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The epidemiology of human immunodeficiency virus in South Africa

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We review the epidemiology of human immunodeficiency virus (HIV) in South Africa where the prevalence of HIV infection is among the highest in the world. The epidemic reached South Africa relatively recently but the prevalence of infection has increased rapidly and there are significant differences among provinces. Although few 15-year-old people are infected the prevalence increases rapidly with age thereafter, especially among women. The prevalence of herpes simplex virus type 2 exceeds that of HIV and curable sexually transmitted infections are common. 'Circular migration' may help to explain the high rates and rapid spread of HIV in the region. The incidence of tuberculosis has increased dramatically as a result of the HIV epidemic. Antiretroviral therapy for the prevention of vertical transmission has been shown to be effective in local conditions but transmission through breast-feeding remains problematical. While some epidemiological models have been developed, much more needs to be done in this regard in order to plan, coordinate and evaluate an effective response to the epidemic. We conclude by discussing some of the research that is needed and steps that could be taken to reduce the continued spread of the infection.

Keywords: HIV; AIDS; South Africa; tuberculosis; migrants; herpes simplex

1. INTRODUCTION

Seventy per cent of people infected with human immunodeficiency virus (HIV) live in sub-Saharan Africa (UNAIDS 2000) but the prevalence varies greatly among countries in this region. Among low-risk groups living outside the capital city, the median prevalence by country ranged from 2.9% in western Africa (0.3–9.8%, $n=14$), to 7.5% in eastern Africa (1.0–18.2%, $n=7$), and 28.2% in southern Africa (9.9–31.5%, $n=10$). Of the 11 countries with the highest HIV prevalence in the world, nine were in southern Africa while the four worst affected countries were Botswana, Swaziland, Lesotho and Zimbabwe, all of which border on South Africa (US Census Bureau 2000).

The reasons for the high rates of infection in southern Africa remain uncertain. Socio-economic conditions are known to be important determinants of the spread of HIV infection, but although the countries bordering South Africa have much in common, their histories over the last 20 years have been very different. Botswana, with the highest rate of infection, has experienced stable, democratic government since independence in 1966, while Mozambique, with the lowest rate of infection, experienced 16 years of protracted civil war from which it only emerged in 1992. While South Africa and Botswana are the richest countries in sub-Saharan Africa (as measured by per capita gross domestic product), Mozambique is the poorest. Within the region, migration between rural and urban areas and also between countries is common and the transport infrastructure is generally well developed, which may help to explain the epidemic patterns in the region. Phylogenetic analysis suggests that the epidemic of HIV-1 in South Africa is the result of multiple introduction of viral strains (Bredell *et al.* 2000) and the dominant subtype C virus is also found in central and other southern African countries which are linked to South Africa by migration (Morris *et al.* 2000).

Once introduced to the heterosexual population in South Africa, HIV-1 increased rapidly and spread widely. In 1990 the prevalence of HIV-1 among women attending antenatal clinics (ANCs) was 0.8%; at the end of 1999 it was close to 23% (DOH 2000). By the year 2010 life expectancy is projected to fall by 20 years (from 68 to 48 years), child mortality to double (from an anticipated 49 without acquired immune deficiency syndrome (AIDS) to 100 per 100 000), and the number of AIDS orphans to increase by 2 million (Taylor 1998).

Curable sexually transmitted diseases (STDs) are common in both urban and rural populations and managing STDs offers the best short-term prospect for reducing HIV transmission. Viral STDs, and in particular herpes simplex virus (HSV), are also common and may contribute significantly to the spread of HIV. Tuberculosis has been a major cause of morbidity and mortality among black and coloured South Africans for the last 100 years and the HIV epidemic has greatly increased the incidence of tuberculosis.

While the extent of the HIV epidemic in the region has been evident for several years, the lack of any serious attempt to deal with the epidemic by governments in the region is striking. While the reasons for this are beyond the scope of this paper, there is a pressing need to develop a good understanding of the biological, social and

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economic determinants of the epidemic so that attempts to control and contain the epidemic are founded on a sound understanding of what should be done and what is likely to work. In this paper we assess the present state of the epidemic, discuss some of the factors that influence the spread of HIV including STDs and migrancy, discuss the impact that HIV is having on tuberculosis, and outline some of the projections that have been made. Finally, we indicate some areas in which more research is needed and suggest some of the interventions that should be implemented.

