INTRODUCTION

Based on recommendation from National Tuberculosis Control Program (NTP) in Iran, all new sputum smear-positive tuberculosis (TB) cases are treated with four first-line drugs: isoniazid (INH), rifampin (RMP), pyrazinamide, and ethambutol. Among these drugs, RMP is the most effective agent and its absence from treatment regimens has considerable implications for the individual patient and the for NTP. Generally, patients infected rifampin-monoresistant (RMR) bacilli need a longer treatment duration (up to 18 months) and more expensive drugs. It is important to include INH in this regimen, and the risk of misclassification of RMR as multidrug-resistant (MDR) TB is common. In addition, these patients continued to expectorate smear-positive sputum longer than patients with drug-sensitive bacilli, increasing the probability of spread of infection. Therefore, resistance to RMP represents a major risk factor for treatment failure with recommended standard TB therapy.

With advances in molecular biology, the basis of resistance to RMP is well characterized. Resistance to RMP is caused by point mutations in the beta subunit of the DNA-dependent RNA polymerase rpo gene. These mutations can be detected by using single polymerase chain reaction (PCR), multiplex PCR, or DNA sequencing. In Iran, prevalence data for drug-resistant strains for entire country are not available. During 1998–2000, Masjedi and others reported information about drug-resistant TB, which was comparable with international data. Subsequent investigations reported emergence of highly drug-resistant strains of Mycobacterium tuberculosis in Iran. Likewise, a few other studies documented drug-resistant TB in different provinces of Iran. However, the true extent of drug-resistant TB is not clear. Considering the impact of drug-resistant TB, we retrospectively analyzed susceptibility patterns of strains that were collected in previous years.

We reviewed laboratory and clinical information for smear-positive TB cases.

The study included 85% of all diagnostic health centers that used the directly observed therapy, short course (DOTS) strategy in Iran. Results showed high levels of MDR and RMR strains. In Iran, the DOTS strategy was initiated in 1995, and treatment protocols are uniformly implemented by NTP for registered pulmonary TB patients. Because RMP is never prescribed as a single drug for treatment of active TB, analyzed the clinical and/or epidemiologic features that promote RMR-TB. To our knowledge, this is the first report that describes and highlights the high prevalence of RMR in Iran.

MATERIALS AND METHODS

Data and specimen collection. This study was conducted during February 2010–February 2011. The study included TB patients who remained or became sputum smear positive at the after two, four, six, and nine months of standard therapy. These patients were referred to DOTS health units throughout Iran. A total of 5,362 pulmonary specimens from 3,020 patients were collected. Samples with questionnaires were transported to National Reference TB Laboratory of Iran for culture, direct susceptibility testing, and genotyping.

The required questionnaires were completed and signed by DOTS medical officers. The questionnaire included information on sex, date and country of birth, close contact (> 16 hours contact), family or previous history, previous TB therapy, human immunodeficiency virus (HIV) infection, previous laboratory results (if any), and the category (I and/or II) treatment, accordingly. The Scientific Board of the National Research Institute of Tuberculosis and Lung Disease of Iran approved the study.

Genomic DNA preparation. Mycobacterial genomic DNA was extracted directly from sputum smear-positive specimens. In brief, the digested and decontaminated suspension was extracted directly from sputum smear-positive specimens.
is the number of different MIRU-VNTR types described. 19 The DR region was amplified by PCR using primers DRA (5'-biotin-CCG AGA GGG GAC GGA AAC-3') and DRb (5'-GGT TTT GGG TCT GAC GAC-3'), 20–50 ng of DNA, and 0.5 units of Taq DNA polymerase. The PCR conditions were 35 cycles for 1 minute at 95°C, 1 minute at 55°C, and 30 seconds at 72°C. The initial denaturation and final extension steps were each 10 minutes. Amplified DNA was hybridized to 43 immobilized oligonucleotides derived from the spacer sequences of M. tuberculosis H37Rv and M. bovis BCG P3 by reverse line blotting. Hybridized DNA was detected by enhanced staining and viewing under ultraviolet light.

