Transmission Dynamics of Tuberculosis in Tarrant County, Texas

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To understand the transmission dynamics of tuberculosis in Tarrant County, Texas, we performed a population-based study of 159 patients with culture-proven tuberculosis, combining restriction fragment length polymorphism (RFLP) analysis of *Mycobacterium tuberculosis* isolates with prospective interviewing to identify epidemiologic links between patients. Patients whose isolates had identical or closely related RFLP patterns were considered a cluster. Seventy-six (48%) of 159 patients were in 19 clusters, suggesting that recent transmission accounted for 36% of tuberculosis morbidity. Unconditional logistic regression showed that birth in the United States, continuous residence in Tarrant County, a history of homelessness, and a history of visiting or working in bars were independent predictors of clustering. Four homeless shelters and five bars were associated with specific clusters, suggesting that they were sites of tuberculosis transmission. Patients in some clusters recognized more photographs of patients in their cluster than did patients outside their cluster. We conclude that (*1*) homeless shelters and bars are important sites of tuberculosis transmission in Tarrant County, and (*2*) the use of photograph recognition of patients with tuberculosis, in combination with RFLP analysis, has the potential to enhance tuberculosis control by facilitating identification of epidemiologic links between patients.

Keywords: epidemiology; homeless; restriction fragment length polymorphism; tuberculosis; transmission; urban

Restriction fragment length polymorphism (RFLP) analysis of repetitive genetic elements of *Mycobacterium tuberculosis* provides a molecular "fingerprint" that can be used to identify individual strains (1). Studies based on RFLP analysis have provided new insights into the transmission dynamics of tuberculosis, but few population-based studies have included the detailed epidemiologic data (2–6) that are essential for understanding the nature of transmission links between patients. Delineation of these links is critical for optimizing strategies that minimize tuberculosis transmission.

RFLP-based studies in different parts of the United States have revealed that routine contact investigation often fails to identify epidemiologic connections between patients with tuberculosis who are linked by recent disease transmission, and improved methods to identify such links are urgently needed to improve tuberculosis control (2, 3, 5, 6). These RFLP-based studies have also demonstrated significant variability in the local transmission dynamics of tuberculosis. For example, recent tuberculosis transmission was associated with homelessness in Los Angeles and in Houston (2, 7), but not in San Francisco, New York City, or Baltimore (3, 5, 8). In cities where comprehensive molecular epidemiologic studies have been performed, the prevalence of human immunodeficiency virus (HIV) infection among tuberculosis patient was high, ranging from 19 to 44% (2, 5, 7, 8).

We performed a prospective, population-based, molecular epidemiologic study of patients with tuberculosis in Tarrant County, Texas, with two goals: first, to understand the transmission dynamics of tuberculosis in an urban area where the prevalence of HIV infection is relatively low; second, to evaluate the utility of photograph recognition as a tool to establish epidemiologic connections between patients with tuberculosis who were linked by recent disease transmission.

METHODS

Study Subjects

From January 1, 1995 through December 31, 1996, 192 persons were prospectively identified as having culture-proven tuberculosis in Tarrant County. Patients who provided informed consent were interviewed and photographed. This study was approved by the Institutional Review Board of the University of North Texas Health Science Center (Fort Worth, TX).

Interview

Before RFLP results were available, each subject was interviewed by the same person (S. E. W.), using a data collection instrument to obtain information about demographics, alcohol and drug use, as well as detailed information about contacts and locations where the subjects spent significant amounts of time during the period from January 1991 to the time when tuberculosis was diagnosed. During the interview, subjects were shown photographs of other patients who had been enrolled earlier in the course of the study. Subjects were asked if they recognized the persons photographed, to characterize the nature of the relationship with the photographed subject, and to identify the type of location where contact occurred. The median income for residents in the census tract block where the subject lived at the time that tuberculosis was diagnosed was used as an estimate of the subject's annual income.

RFLP Analysis

All initial *M. tuberculosis* isolates from the study subjects were subjected to IS6110-based RFLP analysis (9, 10). RFLP patterns were compared as described (2, 9) by two of the authors (Z. Y. and M. D. C.), who had no information about the subjects. IS6110-based RFLP results are inconclusive if RFLP patterns with fewer than six fragments are identical, or if RFLP patterns are identical except that one isolate

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has an additional fragment, or has one fragment that differs in size (10–12). In these cases, we performed pTBN12-based RFLP analysis (12–14).