2. METHODS AND DATA

In this paper we use data from studies described in this section to develop an overview of the epidemic of HIV in South Africa. National ANC HIV surveys, conducted annually since 1990, provide information on the overall prevalence, age-prevalence, time-trends and geographical variation of HIV among women of reproductive age. Extensive biomedical, behavioural and socio-economic studies have been carried out at two sentinel sites, one in Hlabisa, a rural district of KwaZulu/Natal, the other in Carletonville, an urban gold-mining centre in Gauteng. Data have also been collected at STD, family planning and tuberculosis clinics, as well as referral hospitals and work places. Particular risk groups that have been studied include sex workers and truck drivers.

(a) *National ANC data*

In 1990 the Department of Health initiated a national HIV surveillance programme based on anonymous, unlinked, cross-sectional surveys of women attending public ANCs. In October and November each year approximately 2000 blood samples, taken for the prevention of haemolytic disease in newborn babies, are collected in each of the nine provinces (Küstner *et al.* 1998). Initially clinics were chosen randomly within each province but in 1998 probability-proportional-to-size cluster sampling was introduced in all provinces except Mpumalanga (DOH 2000).

(b) *Carletonville*

The Mothusimpilo ('Working-together-for-health') Project was designed to demonstrate the feasibility of using sustainable, community-based interventions to reduce the transmission of HIV and AIDS in Carletonville, the largest gold-mining complex in the world (shown in figure 2*b*). The most important urban settlement in the district is the township of Khutsong with approximately 56 000 people. Approximately 70 000 migrant mineworkers from rural areas in South Africa, Mozambique, Botswana and Lesotho live in single-sex hostels provided by the mining houses (Williams *et al.* 2000*a*). Biomedical, behavioural and social studies have been carried out to identify and explore the determinants of the epidemic and to assess the effectiveness of the intervention.

In August 1998 a survey was carried out on random samples of 1185 men and women aged 13–59 years stratified by housing type in Khutsong, of 899 mineworkers stratified by hostels, and of 145 sex workers living in informal settlements or 'hotspots' (Williams *et al.* 2000*b*). Blood and urine samples were tested for HIV, HSV, syphilis, gonorrhoea and chlamydia, and participants answered a modified version of the UNAIDS four-centre study questionnaire (UNAIDS 1998). The questionnaire included sections on demography, social factors including education and income, knowledge of STDs including HIV, attitudes towards HIV and to people infected with HIV, details of sexual practices and networking, and social capital. The survey was repeated in August 1999 but the Khutsong sample was limited to those aged 15–25 years to obtain more precise information on young people; a survey carried out in October 2000 was a repeat of the 1998 survey but these last data have still to be analysed.

(c) *Hlabisa*

About 215 000 predominantly Zulu-speaking people live in the Hlabisa health district in northern KwaZulu/Natal (shown in figure 2*b*). Homesteads are widely scattered and people depend on subsistence farming, migrant labour and pensions. The South African Medical Research Council (MRC) has conducted research in the area since the early 1990s. Following an STD survey carried out in 1996 a mass media campaign was developed to increase awareness of, and treatment-seeking behaviour for, STDs, strengthen STD case management in the public and private sectors, and design strategies to reduce STDs among migrant workers and their partners (Wilkinson *et al.* 1998)

Hlabisa has been identified as a potential site for HIV vaccine trials. A Community Advisory Board was elected in 1998 to promote a partnership among researchers, research participants and community members, and to ensure that the needs and concerns of the local people are properly considered, understood and dealt with (Frohlich 2000). Estimates of HIV prevalence and incidence in the general population are being made, and baseline data are being collected on key demographic and health variables (Gouws *et al.* 2000).

About 50% of adult men and 20% of adult women in Hlabisa are working outside the district at any given time and a study of the impact of migrancy on HIV transmission is being done with men from Hlabisa who work on the gold mines in Carletonville (800 km away) and in factories in Richards Bay (80 km away) and with their partners who stay in Hlabisa (Lurie *et al.* 2000).

