Molecular Diagnosis and Prophylactic Therapy for Presymptomatic Chinese Patients With Wilson Disease

Zhi-Ying Wu, MD, PhD; Min-Ting Lin, MD; Shen-Xing Murong, MD; Ning Wang, MD, PhD

**Background:** The potential for therapy for Wilson disease (WD) emphasizes the importance of presymptomatic diagnosis in families with WD (WD families).

**Objectives:** To investigate the feasibility of presymptomatic DNA diagnosis and evaluate the efficacy of zinc sulfate therapy in WD families.

**Methods:** Seventy-eight clinically unaffected siblings were studied from 51 unrelated WD families that were ascertained by affected individuals. The diagnosis in presymptomatic patients was established by a combination of direct mutational analysis and haplotype analysis with 3 short tandem repeat markers. The presymptomatic patients were treated with 50 mg of elemental zinc sulfate twice a day from the time of molecular diagnosis and followed up for 3 to 5 years.

**Results:** Of the 78 siblings, 17 were diagnosed as presymptomatic patients. Kayser-Fleischer rings were absent in 7 and faint in 4 of the 17 presymptomatic patients. The serum ceruloplasmin values gradually increased and 24-hour urinary copper values gradually diminished during zinc therapy, which indicate effective control of copper metabolism. None of the siblings developed clinical symptoms of WD or adverse effects from zinc therapy.

**Conclusion:** We conclude that presymptomatic DNA diagnosis and zinc therapy are effective treatment of patients with WD.

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Wilson disease (WD), an autosomal recessive disorder of copper metabolism, causes toxic accumulation of copper in the liver, brain, cornea, and kidney. The disease phenotype includes progressive liver cirrhosis, neurologic impairment, and Kayser-Fleischer (K-F) rings and/or renal malfunction. Wilson disease can be treated successfully, but treatment must be lifelong. Without effective anticyper treatment, WD is usually crippling and frequently fatal. However, prophylactic therapy in affected but presymptomatic patients can prevent the onset of symptoms. Thus, prompt and accurate presymptomatic diagnosis is critically important.

Clinical and biochemical screening, including liver biopsy for hepatic copper analysis, remains the standard for diagnosis. However, these standard tests may give false-positive results or cause the diagnosis of WD to be missed. A missed diagnosis can result in lost opportunities for prophylactic therapy, whereas false-positive diagnosis may result in inappropriate lifelong administration of potentially toxic drugs in heterozygote carriers and those with non-Wilsonian liver disease. Furthermore, the standard criteria cannot be applied for carrier detection or presymptomatic diagnosis. Molecular diagnosis has the potential to overcome all of these limitations when the siblings of an index case are screened.

Therapy with penicillamine in presymptomatic patients was reported many years ago. However, penicillamine is an exceedingly toxic drug and may lead to adverse effects primarily involving the immune system or connective tissue. Also, it can cause the onset of neurologic disease when used in the initial therapy for presymptomatic patients. Zinc has been developed as an effective and nontoxic therapy in WD that blocks the absorption of copper and increases copper excretion in the stool. In this study, we used molecular diagnosis to identify 17 presymptomatic patients from 78 clinically unaffected siblings of 51 families with WD (hereafter referred to as WD families). Of the 17 presymptomatic patients, 14 were prescribed zinc sulfate as prophylactic therapy from the time of diagnosis and remained well 3 to 5 years later. The other 3 refused the prophylactic therapy and manifested symptoms later.

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Seventy-eight clinically unaffected siblings were studied from 51 unrelated WD families that were ascertained by the presence of affected individual family members. Genotypes of 51 propositi and 102 parents have been described elsewhere. Of 78 siblings, 53 were from 32 families with 2 known mutations and 25 were from 19 families with 1 known mutation. Informed consent for each subject was obtained according to the policy of Fujian Medical University, Fuzhou, People’s Republic of China. Genomic DNA was isolated from peripheral-blood lymphocytes by use of standard methods.

According to the genotypes of propositi,7 genotypes of 78 siblings were detected by single-stranded conformational polymorphism (SSCP) analysis of specific coding regions generated by polymerase chain reaction amplification. For example, the genotype of the propositus from family 4 was Thr935Met (exon 12)/Arg778Leu (exon 8), so genotypes of siblings from this family were identified by SSCP analyses of exon 12 and exon 8. Procedures of polymerase chain reaction amplification and SSCP analysis with nondenaturing polyacrylamide gel electrophoresis have been described elsewhere.7

HAPLOTYPE ANALYSIS

The siblings from 19 families with 1 known mutation were investigated by haplotype analysis. Three short tandem repeat (STR) markers, D13S133, D13S301, and D13S314, were analyzed in the confirmed propositi together with the parents and the siblings. Procedures of polymerase chain reaction amplification and measurement of these STR polymorphisms with denaturing polyacrylamide gel electrophoresis have been described elsewhere.8

Mothers and fathers had no detected mutations, as determined by SSCP analysis. Maternal alleles were determined by using parents as heterozygous controls. The exhibiting bands in nondenaturing polyacrylamide gel (SSCP bands) of siblings were compared with those of the propositus and parents, so the results could be obtained definitely. The exhibiting bands in nondenaturing polyacrylamide gel (SSCP bands) of siblings were compared with those of the propositus and parents, so the results could be obtained definitely.