Definition of Clustering

As the primary means to identify clusters, we used IS6110-based RFLP patterns because they are more polymorphic than pTBN12-based patterns, which are more temporally stable (10, 12, 14–16). We considered *M. tuberculosis* isolates from different subjects to be the same strain if IS6110-based RFLP patterns (*1*) revealed six or more fragments of identical size; (*2*) revealed six or more fragments of identical size, except that one isolate showed one additional fragment or one fragment of different size, and pTBN12-based RFLP patterns were identical; or (*3*) revealed five or fewer bands of identical size and pTBN12-based RFLP patterns were identical. Two or more patients infected with the same *M. tuberculosis* strain constituted a "cluster," numbered according to the number of IS6110 fragments in the isolates.

Statistical Analysis

All statistical tests were two-sided, with levels of 0.05 or less considered significant. Comparisons of proportions between groups were done by Fisher exact test. Unconditional logistic regression was used to derive maximum likelihood odds ratios and 95% confidence intervals for risk of clustering associated with each demographic variable and other categorical variables that might contribute to transmission of tuberculosis. Factors that were significantly associated with clustering were analyzed by multiple logistic regression, using a stepwise approach to identify factors that were independent predictors of clustering (17, 18).

Subjects interviewed later were shown more photographs of other subjects than those interviewed earlier. To fairly compare the mean number of photographs of subjects in a cluster recognized by subjects in different groups, least-square means were reported to adjust for the number of photographs shown (19). To test for group differences in adjusted means, nonparametric analyses of covariance were used (20), with groups and number of photographs recognized as the independent and dependent variables, respectively, and number of photographs shown as the covariate.

RESULTS

Study Population

Of 192 patients with culture-proven tuberculosis during the study period, 171 (89%) agreed to participate. Of these, stored *M. tuberculosis* isolates were available for 159 subjects (93%), who were included in the study. Of these, 107 (67%) were male and 99 (62%) were born in the United States; 48 (30%) were non-Hispanic white, 47 (30%) were African American, 33 (21%) were Asian, and 30 (19%) were Hispanic. The mean age was 43.5 ± 17.5 years. Serologic testing for HIV was performed in 157 (99%) patients. A total of 13 (9%) subjects were HIV infected and 33 (21%) had a history of substance abuse. At the time of diagnosis of tuberculosis, 141 (89%) subjects lived in private homes, 13 (8%) were homeless, and 4 (3%) were incarcerated. Thirty-four (21%) subjects lived in census tracts where the annual median income was less than $15,000 (U.S.).

RFLP Analysis

IS6110-based RFLP analysis was performed for all 159 isolates, and pTBN12-based RFLP analysis was performed for 41 isolates with five or fewer IS6110 fragments and for 15 isolates with six or more IS6110 fragments. A total of 83 patients were nonclustered and 76 patients were clustered in 19 clusters, varying in size from 2 to 32 patients (Figure 1). If we assume that one patient in each cluster was the index case and that the other cases in the cluster resulted from recent transmission, 36% (57 patients) of the morbidity due to tuberculosis in Tarrant County resulted from recent transmission during the study period.

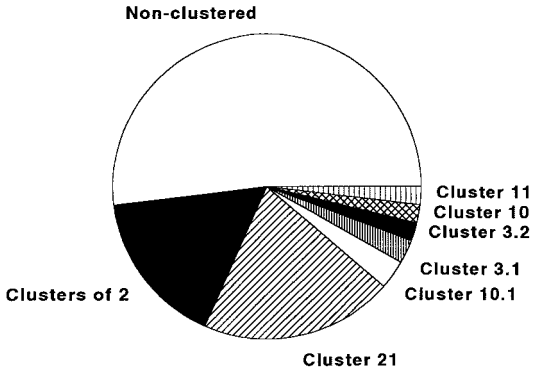

Figure 1. Distribution of clustered and nonclustered patients in Tarrant County. In the study population of 159 patients, the percentages that were nonclustered and clustered are shown. The six largest clusters are shown individually, and the *solid black area* shows 13 clusters, each consisting of two patients.