(d) *Other settings*

Studies of HIV and STDs have been reported using data from STD clinics in urban centres and at referral hospitals where extensive studies of vertical transmission have been carried out and some of these are referred to below.

(e) *Risk groups*

Since 1992 the MRC has conducted research among an estimated 800 sex workers operating at truckstops on the national highway in the KwaZulu/Natal midlands between Durban and Johannesburg. Between August 1996 and June 1998, 477 women from five truckstops were screened for HIV as part of a microbicide trial (Ramjee *et al.* 1998). In 1998 sex workers were trained to recruit truck drivers from among their clients and a saliva test was used to determine their HIV status (Ramjee *et al.* 2000).

3. HIV INCIDENCE AND PREVALENCE

(a) *Variation in time and space*

The national ANC HIV prevalence for the last 10 years is shown in figure 1 (DOH 2000; Swanevelder *et al.* 1998). Fitting a logistic curve with a variable asymptote gives an asymptotic prevalence of $29.6 \pm 4.0\%$ with an intrinsic doubling time at the start of the epidemic of 15.1 ± 3.0 months (here and elsewhere errors are 95% confidence limits). There is, however, substantial

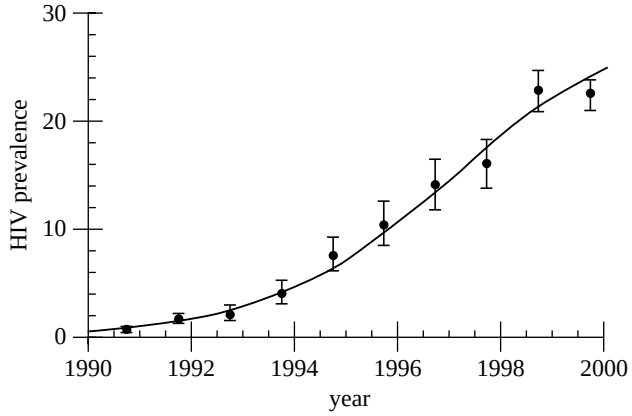

Figure 1. Prevalence of HIV infection from national ANC data. The fitted line is a logistic curve with an asymptote of $29.6 \pm 4\%$ and an intrinsic doubling time of 15.1 ± 3.0 months. Errors are 95% confidence limits.