**INH resistance-related mutations in katG315 and the inhA promoter.** Two codons of katG315, and inhA-15 were used to detect INH-resistant strains according to the protocol of Kazumi and Mitara with minor modifications. The PCRs were conducted in 25-µL mixtures containing 10 pmol of specific primers (Table 1), 5.5 mM MgCl₂, 0.2 mM dNTP, 1× PCR buffer, and 1.25 units of Hot Start Taq DNA polymerase, 2% dimethylsulfoxide, and 50 ng of DNA. The PCR conditions were an initial denaturation step at 95°C for 5 minutes; 35 cycles of denaturation at 95°C for 30 seconds, annealing at 70°C for 30 seconds, and extension at 72°C for 30 seconds; and a final extension at 72°C for 7 minutes. The PCR products were separated by electrophoresis on 8% polyacrylamide gels. Fragments were visualized by staining the gels with ethidium bromide staining and viewing under ultraviolet light.

**RESULTS**

**Study population.** A total of 5,361 positive sputum specimens were collected from 3,020 pulmonary TB patients who were referred to TB diagnostic centers in different provinces of Iran. Of these patients, only 1,242 (41.1%) had smear, culture, and DNA results positive for M. tuberculosis. The remaining specimens were excluded because they were either smear positive/culture negative (985 of 3,020, 32.6%) or had no suitable DNA to perform molecular genotyping (312 of 3,020, 10.3%). In addition, 445 (14.7%) of 3,020 samples were contaminated or contained Mycobacterium spp. other than M. tuberculosis (36 of 3,020, 1.1%). The mean age of patients was 46.9 years (range = 1–16 years). Six hundred eighty-five patients (55.1%) of 1,242 were female and 557 (44.8%) of 1,242 were male. A total of 1,172 patients were from native populations (1,172 of 1,242, 94.6%), 1,090 of 1,242 (87.7%) were from rural areas.

### Table 1

<table>
<thead>
<tr>
<th>Multiplex allele-specific PCR (MAS-PCR)</th>
<th>Primer name Primer oligo sequence, 5′→3′</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiplex-PCR (rpoB 516, 526, 531)</td>
<td>rpoB516 (forward primer) CAGCTGAGCCAAATTGATGGA</td>
</tr>
<tr>
<td></td>
<td>rpoB 526 (forward primer) CTGCGGGGTTGACCCA</td>
</tr>
<tr>
<td></td>
<td>rpoB 531 (forward primer) CACAAGCGCGACGACGTC</td>
</tr>
<tr>
<td>Multiplex-PCR (rpoB 507, 518, 533)</td>
<td>rpoB 507 (forward primer) GGCTATTGCCAGGCA</td>
</tr>
<tr>
<td></td>
<td>rpoB 518 (forward primer) TACGGCAATTTCATGAGCAGA</td>
</tr>
<tr>
<td></td>
<td>rpoB 533 (forward primer) CGCGCAACTGTCGGCGCT</td>
</tr>
<tr>
<td>Multiplex-PCR (rpoB 511, 513, 522)</td>
<td>rpoB511 (forward primer) TTTCAATTGCAGCCGTCGA</td>
</tr>
<tr>
<td></td>
<td>rpoB 513 (forward primer) CACACGCAATGTCAGCCCG</td>
</tr>
<tr>
<td></td>
<td>rpoB 522 (forward primer) GACCGAGACACCGGCTG</td>
</tr>
<tr>
<td></td>
<td>RIRm (reverse primer) TTGAGCGCGCGTGACAC</td>
</tr>
<tr>
<td>PCR(katG 315)</td>
<td>katG (forward primer) GCAGATGGGGGCTGATGAC</td>
</tr>
<tr>
<td>PCR(katG 315)</td>
<td>katG5 (reverse primer) ATACGCACCTTGCAGGCG</td>
</tr>
<tr>
<td>PCR(inhA)</td>
<td>inhA-P15 (forward primer) GGCCTGTCACAGTACCA</td>
</tr>
<tr>
<td>PCR(inhA)</td>
<td>inhA-PF2 (reverse primer) CACCCGACAACCTATCG</td>
</tr>
</tbody>
</table>

*PCR = polymerase chain reaction.
94.3%) and the remainder were nationals from neighboring countries (Afghani = 62; Iraqi = 3; Azerbaijani = 5).

