Effects of Coenzyme Q₁₀ in Early Parkinson Disease

Evidence of Slowing of the Functional Decline

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Background: Parkinson disease (PD) is a degenerative neurological disorder for which no treatment has been shown to slow the progression.

Objective: To determine whether a range of dosages of coenzyme Q₁₀ is safe and well tolerated and could slow the functional decline in PD.

Design: Multicenter, randomized, parallel-group, placebo-controlled, double-blind, dosage-ranging trial.

Setting: Academic movement disorders clinics.

Patients: Eighty subjects with early PD who did not require treatment for their disability.

Interventions: Random assignment to placebo or coenzyme Q₁₀ at dosages of 300, 600, or 1200 mg/d.

Main Outcome Measure: The subjects underwent evaluation with the Unified Parkinson Disease Rating Scale (UPDRS) at the screening, baseline, and 1-, 4-, 8-, 12-, and 16-month visits. They were followed up for 16 months or until disability requiring treatment with levodopa had developed. The primary response variable was the change in the total score on the UPDRS from baseline to the last visit.

Results: The adjusted mean total UPDRS changes were +11.99 for the placebo group, +8.81 for the 300-mg/d group, +10.82 for the 600-mg/d group, and +6.69 for the 1200-mg/d group. The P value for the primary analysis, a test for a linear trend between the dosage and the mean change in the total UPDRS score, was .09, which met our prespecified criteria for a positive trend for the trial. A prespecified, secondary analysis was the comparison of each treatment group with the placebo group, and the difference between the 1200-mg/d and placebo groups was significant (P = .04).

Conclusions: Coenzyme Q₁₀ was safe and well tolerated at dosages of up to 1200 mg/d. Less disability developed in subjects assigned to coenzyme Q₁₀ than in those assigned to placebo, and the benefit was greatest in subjects receiving the highest dosage. Coenzyme Q₁₀ appears to slow the progressive deterioration of function in PD, but these results need to be confirmed in a larger study.

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vodopa and selegiline hydrochloride does not affect mitochondrial function. The possibility that a systemic insult to the mitochondria could preferentially injure nigral dopaminergic neurons has been supported by the demonstration that systemic administration of rotenone, which inhibits complex I but is not selectively taken up into dopaminergic neurons, causes preferential injury to the nigral dopaminergic neurons in rats.17

Coenzyme Q10 is the electron acceptor for complexes I and II and also a potent antioxidant. Shults et al18 demonstrated reduced levels of coenzyme Q10 in the mitochondria isolated from platelets of patients with PD, and the serum level of coenzyme Q10 in patients with parkinsonism has been reported to be significantly lower than that in age-comparable patients with stroke.19 Beal et al20 demonstrated that oral supplementation with coenzyme Q10 reduced the loss of dopamine and dopaminergic axons in the striatum in 1-year-old mice treated with MPTP. Matthews et al21 found that oral supplementation with coenzyme Q10 in rats resulted in significant increases in the concentration of coenzyme Q10 in mitochondria in the cerebral cortex. In a pilot study, Shults et al22 demonstrated that oral consumption of coenzyme Q10 at dosages of 400, 600, or 800 mg/d by patients with PD was well tolerated and resulted in significant elevations of plasma levels of coenzyme Q10. On the basis of this work, we undertook a dosageranging study to evaluate the safety and tolerability of high dosages of coenzyme Q10 in patients with early PD and the ability of coenzyme Q10 to reduce the rate of functional decline in such patients.

METHODS
ORGANIZATION

This multicenter study was organized by the University of California–San Diego in conjunction with the Parkinson Study Group; the Clinical Trials Coordination Center and the Department of Biostatistics at the University of Rochester, Rochester, NY; the Department of Neurology and Neuroscience at the Weill Medical College of Cornell University, New York, NY; and the enrolling sites. The National Institute of Neurological Disorders and Stroke sponsored the trial. Coenzyme Q10 and matching placebo were supplied by Vitaline Corp, Ashland, Ore. Ten investigators at 10 Parkinson Study Group sites in the United States were responsible for the recruitment, enrollment, and follow-up of subjects. The institutional review board at each site reviewed and approved the protocol. The principal investigator and the Steering Committee guided the trial. The Safety Monitoring Committee, established by the Steering Committee, and the Performance and Safety Monitoring Board, constituted by the National Institute of Neurological Disorders and Stroke, independently and periodically reviewed enrollment, premature terminations, end points, adverse events, and laboratory results.