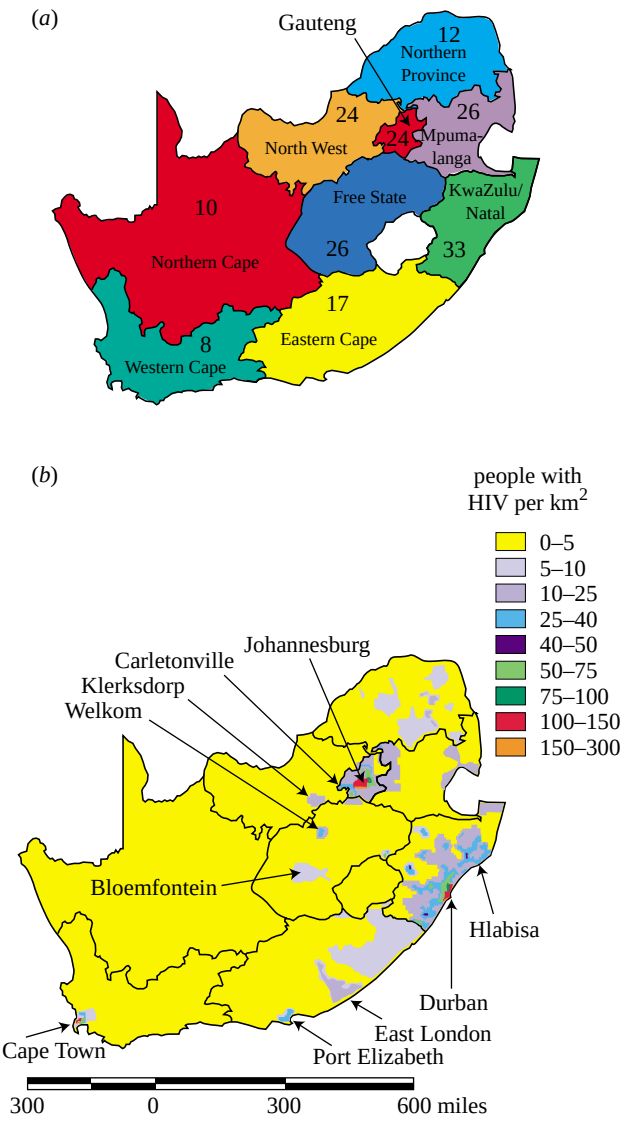

Figure 2. (*a*) Prevalence (%) of HIV infection among women attending ANCs in the provinces of South Africa. (*b*) The number of people living with HIV infection per km^2. The estimates are from maximum-likelihood fits to the annual data from 1990 to 1999 using logistic regressions with variable asymptotes.

geographical variation (figure 2*a*, table 1) and at the end of 1999 the rates declined from a high of 33% in KwaZulu/Natal, through the northeastern provinces to the Eastern Cape, to a low of 10% in the Western Cape. The population of South Africa is very unevenly distributed, however, and a more instructive map is obtained by combining the provincial prevalence data with the population density (Williams *et al.* 2000*c*) to get the distribution of people infected with HIV (figure 2*b*). Although the Western Cape has low rates of infection, Cape Town has a large population and a high density of people infected with HIV. While the overall infection rates in KwaZulu/Natal are high, the population is patchily distributed and infections do not occur evenly through the province. In the former Transkei, to the northeast of East London, infected people are more evenly spread over a large area. The mining centres at Carletonville, Klerksdorp and Welkom show high densities of infected people as do the port cities of Port Elizabeth, East London and Durban and the major industrial and commercial centre of Johannesburg.

In all provinces the current HIV prevalence is close to the estimated asymptote (table 1) so that the prevalence in the Western Cape is likely to remain significantly below the current level in the Eastern Cape and the prevalence there below that in KwaZulu/Natal. These trends will become clearer over the next few years.

The intrinsic doubling times given in table 1 range from 8 to 13 months and, excluding Mpumalanga for which the data are problematical, there is a significant correlation between the intrinsic doubling time and the asymptotic prevalence ($\rho = 0.84$, $p = 0.0015$) so that provinces that have a high asymptotic prevalence tend to have a lower epidemic growth rate.

The prevalence of HIV among women attending ANCs in rural Hlabisa matched the provincial prevalence closely; between 1992 and 1999 the former increased from 4.2 to 34% (Gouws *et al.* 2000) while the latter increased from 4.5 to 33% (from the data in table 1).

(b) *Prevalence in risk groups*

At truckstops in the KwaZulu/Natal midlands, 51% (47–56%) of sex workers (mean age 25 years) and 56% (51–62%) of their truck driver clients (mean age 37 years) were HIV positive (Ramjee & Gouws 2001). Between 1988 and 1994 the prevalence of HIV infection at sentinel STD clinics in Johannesburg rose from 0.8 to 19% among men and from 1.2 to 26% among women (Department of Health 1994) giving a doubling time of about 15 months for both men and women. In 1993 and 1994, 30% of men attending STD clinics in Durban, Johannesburg and Cape Town were HIV positive (Chen *et al.* 2000), and in 1997, 43% of STD patients attending a primary care clinic in Hlabisa were HIV positive (Wilkinson & Wilkinson 1998).

(c) *Age-prevalence*

The gender differences in the age-specific prevalence of infection are illustrated in figure 3 for young men and women in Carletonville in 1998 (Williams *et al.* 2000*a*). Below 15 years of age the prevalence was close

Table 1. Provincial HIV prevalences.

(The best estimate of the current prevalence, the asymptotic prevalence (from a logistic regression), and the intrinsic doubling time at the start of the epidemic with 95% confidence limits. The following data points were omitted because the significance level of the HSD test for deviations from the fitted line was < 0.01: Mpumalanga 1993 ($p = 10^{-12}$) and 1994 ($p = 10^{-9}$); North West 1991 ($p = 10^{-5}$) and 1997 ($p = 10^{-20}$).)