Factors Associated with Clustering

Table 1 shows the demographic and other features of clustered and nonclustered subjects. In univariate analysis, clustering was significantly more common in patients 31–40 years old, non-Hispanic whites and African Americans, subjects born in the United States, low-income subjects, and drug users. HIV infection was not associated with clustering. Patients who were homeless at the time of diagnosis or at any time since 1991 were significantly more likely to be clustered. Clustering was also more common in patients who, since 1991, had lived in Tarrant County continuously, were incarcerated or worked in a jail or prison, used bus transportation, went to or worked in bars, or worked in a labor pool.

Among the variables that were significantly associated with clustering in the univariate analysis, only four were independent predictors of clustering (Table 1). The likelihood of clustering was 2- to 3-fold higher in patients who were born in the United States, had lived continuously in Tarrant County since 1991, or went to or worked in bars. Patients who had been homeless at any time since 1991 were four times more likely to be clustered than patients without a history of homelessness.

Potential Sites of Tuberculosis Transmission

We have previously identified sites for tuberculosis transmission by selecting locations where a significantly higher percentage of clustered patients spent time than the corresponding percentage of nonclustered patients (2, 20). The latter serve as a control group of patients who were not linked by disease transmission. Of the 19 clusters, subjects in seven clusters (each of two patients) and two clusters (each of three patients) shared no common locations. In four additional clusters, each of two patients, the percentage of clustered patients who spent time at common locations was not significantly higher than that of nonclustered patients. However, in six clusters, clustered patients were significantly more likely to have spent time at common locations than nonclustered subjects (Table 2). Subjects in the largest cluster of 32 patients (Cluster 21) were significantly more likely than nonclustered subjects to have spent time at four different shelters, two bars, a hospital, and the Tarrant County Jail. Subjects in the next largest cluster of five patients (Cluster 10.1) were significantly more likely than nonclustered subjects to have spent time at four different bars and three shelters. For the four smaller clusters, fewer potential transmission sites were identified, including two shelters, two bars, a motel, and the Tarrant County Jail. Shelters 3 and 4 and Bar 1 were potential transmission sites for several clusters.

TABLE 1. RELATIONSHIP OF DEMOGRAPHIC FEATURES AND OTHER CHARACTERISTICS TO RISK OF CLUSTERING

	Clustered (*n* = 76)	Nonclustered (*n* = 83)	Crude		Adjusted*	
	No., %	No., %	OR	(95% CI)	OR	(95% CI)
Age, yr						
⩽ 30	13, 17	24, 29	1.0			
31–40	24, 32	13, 16	3.4	(1.3, 8.9)		
41–55	25, 33	22, 27	2.1	(0.9, 5.1)		
> 55	14, 18	24, 29	1.1	(0.4, 2.8)		
Male	57, 75	50, 60	2.0	(1.0, 3.9)		
Ethnicity						
Hispanic	8, 11	22, 27	1.0			
Non-Hispanic White	30, 39	18, 22	4.4	(1.6, 12.0)		
African American	27, 36	20, 24	3.7	(1.4, 10.0)		
Asian	10, 13	23, 28	1.2	(0.4, 3.6)		
Other	1, 1	0, 0	—			
Born in the United States	62, 82	37, 45	5.5	(2.7, 11.4)	2.7	(1.2, 6.0)
Census median income, U.S.$						
> 32,500	14, 19	23, 30	1.0			
20,001–32,500	17, 23	27, 35	1.0	(0.4, 2.5)		
15,001–20,000	20, 27	15, 19	2.1	(0.8, 5.4)		
⩽ 15,000	22, 30	12, 16	3.1	(1.2, 8.3)		
HIV positive	9, 13	4, 6	2.6	(0.8, 8.9)		
Drug user	24, 32	9, 11	3.8	(1.6, 8.8)		
Residence at time of diagnosis						
Private home	63, 83	78, 94	1.0			
Homeless/shelter	11, 14	2, 2	6.8	(1.5, 31.9)		
Jail	1, 1	3, 4	0.4	(0.0, 4.1)		
Other	1, 1	0, 0	—			
Always lived in Tarrant County†	62, 82	41, 49	4.5	(2.2, 9.3)	2.5	(1.1, 5.6)
Homeless†	29, 38	6, 7	7.9	(3.1, 20.5)	4.2	(1.5, 11.7)
Stayed or worked in a residential facility†	36, 47	29, 35	1.7	(0.9, 3.2)		
Inmate or worker in jail or prison†	23, 30	13, 16	2.3	(1.1, 5.0)		
Used bus transportation†	30, 39	14, 17	3.2	(1.5, 6.7)		
Went to or worked in bars†	39, 51	19, 23	3.6	(1.8, 7.0)	2.3	(1.1, 5.0)
Worked out of a labor pool†	26, 34	7, 8	5.6	(2.3, 14.0)		