RECRUITMENT, ENROLLMENT, AND RANDOMIZATION

Eighty subjects with early PD were enrolled in the study at 10 sites. Inclusion criteria required the presence of all 3 cardinal features of PD (resting tremor, bradykinesia, and rigidity), which had to be asymmetrical. The diagnosis of PD must have been made within the previous 5 years in men or in women 30 years or older. Women must have been postmenopausal for at least 2 years or surgically sterile or using a reliable form of contraception for at least 2 months before screening and must have agreed to continue its use for the duration of participation in the study.

Exclusion criteria included the following:

1. The use of any medication for PD for 60 days before the baseline visit.
2. Parkinsonism due to drugs.
3. The use of antioxidants such as selegiline, vitamin E, and ascorbic acid (vitamin C) within 60 days of the baseline visit, and previous use of coenzyme Q10 within 120 days of the baseline visit. There was no limitation on the use of antioxidants before prettrial discontinuation of therapy. Patients were asked to take a standard daily multivitamin without minerals but no other supplemental vitamins.
4. The use of drugs known to interfere with mitochondrial activity.
5. The use of methylphenidate hydrochloride, cinnarizine, reserpine, amphetamines, or monoamine oxidase-A inhibitors within 6 months before the baseline visit.
6. An unstable dosage of drugs active in the central nervous system (eg, anxiolytics, hypnotics, benzodiazepines, and antidepressants) during the 60 days before the baseline visit.
7. The use of appetite suppressants within 60 days before the baseline visit.
8. Diseases with features of PD (eg, progressive supranuclear palsy, essential tremor, multiple system atrophy, striatonigral degeneration, olivopontocerebellar atrophy, and postencephalitic parkinsonism).
10. The presence of dementia as evidenced by a Mini-Mental State Examination score of less than 24.
11. The presence of depression as indicated by a score on the Hamilton Depression Rating Scale of greater than 10.
13. Disability sufficient to require treatment with dopaminergic drugs, as determined by the enrolling investigator.
14. A modified Hoehn and Yahr Scale score of greater than 2.5.
15. The presence of other serious illnesses.
16. Participation in other drug studies or the use of other investigational drugs within 30 days before screening.
17. A history of electroconvulsive therapy.
18. A history of brain surgery for PD.
20. A tremor score on the Unified Parkinson’s Disease Rating Scale (UPDRS) of 3 or greater.
21. At the screening visit, after the nature, purpose, and potential risks and benefits of the study were explained to the subject, written informed consent was obtained. The subject underwent evaluation with a medical history, physical examination, and a battery of clinical assessments of PD (the UPDRS,25 the Hoehn and Yahr Scale,25 the Schwab and England Scale,25 and a timed tapping task). Previous studies have established good interrater reliability for the UPDRS.26-28 For the timed tapping task, the subject alternately touched 2 counters, separated by 20 cm, with the index finger of 1 hand as many times as possible during 1 minute. Subjects performed 2 trials with each hand.
22. Screening laboratory studies included electrocardiography, a chemistry panel (levels of albumin, alkaline phosphatase, aspartate transaminase, alanine transaminase, bicarbonate, serum urea nitrogen, calcium, chloride, creatinine, glucose, lactate dehydrogenase, phosphorus, potassium, sodium, total bilirubin, total creatine kinase, total protein, and uric acid), complete blood cell count, and urinalysis.
23. The baseline visit occurred within 1 month of the screening visit. In addition to the clinical assessments of PD, a blood
sample (approximately 110 mL) was obtained to determine complex I activity in platelets and levels of coenzyme Q₁₀ in plasma. On completion of the baseline visit, each patient was randomly assigned to receive coenzyme Q₁₀ at a dosage of 300, 600, or 1200 mg/d or matching placebo in a 1:1:1:1 allocation using a computer-generated randomization plan that included stratification by the investigator and blocking (with a block size of 8) to ensure that each investigator had approximately the same number of subjects assigned to each treatment group. Subjects, enrolling investigators, enrolling coordinators, and other personnel involved in the care of the patients and the acquisition and analysis of data were masked to treatment assignment until completion of the study.