province	prevalence (%)		doubling time (months)
	current	asymptote	
Eastern Cape	17.3 ± 2.6	20.1 ± 3.4	12.8 ± 1.3
Free State	26.3 ± 2.5	28.9 ± 2.6	13.2 ± 1.4
Gauteng	23.9 ± 1.8	25.4 ± 1.7	11.9 ± 0.8
KwaZulu/Natal	32.1 ± 2.4	34.7 ± 2.3	14.6 ± 1.1
Mpumalanga	26.2 ± 2.4	26.6 ± 1.5	9.3 ± 0.8
Northern Cape	10.4 ± 2.8	10.9 ± 2.1	9.8 ± 1.8
Northern Province	12.0 ± 1.9	13.0 ± 2.3	8.6 ± 1.9
North West	23.7 ± 2.8	27.5 ± 4.2	13.4 ± 2.5
Western Cape	8.0 ± 2.3	9.6 ± 3.2	11.2 ± 1.7

to zero for both sexes but increased rapidly thereafter reaching 39% in 20-year-old women and 8% in 20-year-old men. The peak prevalence was 58% at 24 years of age among women and 45% at 32 years of age among men.

By analysing a range of age-specific prevalence data, four different patterns of infection have been identified among (i) women attending ANCs; (ii) women in the general population; (iii) men in the general population; and (iv) male migrant workers (Williams *et al.* 2000*d*). The age-prevalence of infection among women attending ANCs is shifted down by *ca.* 3 years compared with urban women so that ANC data overestimate infection rates in young women and underestimate infection in older women. The age-prevalence of infection among urban men is shifted up by *ca.* 6 years compared with urban women (figure 3) while the age-prevalence among mineworkers and truck drivers shows no significant age-dependence between 25 and 50 years of age, in sharp contrast to the results for urban men. No differences were found when comparing urban and rural populations of either men or women. Within each of the four groups the shapes of the age–prevalence curves have not changed significantly over time, suggesting that the prevalence is increasing at the same rate for all ages (Williams *et al.* 2000*d*).

Several factors might explain these differences. There was no significant difference in the reported age at sexual debut: the mean age at first sex for men was 16.5 years (95% in the range 12.8–20.1 years) and for women 16.4 years (95% in the range 12.6–20.1 years). However, 24-year-old women in Carletonville have casual male partners whose mean age is 30 years, which explains the shift to older ages of infection in men compared with women. Furthermore, women also have a higher risk of infection per partnership than do men (figure 4); the estimated risk of infection after one partnership is 27% for women and 8% for men. Using the reported age

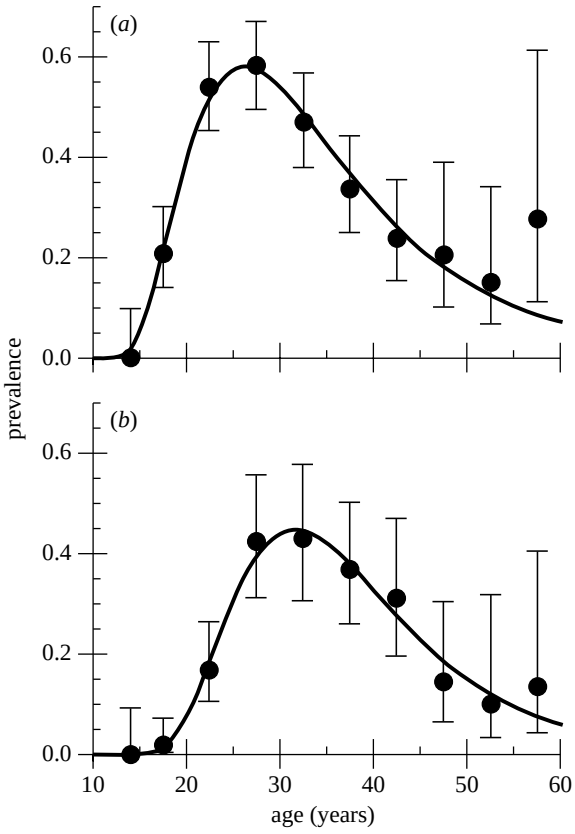

Figure 3. The age-prevalence of HIV infection among (*a*) women and (*b*) men in Carletonville.

difference between sexual partners and assuming that male-to-female transmission is three times more likely than the reverse (per sexual contact with an infected person) gives a good fit to the data so that these two factors alone provide a sufficient explanation for the gender differences in the age-prevalence of infection (Williams *et al.* 2000*e*).

