrial DNA polymorphisms associated with linezolid-induced lactic acidosis is debatable given the small number of patients whose mitochondrial DNA has been analyzed to detect single-nucleotide polymorphisms associated with lactic acidosis. We do not know if the variant was present in the transplanted livers, but we believe that it is not justified to determine liver sequences. As this variant may be common, it is possible that the variant was present in the transplanted livers.

There is no proven therapy to treat linezolid-induced lactic acidosis. Removal of the offending agent and care support are the most important measures. Because the mechanism of lactic acidosis associated with linezolid might be related to mitochondrial toxicity, use of respiratory chain cofactors (e.g., thiamine, riboflavin, l-carnitine, or coenzyme Q10) has been attempted in a few cases as a treatment strategy (4).

In summary, as we report here, the majority of episodes of linezolid-related hyperlactatemia occur in patients receiving prolonged therapy. It could be useful to measure serum lactate levels in liver transplant patients taking linezolid, especially if they are taking other drugs potentially able to induce lactic acidosis or to inhibit the P-glycoprotein or if they have renal insufficiency. In these patients, it could also be useful to perform a genetic study looking for the described polymorphisms.

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REFERENCES