Participants underwent reevaluation at 1, 4, 8, 12, and 16 months (±7 days) after the baseline visit using the battery of clinical examinations, and the enrolling investigator determined whether sufficient disability had developed to require treatment with levodopa. Each subject was followed up for 16 months or until the investigator determined that the patient needed treatment with levodopa. A blood sample was again drawn at the final visit for evaluation of platelet mitochondrial function and plasma levels of coenzyme Q₁₀. Safety laboratory studies (chemistry panel, complete blood cell count, and urinalysis) were performed at the 1-, 4-, and 8-month and final visits.

INTERVENTION

Each patient was randomly assigned to receive coenzyme Q₁₀ at a dosage of 300, 600, or 1200 mg/d or matching placebo. The study medication was taken 4 times each day, with breakfast, lunch, and dinner and at bedtime. The wafers with active study drug contained 300 mg of coenzyme Q₁₀ and 300 IU of vitamin E as a lipophilic carrier. Matching placebo wafers also contained 300 IU of vitamin E each.

OUTCOMES, STATISTICAL METHODS, AND SAMPLE SIZE

Safety and Toleranceability

All adverse events (using World Health Organization terminology) and abnormal laboratory values were analyzed by treatment group and severity. Only new events not present at the screening or baseline visit were counted. The Cochrane-Armitage exact test for trend (1-tailed) was used to compare treatment groups with regard to the proportion of subjects experiencing a particular adverse event or an abnormal laboratory value. We used 1-tailed tests because the finding of poorer tolerability in the placebo group would have been highly unlikely and of no interest. Compliance, as measured by pill counts, was summarized descriptively by treatment group.

Efficacy and Trial Design

The primary response variable was the change in the total score on the UPDRS from the baseline to the last visit. The last visit was at which the investigator judged that disability requiring levodopa therapy had developed, the last visit before a premature termination, or the 16-month visit. At each visit, the investigator was asked to assess whether the subject had reached disability sufficient to require treatment with levodopa using a form that asked a series of questions regarding occupation, gait, balance, finances, domestic responsibility, and activities of daily living. The series of questions was based on our previous experience with this end point. The decision was the responsibility of the enrolling investigator.

Mitochondrial Assays

At the baseline and final visits, venous blood was collected into two 50-mL syringes containing 5 mL of anticoagulant sodium citrate solution. The samples were transferred at room temperature to the Mitochondrial Research Laboratory at the University of California–San Diego by overnight courier. Complex I and citrate synthetase activities were measured by means of well-established techniques. The Mitochondrial Research Laboratory, University of California–San Diego, also performed the assay for complex I/III using the rotenone-

Plasma Level of Coenzyme Q₁₀

Subjects were asked to not take study medication after the last dose on the day before follow-up visits to obtain a plasma level representative of a steady state. The samples were kept at each site at −80°C until shipped on dry ice to the laboratory at Weill Medical College of Cornell University. Assays for plasma levels of coenzyme Q₁₀ were performed by means of techniques previously described with modification. The values from 1 subject, who was assigned to receive coenzyme Q₁₀ at a dosage of 600 mg/d, appeared to represent a reversal of the baseline and final visits and were not included in the analysis.

Comparisons of plasma levels at the final visit among patients treated with coenzyme Q₁₀ and placebo were made using analysis of covariance, adjusting for the baseline value as a covariate.
sensitive reduced form of nicotinamide adenine dinucleotide (NADH) cytochrome-c reductase. The electron transport activities were normalized to that of citrate synthetase to correct for any differences in mitochondrial mass. Comparisons of complex I and complex I/III activity at the baseline and final visits among patients treated with coenzyme Q10 and placebo were made using analysis of covariance, adjusting for the baseline value and investigator as covariates.

All statistical analyses were performed using SAS software (Version 8; SAS Institute Inc, Cary, NC).

RESULTS

SUBJECTS ENROLLED

Eighty subjects were enrolled from May 24, 1999, through February 17, 2000 (Figure 1). At the baseline visit, the groups were well matched for sex, age, severity of PD (the UPDRS and Hoehn and Yahr Scale scores and the timed tapping score), disability (the Schwab and England Scale score) and intellectual function (the Mini-Mental State Examination score) (Table 1). The characteristics of our subjects were very similar to those in previous studies enrolling subjects who did not have disability sufficient to require levodopa therapy.30,34 Three subjects prematurely terminated or were lost to follow-up from the study before the investigator determined that they had reached the point that their disability warranted use of levodopa (Figure 1). Increased tremor, lower-back pain, and increased nocturia developed in 1 subject who was receiving 1200 mg/d of coenzyme Q10 and who prematurely terminated. This subject was noncompliant, and the investigator did not believe that the symptoms were
related to the study drug. This subject was lost to follow-up.