(d) *Incidence estimates*

Figure 5 shows the age-specific incidence of infection for women attending ANCs in Hlabisa in 1998 (Williams *et al.* 2001) derived from the age-specific prevalence and changes in overall prevalence with time and independently using a sensitive-less sensitive or 'detuned' enzyme-linked immunosorbent assay (ELISA) (Gouws *et al.* 2001). The incidence peaks at 24% per annum among 22-year-old women. A similarly high incidence of 18% (13–23%) per annum was found in a cohort study of sex workers at truckstops (mean age 25 years, range 15–48 years) from 1996 to 1999 (Ramjee 2000).

4. FACTORS AFFECTING THE EPIDEMIC

Many factors contribute to the spread of HIV. Here we consider other STDs and migrancy, both of which are of particular importance in South Africa, some of the social factors that influence sexual behaviour, and vertical transmission. We present data that illustrate the extent to which HIV infection is contributing to the spread of tuberculosis.

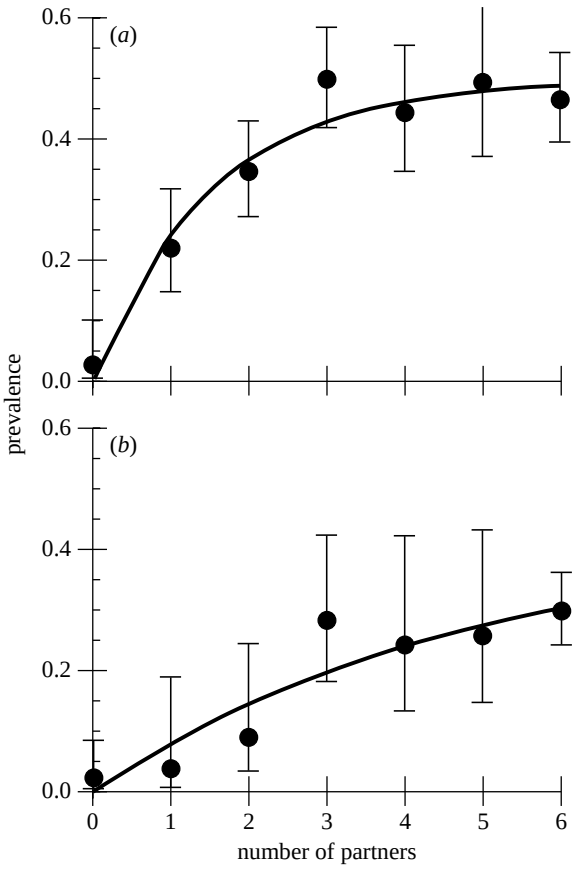

Figure 4. The prevalence of HIV infection plotted against the reported number of sexual partners for (*a*) women and (*b*) men in Carletonville in 1998. Fitted curves assume a constant risk per partnership.

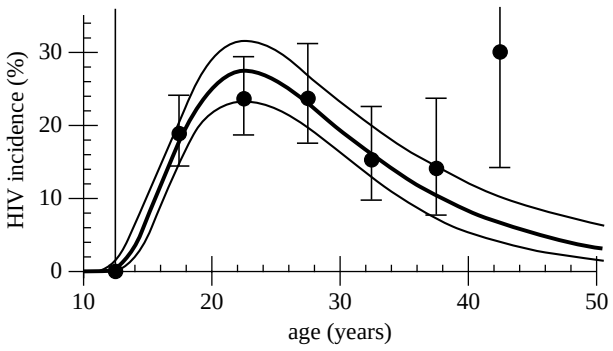

Figure 5. The lines give the annual incidence (with 95% confidence bands) of HIV infection per susceptible person for women attending ANCs in Hlabisa in 1998. The filled circles give the estimates (with 95% binomial confidence limits), for the same sample of women, obtained from a sensitive-less sensitive ELISA assay (Gouws *et al*. 2001).