Definition of abbreviations: CI = confidence interval; OR = odds ratio.

* Based on subset of subjects with all nonmissing variables used in analysis (n = 65 clustered and 67 nonclustered).

† For these variables, patients were asked whether they had any of these potential risk factors for tuberculosis transmission since 1991.

Because many clustered patients spent time at several locations, multiple logistic regression was performed to identify locations that were independently associated with clustering. This analysis was not possible for the four smaller clusters because many patients in these clusters went to the same locations. However, spending time at Shelter 1 or at the Tarrant County Jail were independent predictors of being in the 32-person Cluster 21 ($p < 0.001$ and $p = 0.02$, respectively). In addition, visiting Bar 1 was independently associated with the five-person Cluster 10.1 ($p < 0.001$).

Photograph Recognition among Patients with Tuberculosis

A total of 17 of the 19 clusters had data available for photograph recognition analysis. In eight clusters, subjects were significantly more likely to be recognized by subjects in their clusters than by subjects not in their clusters (Table 3). Furthermore, when the multiple logistic regression to identify independent predictors of clustering (Table 1) was recalculated to include the variable of "photograph recognition of any clustered patient," this latter variable was a strong independent predictor of clustering (odds ratio, 3.8; 95% confidence interval, 1.6–9.0).

The type of relationship that patients had with the persons whose photographs they recognized varied in different clusters. To identify the relationships that were most likely to be associated with clustering, we calculated the number of photographs of clustered patients recognized according to the type of relationship with the photographed patient, such as coworker, contact at a bar, and so on. The relationships that were significantly associated with clustering varied in different clusters (Table 4). For example, patients in Cluster 21 knew the first or last name of a mean of 0.47 photographs of other Cluster 21 patients, whereas patients outside Cluster 21 knew the first or last name of a mean of only 0.30 photographs of other Cluster 21 patients. This type of contact indicates that Cluster 21 patients did not have close personal contact with one another. Patients in Clusters 10.1 and 3.1 also had limited contact, in the settings of work, bars, and a labor pool. On the other hand, patients in Clusters 10.2 and 1 had closer personal contact, as they knew the full name of others in the cluster or identified them as friends.

DISCUSSION

We studied the transmission dynamics of tuberculosis in a predominantly urban county in the south–central United States using a combination of prospectively obtained epidemiologic data and RFLP analysis of *M. tuberculosis* isolates. A total of 48% of the patients were clustered in 19 clusters, suggesting that recent transmission accounted for 36% of the tuberculosis morbidity in Tarrant County. We found that four homeless shelters and five bars were frequented significantly more often by patients infected with specific *M. tuberculosis* strains. Multiple logistic regression for the largest clusters showed that one shelter and one bar were independent predictors of clustering, suggesting that they were sites of tuberculosis transmission. Furthermore, patients in half of the clusters recognized more