**TOLERABILITY AND SAFETY**

Coenzyme Q₁₀ was well tolerated; no dosage reductions were needed in any of the treatment groups. The percentages of subjects receiving coenzyme Q₁₀ who reported any adverse event (19 subjects [90%] for the 300-mg/d group; 12 [60%] for the 600-mg/d group; and 21 [91%] for the 1200-mg/d group) were not significantly different from that in the placebo group (13 subjects [81%]) ($P = .51$, Cochran-Armitage exact test for trend). Most adverse events were mild. Eighteen adverse events were experienced by 4 (5%) or more subjects (Table 2). When mild adverse events were excluded, 3 were experienced by at least 4 subjects, including viral infection, pharyngitis, and sinusitis. The differences among the treatment groups were not significant, and no significant trend by dosage was found in the number of subjects experiencing an adverse event.

Analysis of 84 possible high or low laboratory results revealed a nominally significant or marginally significant trend by dosage in 4, including high carbon dioxide levels ($P = .01$), high mean corpuscular hemoglobin concentration ($P = .08$), and high sodium ($P = .06$) and uric acid levels ($P = .08$). The ongoing evaluation of abnormal laboratory results during the study and the review at the completion of the study did not reveal these to be clinically significant.

Analysis of the data for weight, sitting and standing blood pressure, and heart rate did not show any significant differences among the treatment groups (data not shown).

**EFFICACY**

The adjusted mean changes in the total UPDRS score from the baseline to the final visit (positive values indicate worsening) were +11.99 for the placebo group, +8.81 for the 300-mg/d group, +10.82 for the 600-mg/d group, and +6.69 for the 1200-mg/d group (Table 3). Our primary analysis was a test for a trend between dosage and the mean change in the UPDRS score, and $P = .09$ (2-sided) was significant according to our prespecified criteria. The difference in the change in the total UPDRS score between the placebo group and the 1200-mg/d group was 5.30 (95% confidence interval, 0.21-10.39). A prespecified secondary analysis was comparison of each active treatment group with the placebo group. The difference was significant for the 1200-mg/d group ($P = .04$) but not for the 300- ($P = .22$) or the 600-mg/d ($P = .66$) groups.

The reduction in the worsening of the total UPDRS score was the result of slowed decline in all 3 components of the UPDRS, ie, mental (part I), activities of daily living (part II), and motor (part III), with the greatest effect in part II (Table 3). The greatest reduction was seen at the highest dosage (1200 mg/d). Results for the placebo vs the combined drug groups were similar (data not shown).

We also found a reduction in the worsening on the Schwab and England Scale, as assessed by the examiner ($P = .04$) but not by the patient ($P = .81$). The discrep-

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**Table 2. Adverse Events Reported by at Least 4 Subjects**