Table 2. Prevalence (%) of recently acquired syphilis (RPR- and TPHA-positive) and current gonorrhoea and chlamydia for various population groups.

place	population	syphilis	gonorrhoea	chlamydia
national[a]	ANC	7.6	8.0	16.0
Hlabisa[b]	men	9.3	2.3	5.6
Hlabisa[b]	women	8.5	5.8	6.4
Hlabisa[c]	pregnant	8.4	7.8	12.9
Hlabisa[c]	non-pregnant	8.0	4.0	8.0
Carletonville[d]	miners	5.2	3.0	3.8
Carletonville[d]	men	6.1	3.4	5.2
Carletonville[d]	women	9.7	6.9	8.1
Carletonville[d]	CSW	23.3	15.7	9.1
KwaZulu/Natal[e]	CSW	42.3	14.1	16.4

[a] ANCs nationwide, 1980–1996 (Pham-Kanter *et al*. 1996).
[b] Community survey, 1995 (Colvin *et al*. 1998).
[c] Pregnant and non-pregnant women from STI surveillance in primary health care, ANC and family planning clinics, and a community survey in 1996. Approximately 6900 pregnant and 49 000 non-pregnant women aged 15–49 years (Wilkinson *et al*. 1999).
[d] Community survey, 1998, see § 2 for details (Williams *et al*. 2000*b*).
[e] Commercial sex workers (CSW) recruited at five truckstops in the KwaZulu/Natal midlands, 1996 and 1997. See § 2 for details (Ramjee *et al*. 1998). (A re-analysis of these data with a larger sample size gives a revised value of 32% for syphilis.)

(a) *Bacterial STDs*

Other STDs, which were already common in South Africa in the 1940s (Kark 1949), increase the likelihood of HIV transmission (Rehle *et al*. 1998; Fleming & Wasserheit 1999) and various surveys among commercial sex workers, mineworkers, women attending ANCs, and rural and urban adults are summarized in table 2. The prevalence of recently acquired syphilis (rapid plasma reagin (RPR) and *Treponema pallidum* haemagglutination assay (TPHA)-positive) ranges from 5 to 10% for men, 7 to 10% for community women and 23 to 42% for commercial sex workers. The prevalence of gonorrhoea is generally lower than that of recently acquired syphilis, ranging from 2.3 to 3.4% for men, 5.8 to 8% for community women, and 14 to 16% for commercial sex workers. The prevalence of chlamydia generally lies between that of syphilis and gonorrhoea except that in pregnant women the prevalence is higher than for syphilis or gonorrhoea. Asymptomatic infections are common especially among non-pregnant women. In Hlabisa, among pregnant women with syphilis, gonorrhoea and chlamydia, 4.9, 6.1 and 8.0%, respectively, were asymptomatic while the corresponding rates among non-pregnant women were much higher at 67, 37 and 36%, respectively (Wilkinson *et al*. 1999). The high prevalence of curable STDs offers an important opportunity for immediate interventions to reduce the further spread of HIV but syndromic management alone may not be sufficient.

Few estimates have been made of the incidence of STDs in South Africa. A survey in primary care clinics and general practices in Hlabisa in 1996 (Wilkinson *et al*. 1998) estimated the annual incidence of symptomatic STDs among all adults to be 9%, with a peak incidence of 16% among those aged 20–24 years. The cumulative age-prevalence of exposure to syphilis (TPHA positive) in Carletonville in 1998 is given in figure 6 (Williams *et al*. 2000*b*). The asymptotic prevalence among men (86%) is