Most (1,007 of 1,242, 81.0%) patients had isolates with wild-type \( \text{rpoB}, \text{KatG} \) and \( \text{in} \text{HA} \) mutations. Overall, 73 (5.8%) had MDR-TB, 92 and 70 had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had MDR-TB, 92 and 70 had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded). Most (57 of 73, 78.0%) MDR-TB had isolates with RMP (7.4%) or INH (5.6%) monoresistant TB, respectively (Table 2) (repeat isolates were excluded).
the higher number of patients. Twelve and eight clusters consisted of two (52.1%) and three (34.7%) patients, respectively. The clustering rate was 0.22463769 by MIRU-VNTR and 0.5 by spoligotyping (Figure 2).

Review of patient questionnaires identified a transmission link for seven patients (13%) in three clusters (H3 from Kerman, T from Tehran, and CAS lineage from Khuzestan). Allelic diversity for each MIRU-VNTR locus based on the Hunter-Gaston Index showed 13 loci with a higher discrimination value of 0.6, whereas the loci MIRU04 and Mtub30 had values of 0.42 and 0.57, respectively. Clinically, TB patients with RMR isolates were classified into four groups depending on their smear and culture positivity: group A (positive after 9 months), group B (positive after 6 months) group C (positive after 4 months), and group D (positive after 2 months) (Table 3). Prevalence of RMR in smear-positive TB patients after the second month of therapy was low (11 of 92, 11.9%) in comparison with other groups \( (P < 0.05) \). Most (7 of 11, 63.6%) of these patients had a history of TB or close contact with TB patients. In addition, two patients in group D were positive for HIV. A total of 31 patients (11 [37.9%] of 29 in group A, 7 [25.9%] of 27 patients in group B, 6 [24%] in group C, and 7 [63.6%] in group D had a family or

**Figure 1.** Cases of rifampin-monoresistant tuberculosis in Iran.
previous history of TB. We found no other correlated risk factor for 59 (64.1%) of 92 patients ($P < 0.05$).

**DISCUSSION**

Introduction of new algorithms for rapid identification of drug-resistant TB by using molecular test is one major advancement in TB laboratory diagnostics.$^{6,7,22}$ Application of these molecular-based detection assays (PCR, PCR–restriction fragment length polymorphism, or multiplex PCR) could effectively help in screening and identifying large numbers of suspected TB cases throughout Iran. As a result, during 2010–2011, we examined 3,020 smear-positive TB patients for genotyping. Retrospective analysis of these data

<table>
<thead>
<tr>
<th>Group receiving (DOTS)</th>
<th>Nationality</th>
<th>Mean ± SD age, years</th>
<th>M/F</th>
<th>History of TB</th>
<th>Close or family contact</th>
<th>Spoligotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (positive after 9 months)</td>
<td>20</td>
<td>6</td>
<td>3</td>
<td>47.2 ± 12.5</td>
<td>18/11</td>
<td>4</td>
</tr>
<tr>
<td>B (positive after 9 months)</td>
<td>18</td>
<td>9</td>
<td>–</td>
<td>39.7 ± 6.9</td>
<td>19/8</td>
<td>2</td>
</tr>
<tr>
<td>C (positive after 4 months)</td>
<td>17</td>
<td>8</td>
<td>–</td>
<td>40.5 ± 11.3</td>
<td>13/12</td>
<td>3</td>
</tr>
<tr>
<td>D (positive after 2 months)</td>
<td>6</td>
<td>5</td>
<td>–</td>
<td>37.0 ± 16</td>
<td>7/4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>61 (66.3%)</td>
<td>28 (30.4%)</td>
<td>3 (3.2%)</td>
<td>41.1 ± 11.6</td>
<td>57/35</td>
<td>13 (14.1%)</td>
</tr>
</tbody>
</table>

*RMR-TB – rifampin-monoresistant tuberculosis.*

![](image.png)

**Figure 2.** Spanner diagram showing clusters of rifampin-monoresistant isolates of *Mycobacterium* tuberculosis classified by spoligotyping and mycobacterial interspersed repetitive unit–variable number tandem repeat in Iran. Scale bar indicates nucleotide substitutions per site.
identified important epidemiologic aspects of TB in different provinces of Iran. Findings showed that 985 (32.6%) of 3,020 smear-positive TB patients had negative culture results during therapy. A prevalence of 32.6% smear-positive, culture-negative patients may underlie the importance of culture examination during follow-up studies.