<table>
<thead>
<tr>
<th>Adverse Event</th>
<th>Placebo Group, No. (%)</th>
<th>300 mg/d</th>
<th>600 mg/d</th>
<th>1200 mg/d</th>
<th>$P$ Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1 (6.3)</td>
<td>1 (4.8)</td>
<td>0</td>
<td>2 (8.7)</td>
<td>.50</td>
</tr>
<tr>
<td>Arthralgia</td>
<td>1 (6.3)</td>
<td>2 (9.5)</td>
<td>1 (5.0)</td>
<td>4 (17.4)</td>
<td>.20</td>
</tr>
<tr>
<td>Back pain</td>
<td>1 (6.3)</td>
<td>1 (4.8)</td>
<td>1 (5.0)</td>
<td>1 (4.3)</td>
<td>.50</td>
</tr>
<tr>
<td>Coughing</td>
<td>2 (9.5)</td>
<td>1 (5.0)</td>
<td>2 (8.7)</td>
<td>.29</td>
<td></td>
</tr>
<tr>
<td>Diarrhea</td>
<td>1 (6.3)</td>
<td>2 (10.0)</td>
<td>3 (13.0)</td>
<td>.15</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td>1 (6.3)</td>
<td>0</td>
<td>2 (10.0)</td>
<td>2 (8.7)</td>
<td>.16</td>
</tr>
<tr>
<td>Dyspepsia</td>
<td>0</td>
<td>1 (4.8)</td>
<td>2 (10.0)</td>
<td>2 (8.7)</td>
<td>.25</td>
</tr>
<tr>
<td>Fall</td>
<td>1 (6.3)</td>
<td>3 (14.3)</td>
<td>0</td>
<td>1 (4.3)</td>
<td>.50</td>
</tr>
<tr>
<td>Fatigue</td>
<td>1 (6.3)</td>
<td>2 (9.5)</td>
<td>1 (5.0)</td>
<td>0</td>
<td>.18</td>
</tr>
<tr>
<td>Flatulence</td>
<td>1 (6.3)</td>
<td>0</td>
<td>2 (10.0)</td>
<td>1 (4.3)</td>
<td>.50</td>
</tr>
<tr>
<td>Headache</td>
<td>1 (6.3)</td>
<td>1 (4.8)</td>
<td>2 (10.0)</td>
<td>3 (13.0)</td>
<td>.23</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>2 (12.5)</td>
<td>1 (4.8)</td>
<td>0</td>
<td>1 (4.3)</td>
<td>.18</td>
</tr>
<tr>
<td>Infection, bacterial</td>
<td>0</td>
<td>3 (14.3)</td>
<td>0</td>
<td>1 (4.3)</td>
<td>.50</td>
</tr>
<tr>
<td>Infection, viral</td>
<td>2 (12.5)</td>
<td>4 (19.0)</td>
<td>4 (20.0)</td>
<td>2 (8.7)</td>
<td>.39</td>
</tr>
<tr>
<td>Myalgia</td>
<td>1 (6.3)</td>
<td>3 (14.3)</td>
<td>0</td>
<td>2 (8.7)</td>
<td>.46</td>
</tr>
<tr>
<td>Nausea</td>
<td>0</td>
<td>3 (14.3)</td>
<td>1 (5.0)</td>
<td>2 (8.7)</td>
<td>.39</td>
</tr>
<tr>
<td>Pain</td>
<td>2 (12.5)</td>
<td>0</td>
<td>0</td>
<td>2 (8.7)</td>
<td>.50</td>
</tr>
<tr>
<td>Pharyngitis</td>
<td>0</td>
<td>2 (9.5)</td>
<td>1 (5.0)</td>
<td>2 (8.7)</td>
<td>.29</td>
</tr>
<tr>
<td>Sinusitis</td>
<td>1 (6.3)</td>
<td>2 (9.5)</td>
<td>0</td>
<td>3 (13.0)</td>
<td>.39</td>
</tr>
<tr>
<td>Reported by at least 4 (5%) of subjects, excluding mild</td>
<td>0</td>
<td>1 (4.8)</td>
<td>1 (5.0)</td>
<td>2 (8.7)</td>
<td>.18</td>
</tr>
<tr>
<td>Reported by at least 4 (5%) of subjects, excluding unlikely related</td>
<td>1 (6.3)</td>
<td>0</td>
<td>2 (10.0)</td>
<td>1 (4.3)</td>
<td>.50</td>
</tr>
</tbody>
</table>

* Determined by the Cochran-Armitage exact test for trend.
ality between the results, as determined by the examiners and the patients, appeared to be primarily due to discordance between 1 subject, who was assigned to the 1200 mg/day treatment group, and the examiner. Coenzyme Q10 did not have a significant effect on the scores for the Hoehn and Yahr Scale or the timed tapping task. Examination of data at the month-1 visit indicated that coenzyme Q10 did not have a significant effect on the total UPDRS score at that point (Table 4). However, at the 1-month visit, we noted benefit on part II of the UPDRS, particularly at the highest dosage.

Figure 2 shows the course of the total UPDRS scores across the 16 months of the study with the last observation carried forward. By the 8-month visit, the scores had clearly separated and established a pattern of the 300- and 600-mg/d groups being similar, with lower scores than those of the placebo group, and with the scores for the 1200-mg/d group being substantially lower than those of the other groups. This pattern persisted until the end of the study and was the result of similar changes in all 3 components of the UPDRS (Figure 3).