The presymptomatic patients were treated with 50 mg of elemental zinc sulfate twice a day, separated from food by at least 1 hour, from the time of molecular diagnosis and followed up for 3 to 5 years. Also, they were put on a low-copper diet and dietary copper intake was restricted to less than 1 mg/d. At the time of diagnosis, we performed routine clinical studies, including a detailed physical and neurologic examination, blood cell counts, urinalysis, and serum biochemical determinations. Kaiser-Fleischer rings of the cornea were also identified by slitlamp examination. Serum ceruloplasmin levels and 24-hour urine copper levels were measured at the time of diagnosis and once each year.

Data were analyzed with a commercially available statistical package (SPSS, Version 8; SPSS Inc, Chicago, Ill). Results are presented as mean ± SD. Statistical analysis was performed with the t test. The criterion for significant difference was P < .05.

Table 1. Clinical Data and Genotype of Presymptomatic Patients at Time of Diagnosis

<table>
<thead>
<tr>
<th>Patient No./Sex</th>
<th>Family No.</th>
<th>Age, y</th>
<th>CP, mg/dL</th>
<th>Urinary Copper, µg/24 h</th>
<th>K-F Ring</th>
<th>Mutation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/M</td>
<td>4</td>
<td>23</td>
<td>28</td>
<td>3.0</td>
<td>+</td>
<td>Thr935Met Arg778Leu</td>
</tr>
<tr>
<td>2/M</td>
<td>5</td>
<td>12</td>
<td>17</td>
<td>15.0</td>
<td>±</td>
<td>Arg778Leu Arg778Leu</td>
</tr>
<tr>
<td>3/M</td>
<td>11</td>
<td>10</td>
<td>15</td>
<td>18.0</td>
<td>−</td>
<td>Arg778Leu Arg778Leu</td>
</tr>
<tr>
<td>4/M</td>
<td>12</td>
<td>19</td>
<td>24</td>
<td>15.4</td>
<td>±</td>
<td>Arg778Leu Arg778Leu</td>
</tr>
<tr>
<td>5/F</td>
<td>14</td>
<td>8</td>
<td>13</td>
<td>17.3</td>
<td>±</td>
<td>Arg778Leu Arg778Leu</td>
</tr>
<tr>
<td>6/M</td>
<td>14</td>
<td>5</td>
<td>10</td>
<td>16.5</td>
<td>−</td>
<td>Arg778Leu Arg778Leu</td>
</tr>
<tr>
<td>7/F</td>
<td>18</td>
<td>8</td>
<td>13</td>
<td>9.0</td>
<td>+</td>
<td>ND3insA</td>
</tr>
<tr>
<td>8/F</td>
<td>19</td>
<td>21</td>
<td>26</td>
<td>16.5</td>
<td>+</td>
<td>Gln1142His Arg778Gln</td>
</tr>
<tr>
<td>9/M</td>
<td>19</td>
<td>16</td>
<td>21</td>
<td>16.6</td>
<td>−</td>
<td>Gln1142His Arg778Gln</td>
</tr>
<tr>
<td>10/F</td>
<td>24</td>
<td>14</td>
<td>19</td>
<td>15.8</td>
<td>+</td>
<td>Arg786Gln Arg778Leu</td>
</tr>
<tr>
<td>11/F</td>
<td>29</td>
<td>12</td>
<td>16</td>
<td>7.0</td>
<td>±</td>
<td>Arg778Leu ND3</td>
</tr>
<tr>
<td>12/F</td>
<td>33</td>
<td>25</td>
<td>29</td>
<td>9.5</td>
<td>+</td>
<td>Arg786Leu ND3</td>
</tr>
<tr>
<td>13/M</td>
<td>34</td>
<td>24</td>
<td>28</td>
<td>11.0</td>
<td>−</td>
<td>Arg919Gly ND3</td>
</tr>
<tr>
<td>14/M</td>
<td>41</td>
<td>8</td>
<td>11</td>
<td>21.0</td>
<td>−</td>
<td>Arg1041Pro Arg1041Pro</td>
</tr>
<tr>
<td>15/M</td>
<td>50</td>
<td>18</td>
<td>21</td>
<td>5.5</td>
<td>±</td>
<td>Arg778Leu Arg778Leu</td>
</tr>
<tr>
<td>16/F</td>
<td>53</td>
<td>15</td>
<td>18</td>
<td>9.4</td>
<td>−</td>
<td>Thr935Met ND3</td>
</tr>
<tr>
<td>17/M</td>
<td>60</td>
<td>10</td>
<td>13</td>
<td>10.0</td>
<td>+</td>
<td>Arg786Leu ND3</td>
</tr>
</tbody>
</table>

Abbreviations: CP, ceruloplasmin; K-F, Kayser-Fleischer; ND3, no detected mutation; +, positive; ±, faint; −, negative.