TABLE 2. LOCATIONS SHARED BY CLUSTERED AND NONCLUSTERED SUBJECTS

			Clustered	Nonclustered ($n = 83$)	
Cluster	Cluster Size	Location	No., %	No., %	p Value*
21	32	Shelter 1	9, 28	3, 4	< 0.001
		Shelter 2	7, 22	3, 4	0.002
		Shelter 3	7, 22	4, 5	0.006
		Shelter 4	7, 22	5, 6	0.01
		Bar 1	6, 19	3, 4	0.01
		Bar 2	4, 13	1, 1	0.02
		Hospital 1	20, 62	26, 31	0.002
		Tarrant County Jail	8, 25	3, 4	0.002
10.1	5	Shelter 1	2, 40	3, 4	0.02
		Shelter 3	2, 40	4, 5	0.04
		Shelter 4	2, 40	5, 6	0.049
		Bar 1	4, 80	3, 4	< 0.001
		Bar 3	3, 60	1, 1	< 0.001
		Bar 4	2, 40	1, 1	0.008
		Bar 2	2, 40	1, 1	0.008
3.1	4	Shelter 3	2, 50	4, 5	0.02
		Shelter 4	4, 100	5, 6	< 0.001
3.2	3	Bar 1	2, 67	3, 4	0.009
		Tarrant County Jail	2, 67	3, 4	0.008
2.1	2	Motel 1	2, 100	0, 0	< 0.001
		Shelter 3	2, 100	4, 5	0.004
		Shelter 4	2, 100	5, 6	0.006
12.1	2	Bar 5	2, 100	0, 0	< 0.001

* Two-sided Fisher exact test.

photographs of patients in their cluster than did patients outside their cluster, suggesting that there was significant contact among clustered patients. In most clusters, this contact was limited, occurring in the setting of work, labor pools, or bars, and patients often did not know the full names of the persons whose photographs they recognized. These findings confirm previous reports that casual contact can result in extensive transmission of tuberculosis (21–23). Our findings provide the first evidence that the combination of RFLP analysis and photograph recognition of clustered patients with tuberculosis can facilitate identification of sites of tuberculosis transmission.

The current and prior population-based RFLP studies show that the sites of tuberculosis transmission and the risk factors associated with transmission vary in different cities. These differences underscore the value of applying molecular epidemiologic analysis to local tuberculosis control programs. The major transmission sites in population-based RFLP studies in the urban United States have been variable, including a residential AIDS facility, homeless shelters, and bars frequented by homosexual persons (Table 5). Although the percentage of clustered patients in these population-based studies was similar, there is a striking relationship between the percentage of patients with tuberculosis who were homeless and the percentage of clustered patients who were in large clusters. In Los Angeles, Houston, and Fort Worth, homelessness was common and 42–79% of the clustered patients were in large clusters. In contrast, in Baltimore, only 7% of patients with tuberculosis were homeless, and no large clusters were identified. Furthermore, homelessness was an independent predictor of clustering in Los Angeles, Houston, and Fort Worth, and shelters were identified as major transmission sites for two of these cities. These comparisons demonstrate that, in urban areas where homelessness is common, shelters and other sites where homeless persons congregate are focal points for extensive transmission of small numbers of *M. tuberculosis* strains. Targeting these sites for interventions such as screening for tuberculosis disease and upper air sterilization by UV light may significantly reduce tuberculosis morbidity.

Birth in the United States was an independent predictor of clustering in this and prior studies (2, 3, 8, 24). A significant percentage of foreign-born persons develop tuberculosis from reactivation of infection acquired abroad, whereas tuberculosis in persons born in the United States is more likely to be due to recent infection. Prolonged residence in Tarrant County was also an independent risk factor for clustering, suggesting that some clustered patients who were long-time residents may have been infected in the distant past by *M. tuberculosis* strains that were endemic in Tarrant County for many years, similar to findings in patients with tuberculosis in rural Arkansas (4). Although HIV infection is one of the most potent risk factors for development of tuberculosis, HIV infection was not associated with clustering in Tarrant County, Los Angeles, or Baltimore (2, 5, 6), suggesting that HIV infection increases the number of tuberculosis cases from remote and recent in-

TABLE 3. RECOGNITION OF PHOTOGRAPHS OF CLUSTERED SUBJECTS*

	No. of Photos Recognized by Each Subject in Cluster	No. of Photos Recognized by Each Subject outside Cluster	
Cluster	Mean† SE	Mean† SE	p Value‡
21, n = 28	1.35, 0.25	0.52, 0.12	< 0.001
10.1, n = 4	0.84, 0.18	0.07, 0.03	< 0.001
3.1, n = 4	0.55, 0.14	0.05, 0.02	< 0.001
10.2, n = 3	0.67, 0.07	0.01, 0.01	< 0.001
11, n = 3	2.00, 0.00	0.00, 0.00	< 0.001
1, n = 2	1.00, 0.09	0.01, 0.01	< 0.001
2, n = 2	1.04, 0.32	0.15, 0.04	< 0.001
12.2, n = 2	1.00, 0.00	0.00, 0.00	< 0.001

* Based on data for 137 patients. Twenty-two patients were excluded from analysis because the number of photographs they were shown was unknown or they were not photographed.