### Table 3. Adjusted Mean Change From Baseline*

<table>
<thead>
<tr>
<th>Treatment Groups</th>
<th>Placebo Group</th>
<th>Coenzyme Q10 Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 16)</td>
<td>300 mg/d (n = 21)</td>
</tr>
<tr>
<td>Total UPDRS score</td>
<td>11.99 (9.99 to 15.99)</td>
<td>8.81 (5.42 to 12.20)</td>
</tr>
<tr>
<td>UPDRS mental score</td>
<td>0.90 (0.42 to 1.37)</td>
<td>0.54 (0.14 to 0.95)</td>
</tr>
<tr>
<td>UPDRS motor score</td>
<td>6.54 (3.56 to 9.51)</td>
<td>5.88 (3.38 to 8.39)</td>
</tr>
<tr>
<td>UPDRS ADL score</td>
<td>4.74 (3.10 to 6.38)</td>
<td>2.54 (1.14 to 3.94)</td>
</tr>
<tr>
<td>Hoehn and Yahr Scale score</td>
<td>0.02 (−0.03 to 0.01)</td>
<td>0.16 (0.03 to 0.29)</td>
</tr>
<tr>
<td>Schwab and England Scale score for ADL (examiner)</td>
<td>−7.98 (−10.58 to −5.37)</td>
<td>−4.89 (−7.08 to −2.70)</td>
</tr>
<tr>
<td>Schwab and England Scale score for ADL (subject)</td>
<td>−7.06 (−10.64 to −3.48)</td>
<td>−5.06 (−12.26 to 2.13)</td>
</tr>
<tr>
<td>Timed tapping score</td>
<td>−13.17 (−21.82 to −4.51)</td>
<td>−8.99 (−16.30 to −1.68)</td>
</tr>
</tbody>
</table>

*Changes are given as the last observation carried forward, and reported as adjusted (least squares) means (95% confidence intervals) from the analysis of covariance. Abbreviations are explained in the first footnote to Table 1.

### Table 4. Adjusted Mean Change From Baseline to 1 Month*

<table>
<thead>
<tr>
<th>Treatment Groups</th>
<th>Placebo Group</th>
<th>Coenzyme Q10 Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 16)</td>
<td>300 mg/d (n = 21)</td>
</tr>
<tr>
<td>Total UPDRS score</td>
<td>0.22 (−2.12 to 2.57)</td>
<td>1.35 (−0.63 to 3.34)</td>
</tr>
<tr>
<td>UPDRS mental score</td>
<td>−0.22 (−0.54 to 0.11)</td>
<td>−0.29 (−0.57 to −0.01)</td>
</tr>
<tr>
<td>UPDRS motor score</td>
<td>0.00 (−1.88 to 1.69)</td>
<td>1.54 (−0.95 to 3.12)</td>
</tr>
<tr>
<td>UPDRS ADL score</td>
<td>0.52 (−0.41 to 1.44)</td>
<td>0.12 (−0.66 to 0.91)</td>
</tr>
<tr>
<td>Hoehn and Yahr Scale score</td>
<td>0.01 (−0.14 to 0.16)</td>
<td>0.04 (−0.09 to 0.16)</td>
</tr>
<tr>
<td>Schwab and England Scale score for ADL (examiner)</td>
<td>−0.12 (−1.44 to 1.19)</td>
<td>−0.57 (−1.67 to 0.54)</td>
</tr>
<tr>
<td>Schwab and England Scale score for ADL (subject)</td>
<td>−0.38 (−3.00 to 2.23)</td>
<td>−0.07 (−2.28 to 2.13)</td>
</tr>
<tr>
<td>Timed tapping score</td>
<td>0.68 (−5.24 to 6.60)</td>
<td>2.42 (−2.50 to 7.34)</td>
</tr>
</tbody>
</table>

*Changes are given as the last observation carried forward and reported as adjusted (least squares) means (95% confidence intervals) from the analysis of covariance. Abbreviations are explained in the first footnote to Table 1.

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Analyses of the area under the curve using the total UPDRS actual visit data showed similar, but not as significant, results (data not shown). Examination of the time until the subject was considered to need treatment with levodopa disclosed no significant effect of coenzyme Q10 on this measure ($P = .43$) (Figure 4).

**PLASMA LEVELS OF COENZYME Q10**

All groups receiving coenzyme Q10 had highly significant increases in the mean plasma level of coenzyme Q10 from baseline to the last visit (Figure 5) ($P < .001$), and the mean plasma levels of coenzyme Q10 were significantly different among the 3 groups receiving active drug ($P < .05$), with the exception of the 300- and 600-mg/d groups ($P = .15$). All subjects received 1200 IU of vitamin E daily, and in each treatment group the plasma level of vitamin E increased slightly more than 2-fold (data not shown).