*These presymptomatic patients refused zinc sulfate therapy and thus presented with neurologic (patient 1) or hepatic (patients 7 and 16) symptoms at the ages of 26, 12, and 18 years, respectively.
53 siblings from 32 families with 2 known mutations, 11 siblings who inherited mutations on both alleles, like their propositi, were diagnosed as presymptomatic patients; 17 as heterozygote carriers; and 25 as normal individuals. Among the other 25 siblings from 19 families with 1 known mutation, 16 siblings from 11 families were shown to have different SSCP bands from their propositi, so they were excluded from the presymptomatic diagnosis. They may have been heterozygote carriers or unaffected individuals. The other 9 siblings from 8 families were shown to have the same SSCP abnormal bands as their propositi. They may have been presymptomatic patients or heterozygote carriers. Haplotypes of alleles at 3 STR loci on the same chromosome were constructed for these 25 siblings and their propositi and parents to perform linkage analysis. Among 9 siblings from 8 families, 6 siblings from 6 families who inherited the same haplotypes as their propositi were diagnosed as presymptomatic patients, the other 3, as heterozygote carriers. Among 16 siblings from 11 families, 9 were diagnosed as heterozygote carriers and 7, as unaffected individuals. In conclusion, we identified 17 presymptomatic patients, 29 heterozygote carriers, and 32 unaffected individuals from 78 siblings. The genotypes of these presymptomatic patients are shown in Table 1. The diagnosis of presymptomatic patient and heterozygote carrier in family 53 with SSCP analysis of exon 12 and haplotype analysis by means of 3 STR markers is shown in the Figure.

PROPHYLACTIC THERAPY AND FOLLOW-UP STUDIES OF PRESYMPTOMATIC PATIENTS

At the time of molecular diagnosis, routine clinical studies were carried out and showed normal results among all presymptomatic patients. All of them were asked to follow a low-copper diet and undergo prophylactic treatment with zinc. Fourteen of the 17 presymptomatic patients accepted, but the other 3 refused the therapy. During the subsequent 3 to 5 years, none of the 14 presymptomatic patients who accepted the therapy developed clinical symptoms of WD or adverse effects from zinc therapy. Among the other 3 patients, 1 presented with neurologic symptoms at the age of 26 years, and 2 presented with liver symptoms at 12 and 18 years of age, respectively. The clinical information about these patients, in terms of age, sex, the presence of K-F rings, serum ceruloplasmin levels, and 24-hour urinary copper levels at the time of diagnosis, are given in Table 1. In addition, yearly serum ceruloplasmin values and 24-hour urinary copper values in the presymptomatic patients who accepted the prophylactic therapy are given in Table 2.

The normal ranges of serum ceruloplasmin and urinary copper excretion in our laboratory are 20 to 40 mg/dL and 20 to 50 µg/24 h, respectively. As shown in Table 2 and Table 3, 13 of 14 presymptomatic patients had lower serum ceruloplasmin values (<20 mg/dL). The average serum ceruloplasmin values gradually increased from a baseline mean of 13.94 to 17.60 mg/L, and the mean value after more than 4 to 5 years of zinc therapy was significantly higher than the baseline value by t test (P = .045). The 24-hour urinary copper values of these presymptomatic patients were all above the normal value at the time of diagnosis (baseline) and gradually diminished during zinc therapy. It can be clearly seen in Table 3 that the average 24-hour urinary copper values decreased substantially from a baseline mean of 132.7 to 105.0 µg/24 h, and mean values after more than 2 to 3, more than 3 to 4, and more than 4 to 5 years of zinc therapy were significantly lower than the baseline value by t test (P = .01, .03, and .047, respectively).