† Least-squares mean (standard error), adjusted for number of photographs of subjects in cluster shown to subject.

‡ Nonparametric analysis of covariance, adjusted for number of photographs of subjects in cluster shown to subject.

TABLE 4. RELATIONSHIPS ASSOCIATED WITH RECOGNITION OF PHOTOGRAPHS OF PATIENTS IN THE SAME CLUSTER*

		No. of Photos Recognized by Subjects in Cluster†		No. of Photos Recognized by Subjects Not in Cluster		
Cluster	Type of Relationship	n	Mean† SE	n	Mean† SE	p Value‡
21	Knew any name	28	0.47, 0.09	109	0.30, 0.04	0.002
10.1	Work	4	0.18, 0.05	133	0.03, 0.01	0.005
	Bar		0.21, 0.06		0.03, 0.01	0.005
3.1	Labor pool	4	0.26, 0.07	133	0.03, 0.01	< 0.0001
10.2	Knew whole name	3	0.41, 0.04	134	0.01, 0.004	< 0.0001
1	Friend	2	0.51, 0.06	135	0.01, 0.005	< 0.0001

* Based on data for 137 patients. Twenty-two patients were excluded from analysis because the number of photographs they were shown was unknown or they were not photographed.
† Least-squares mean (standard error), adjusted for number of photographs of subjects in cluster shown to subject.
‡ Nonparametric analysis of covariance, adjusted for number of photographs of subjects in cluster recognized by subject.

fection to a comparable degree. The association between HIV infection and clustering in some cities may be based on local scenarios that foster large tuberculosis outbreaks among HIV-infected persons, such as a residential facility for HIV-infected patients (3, 16) and bars frequented by HIV-infected persons (24, 25).

Contact investigations commonly focus on individuals in close person-to-person contact with patients with tuberculosis, such as household, family, and workplace contacts, rather than locations where the contact with the index case is considered more casual and less regular. There are no standard definitions of close and casual contact, and their separation may not be meaningful, as the extent of contact forms a continuum, and casual contact can be an important source of tuberculosis transmission. For example, bars have been the foci of tuberculosis outbreaks in the absence of close personal contact (21, 25, 26), and visiting or working in bars was an independent predictor of clustering in Tarrant County. Location-based tuberculosis screening at all bars in urban locations frequented by patients with tuberculosis is not feasible. In Tarrant County, there are approximately 1,963 bars (27), and patients in the current study listed 62 bars as locations that they frequented. Nevertheless, the combination of RFLP analysis and detailed epidemiologic investigation identified only five bars as potential transmission sites, demonstrating that this strategy can identify a limited number of locations where intensive interventions can be focused.

Previous studies have shown that contact investigation fails to identify the majority of patients who are linked by recent tuberculosis transmission, probably because the casual contact associated with disease transmission is not identified during routine contact investigations (2, 3, 5, 6). Improved methods to identify these epidemiologically linked patients are urgently needed to identify potential sites of disease transmission. We found that recognition of photographs of patients with tuberculosis was a useful tool for identifying links between patients. However, photograph recognition could be interpreted only in the context of RFLP data because many patients with tuberculosis recognized the photographs of patients who were not in the same cluster or who were not clustered. RFLP analysis requires relatively large amounts of mycobacterial DNA, necessitating subculture of *M. tuberculosis*. The resultant delay hampers the utility of RFLP analysis in routine tuberculosis control activities. Methods of RFLP analysis that require minute amounts of mycobacterial DNA, such as mixed linker polymerase chain reaction with fluorescently labeled IS6110-specific oligonucleotides (28), are under development. If these methods become more widely available and can be used to evaluate clinical samples or primary *M. tuberculosis* cultures, studies should be performed to determine whether the rapid availability of RFLP data, in combination with photograph recognition of patients with tuberculosis, can be used to delineate epidemiologic links between patients and identify local settings that are foci for disease transmission. For example, persons with *M. tuberculosis* with the same RFLP pattern who do not identify each other as contacts may recognize photographs of the other cluster members and provide the location where contact occurred. Other persons at this location could then be screened for tuberculosis infection and disease. If this strategy significantly reduces tuberculosis transmission in settings where personal contact is limited, such as homeless shelters, it may be useful to combine rapid RFLP analysis and photograph recognition during routine contact investigations in these settings.