**MITOCHONDRIAL ASSAYS**

Results of the assay of the activity of complex I normalized to the activity of citrate synthetase did not indicate a significant effect of coenzyme Q10 ($P = .73$). In this assay, the activity of complex I did not depend on endogenous coenzyme Q10, as an excess of exogenous coenzyme Q was added (Figure 6A). We also determined the activity of the electron transport chain from NADH to cytochrome-c reductase (complexes I and III), which did depend on the endogenous coenzyme Q10, and found a significant increase in the activity of the electron transport chain with treatment with coenzyme Q10 ($P = .04$) (Figure 6B).

**COMMENT**

Our dosage-ranging study found that coenzyme Q10 was safe and well tolerated at the dosages of 300 to 1200 mg/d and that the 1200-mg/d dosage was associated with significant slowing of the worsening of PD as measured by
The mechanism(s) through which coenzyme Q10 exerted its beneficial effect cannot be determined from our clinical trial, but our data are consistent with an effect on mitochondrial function. The assay of NADH to cytochrome-c reductase activity, which relies on endogenous coenzyme Q10, demonstrated a significant increase in activity in subjects taking 1200 mg/d of coenzyme Q10. Although the results of our study of mitochondrial activity in platelets do not prove that a similar benefit occurred in the brain, the results are consistent with this possibility. Our data are consistent with the hypothesis that mitochondrial dysfunction plays a role in the pathogenesis of PD and that treatments targeted at mitochondria might ameliorate the functional decline in PD.

Coenzyme Q10 was unlikely to exert its effect through an increase in the level of nigrostriatal dopamine. In preclinical studies, supplementation of the diet of 1-year-old mice with coenzyme Q10 (200 mg/kg per day) for 5 weeks did not affect striatal levels of dopamine or its metabolites.

Investigators have previously described improvement after supplemental coenzyme Q10 treatment in small case series in which the patients appeared to have an inherited deficiency of coenzyme Q10. Similarly, oral coenzyme Q10 treatment (600 mg/d) for 3 months in patients with Friedreich ataxia improved bioenergetics in cardiac and skeletal muscle, but after 6 months of treatment, neurological function was not improved.

The effect of coenzyme Q10 in other diseases, particularly neurological disorders, has been inconsistent. There have been numerous reports of the benefits of coenzyme Q10 in patients with heart disease, but the studies were often not controlled. A recent prospective, randomized, double-blinded, placebo-controlled trial of coenzyme Q10 in congestive heart failure did not show benefit, but the dosage (200 mg/d) may not have been adequate. Previous studies in a variety of muscular disorders have had inconsistent results. The dosages used (30-300 mg/d) may have been inadequate, and heterogeneous neurological disorders were often studied together in these trials. In the present study, the strict inclusion criteria maximized the likelihood that the subjects had idiopathic PD.

Consistent with our findings of a reduction in the functional decline in PD are the results of a trial in which patients with early Huntington disease received coenzyme Q10 (600 mg/d), remacemide hydrochloride (600 mg/d), a combination of remacemide and coenzyme Q10, or placebo. The decline in total functional capacity was not significantly altered by any of the treatments, but subjects receiving coenzyme Q10 (with or without remacemide treatment) showed 13% less decline in total functional capacity than did the subjects who did not receive coenzyme Q10 (P = .15). Previous studies in patients with Huntington disease showed that coenzyme Q10 significantly lowered increased lactate levels in the cerebral cortex, demonstrating that it exerts biological effects in the brain.

Results of our study, in which the greatest benefit was found at a dosage of 1200 mg/d, the study of Huntington disease, in which an intriguing trend toward benefit at a dosage of 600 mg/d was observed, and the congestive heart failure study, in which no benefit was seen at a dosage of 200 mg/d, indicate that the dosage of coenzyme Q10 may be crucial. The beneficial trend in our trial was driven by the effect seen at the highest dosage of coenzyme Q10 (1200 mg/d). The plasma levels of coenzyme Q10 in the groups receiving 300 and 600 mg/d...
were relatively close, as were the total UPDRS scores in both groups. The plasma and presumably brain levels of coenzyme Q₁₀ may be a significant determinant of the effectiveness of the treatment.

In our study, coenzyme Q₁₀ treatment at high dosages was safe and well tolerated and reduced the worsening of PD, as reflected in the total UPDRS score. It would be premature to recommend the use of coenzyme Q₁₀ for the treatment of PD. Our results need to be confirmed in a larger, phase 3 study, and the appropriate dosage and the magnitude of effect need to be better defined.

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