The potential for treatment of WD emphasizes the importance of diagnosis. Because it is inherited in a recessive
sent and ceruloplasmin concentrations may be within the present with liver disease alone, K-F rings are often ab-
in presymptomatic patients. In addition, in patients who thus, they are often absent in younger patients, especially central nervous system and are a late manifestation of WD; result in a false-positive diagnosis. The K-F rings are in-
cept of carriers have low ceruloplasmin levels, which will be missed. The most reliable method for accurately diagnosing WD is by measuring the hepatic copper level. However, liver copper measurements can be misleading, because there is extreme variation of copper deposition in different parts of the liver. Thus, in many cases, WD is difficult to diagnose with standard criteria, especially if K-F rings are not present. In this situation, the diagnoses of asymptomatic siblings in WD families need to be confirmed or ruled out by genetic analysis.

Wilson disease is caused by mutations in the ATP7B gene encoding a putative copper-transporting P-type adenosine triphosphatase. According to the genotypes of propositi that had been confirmed by sequencing previously, the genotypes of siblings can be identified by SSCP analysis and do not need to be confirmed by sequencing, which has simplified the approach. With the cloning of the ATP7B gene, several STR markers from chromosome 13 were found and used for gene diagnosis within families. The accuracy and informativeness of the haplotype analysis depend on the polymorphism information content of each locus and on the relative positions of marker loci around the candidate gene. D13S301 is within the WD locus, while D13S133 and D13S314 are positioned in a 150-kilobase region on either side of the WD locus. The polymorphism information content of these markers is 0.88, 0.89, and 0.89, respectively, in the Chinese population, and the polymorphism information content of D13S133 and D13S314 is 0.83 and 0.89, respectively, in the non-Chinese population. Therefore, these markers are sufficiently close to the WD locus and sufficiently polymorphic to be useful in Chinese or non-Chinese populations. The methods based on these 3 STRs are simple to perform, provide reproducible results, and are highly informative.

In this study, the diagnoses of siblings were established by a combination of direct mutational analysis and haplotype analysis with STR markers. Among 78 siblings from 51 families, 17 siblings were diagnosed as presymptomatic patients, 29 as heterozygote carriers, and 32 as unaffected individuals. At the time of presymptomatic diagnosis, a clinical follow-up study including genetic and psychological counseling and legal safeguarding was begun. Detailed laboratory investigation showed that K-F rings were absent in 7 of 17 presymptomatic pa-
patients and faint in 4 of 17. It is possible that without molecular diagnosis we would have missed the diagnoses of these presymptomatic siblings. Our results indicate that the molecular diagnosis system based on direct mutational analysis and haplotype analysis is an efficient, accurate, and fast diagnostic method that is well suited for routine use in clinical laboratories engaged in determining the status of the siblings in WD families.

Diagnosing these presymptomatic siblings allows prophylactic therapy to be instituted before they become clinically ill. Penicillamine is effective in anticopper therapy but has highly toxic adverse effects. Trientine hydrochloride also has its share of toxic adverse effects. Zinc is recommended for use as maintenance therapy or for the rare patient who is intolerant of trientine or penicillamine. Two groups have reported on the beneficial effects of daily dosages of 75 to 300 mg of elemental zinc sulfate in patients with neurologic manifestations and in maintaining wellness in some asymptomatic patients. In this study, 14 of 17 presymptomatic patients were prescribed zinc sulfate in a comparatively low dose of 50 mg taken twice a day as the maintenance therapy for 3 to 5 years. None developed clinical symptoms of WD or adverse effects from zinc therapy. However, lack of clinical symptoms is not the primary criterion for assessing therapy in presymptomatic patients, because there is no way of knowing when symptoms would have developed in the absence of therapy. To evaluate the efficacy of zinc during years of follow-up, serum ceruloplasmin and 24-hour urinary copper levels were measured in these presymptomatic patients every year. In the absence of chelation therapy, the urinary excretion of copper is a reflection of the body’s accumulation of copper. A value of 125 µg/24 h or less indicates adequate control of copper metabolism in patients with WD. Our data on 24-hour urine copper values displayed in Tables 2 and 3 show that, in general, urinary copper excretion decreases to less than 125 µg/24 h during zinc therapy, indicating good control of copper metabolism. The serum ceruloplasmin values generally support effective control of copper metabolism by zinc therapy, but this variable is not as sensitive as urinary copper values. Our results indicate that zinc is an effective and nontoxic therapy and should be prescribed as the prophylactic therapy in the presymptomatic patients with WD from the beginning.

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Author contributions: Study concept and design (Drs Wu and Wang); acquisition of data (Drs Wu, Lin, and Wang); analysis and interpretation of data (Drs Wu, Lin, Murong, and Wang); drafting of the manuscript (Drs Wu and Wang); critical revision of the manuscript for important intellectual content (Drs Wu, Lin, Murong, and Wang); statistical expertise (Drs Wu and Wang); obtaining funding (Drs Wu, Murong, and Wang); administrative, technical, or material support (Drs Wu, Lin, and Wang); study supervision (Drs Wu and Wang). Drs Wu and Wang contributed equally to this work.

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