Our results confirm those of Bishai and colleagues, who found that recent transmission accounted for 32% of tuberculosis cases in Baltimore from 1994 to 1996, despite an excellent tuberculosis control program that has used directly

TABLE 5. COMPARISON OF POPULATION-BASED MOLECULAR EPIDEMIOLOGIC STUDIES OF TUBERCULOSIS TRANSMISSION IN URBAN AREAS*

Characteristic	San Francisco	Los Angeles	Baltimore	Houston	Tarrant County
Major transmission sites	Residential AIDS facility	Shelters	None	Bars	Shelters, bars
% clustered patients	40†	59	46	59	48
% of clustered patients in large clusters (≥ 10)	41†	79	0	69	42
% homeless patients	Not recorded	48	7	20	22
Homelessness an independent predictor of clustering	Not analyzed	Yes	No	Yes	Yes

* Data obtained from references 2, 3, 5, 7, and 24, and from the current study.
† This percentage may be overestimated because secondary RFLP typing was not used for isolates with fewer than six IS6110 fragments.

observed therapy since 1981 (5). In Tarrant County, 36% of tuberculosis cases were due to recent transmission, despite a tuberculosis control program that has implemented universal, directly observed therapy since 1986 and achieved treatment completion rates of 93–97% in the years 1991 through 1996 (29). These findings suggest that extensive transmission of tuberculosis probably occurs before the initiation of therapy and that earlier diagnosis is essential for reducing such transmission. Prompt diagnosis of tuberculosis may be facilitated by screening high-risk populations by chest radiography (30, 31), perhaps in combination with educational efforts that induce patients to seek medical care at an earlier stage of disease (6).

The largest cluster in the current study was due to a drug-susceptible *M. tuberculosis* strain that contains 21 IS6110 fragments. This strain, designated as 210 (32), also caused the largest cluster of cases in central Los Angeles (2). Patients infected with the 210 strain in central Los Angeles were not more likely to have cavitary disease or to have acid-fast bacilli present on sputum stains than patients infected with other strains (P. Barnes, unpublished data). The 210 strain is widely distributed in the United States (33) and shares many molecular characteristics with the multidrug-resistant W strain that caused large outbreaks in New York City and New Jersey (34). Both strains are part of the Beijing family that is widespread in China and Southeast Asia (34, 35). A Beijing strain introduced into an island community by a single patient with tuberculosis disseminated rapidly over 3 years, at which point it was responsible for 27% of tuberculosis cases on the island (36). These findings suggest that Beijing strain isolates may spread more effectively in the population than other *M. tuberculosis* strains. We have hypothesized that the success of the 210 strain may be due in part to its capacity to grow more rapidly in human macrophages than other *M. tuberculosis* strains (32), and preliminary data suggest that the 210 strain expresses higher levels of mycobacterial genes that may contribute to virulence (P. Barnes, unpublished data). Additional studies of the distinctive characteristics of the 210 strain will improve our understanding of the mechanisms by which *M. tuberculosis* spreads in human populations.

In summary, we found that significant transmission of tuberculosis continued in Tarrant County, despite the universal application of directly observed therapy since 1986. RFLP analysis and epidemiologic data suggested that transmission occurred in four homeless shelters and five bars among persons with limited personal contact. The use of photograph recognition of other patients with tuberculosis, in combination with RFLP analysis, has the potential to enhance tuberculosis control by facilitating identification of local foci of disease transmission.

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