Genotyping identified 238 (18.9%) of 1,242 patients with drug-resistant isolates. Because the rate of RMR (7.4%) was higher than that for MDR (5.6%), precautions must be taken in interpreting the data. Relative frequencies of rpoB gene mutations was high in codons 531 (105 of 165, 63.3%), 526 (68 of 165, 41.2%), 516 (43 of 165, 26.0%), followed by 518 (9 of 165, 5.4%) 513 (7 of 165, 4.2%), and 511 (3 of 165, 1.8%). Worldwide, frequencies of mutation at codon 531 and 526 ranged from 29% to 74% and from 0% to 43%, respectively. Thus, our reported frequencies were consistent with those of previous reports from other locations. The mean rate of RMP-monoresistant TB ranged from 5% to 10%, which was observed in 11 studied provinces (47.6%; P < 0.05). In large metropolitan cities such as Tehran (26 of 324, 8.0%), Khorasan (9 of 119, 7.6%), and Sistan and Balouchestan (10 of 165, 6%), the mean RMR was 6–8% (Figure 2). However, in a few provinces, where the number of collected specimens was low, the detected rate was not fully reliable, either high (up to 20%) or 0%.

Generally, RMR-TB occurred when there is erratic use of drugs, omission of one or more prescribed drugs, suboptimal dosages, poor drug absorption, or an insufficient number of active agents in a drug regimen. Review of classical and clinical information showed no single therapy or suboptimal dosage in studied populations, although 31 (33%) of 92 isolates (P < 0.05) were collected from immigrant or other nationals who either visited Iran for TB treatment (10 of 28, 53.7%) or stayed in Iran < 10 years. Because immigrants enter Iran without been given physical examinations, collected information is limited to patient interviews.

Munsiff and Friedan, 27 Rizdon and others, 28 and Sandman and others 29 described in detail clinical conditions in which RMR-TB might have occurred. They found strong associations between RMP monoresistance and infection with HIV and previous or extrapulmonary TB. In HIV-seropositive patients, malabsorption or drug–drug interactions could lead to altered active levels of anti-TB drugs. More recently, an additional risk factor (excessive alcohol use) has been reported in surveys for Brazil, South Africa, Burundi, and Russia. 30-33 In the present study, 33.6% of RMR patients had a history of TB or had close contact with a known TB patient. This rate reached 58% in immigrants. However, in many cases, no risk factors were found.

Identification of RMR-TB by detection of INH resistance showed poor sensitivity. However, analysis of isolates by the Swedish Supranational Reference Laboratory indicated that most samples were accurately categorized as RMR-TB (the remaining isolates were categorized as MDR-TB). Therefore, a significant occurrence of RMP resistance without an association with INH resistance was verified.

To identify clonal expansion of these specific strains, spoligotyping and MIRU-VNTR analysis was conducted. A combination of these typing methods identified 63 (66.33%) of 92 patients in 23 clusters. Cluster sizes were small, ranging from 2 to 5 isolates. A retrospective epidemiologic analysis identified a transmission link for seven patients in three clusters (3 of 23, 13%). In two clusters, patients were family members (H3 and T lineages) and in another cluster the two patients were in close contact (prison inmates in Khouasatan Province). The CAS (34.7%), Haarlem (21.7%), and Beijing lineages (7.6%) were the most dominant super families among RMR-TB cases. However, CAS (471 isolates, 37.9%) and Haarlem (326 isolates, 26.2%) lineages were also found among susceptible isolates (Table 1). Therefore, these genotypes may be the most common strains circulating 34,35 and are not necessary associated with RMR.

Overall, we showed that RMR-TB was strongly associated with close contact or previous history of TB. However, this estimate did not include use of free TB drugs. It has been more than 15 years that the ban on free sale of TB drugs was implemented in Iran, but enforcement of this ban is questionable.

Another limitation of this study was the low number of collected specimens in a few provinces, which need further investigation. In conclusion, if one considers the higher sensitivity of detection of resistance to RMP than to INH, the true level of INH resistance and MDR-TB might be underestimated. However, our results identified RMP resistance without an association with INH resistance. Therefore, the level of RMR-TB in any specific setting should be identified before new diagnostic algorithms are developed and implemented.

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