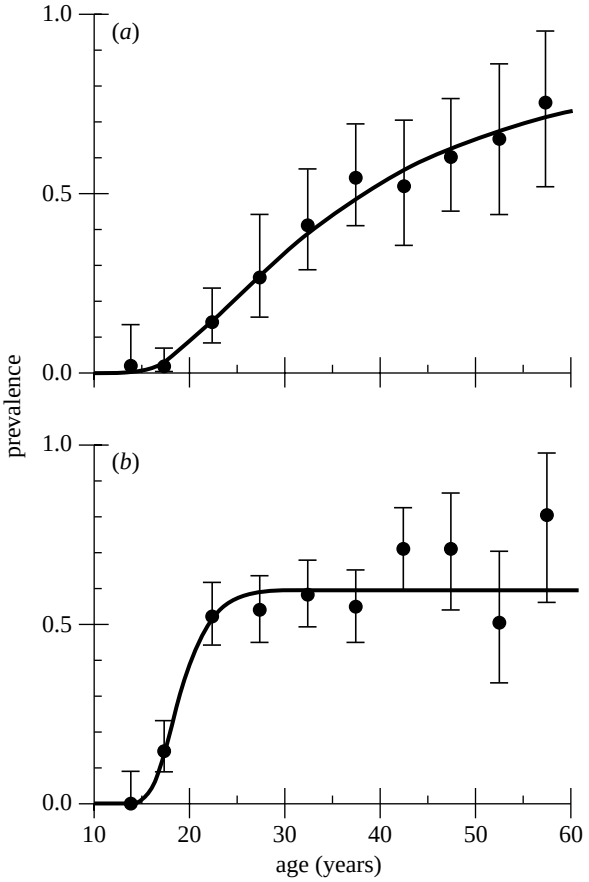

Figure 6. Life-time exposure to syphilis for (*a*) men and (*b*) women living in Carletonville. The fitted curves are cumulative log-normal distributions offset by 10 years. The asymptotic prevalences are 86% for men and 59% for women.

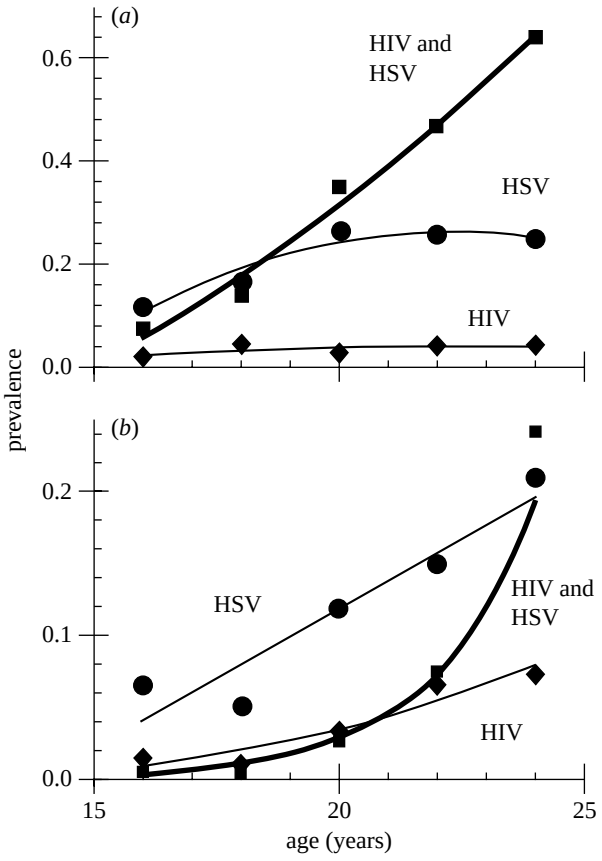

Figure 7. The proportion of (*a*) women and (*b*) men infected with HIV-1 only (diamonds), HSV-2 only (circles) and with both (squares and heavy lines), as a function of age. Fitted curves are polynomial trend lines.

higher than among women (59%), but women become infected more rapidly at an earlier age. The fits in figure 6 suggest that the annual incidence of infection peaks at 9.5% among 18-year-old women (falling to 0.2% 10 years later) and at 2.5% among 25-year-old men (but was still 2.0% 10 years later).

(b) *Viral STDs*

Genital ulcer disease (GUD) is strongly associated with HIV (Wasserheit 1992). Among men attending STD clinics in 1993 and 1994, patients with GUD were more likely to be infected with HIV than were patients with urethritis (39 versus 21%; $p < 0.001$), and those with HSV-2 were more likely to be co-infected with HIV (odds ratio (OR) = 2.7, $p < 0.001$) (Chen *et al.* 2000).

In a multivariate analysis of social and biological risk factors for HIV among young people in Carletonville in 1999, HSV-2 was the single best predictor of HIV status (Auvert *et al.* 2001). At 25 years of age, 70% of women and 29% of men were infected with HIV, while 89% of women and 42% of men were infected with HSV-2, and figure 7 shows the age-prevalence of infection with HIV only, HSV-2 only or both. For women below 20 years of age the OR is 22 ($p < 0.000\,01$) while for women above 20 years of age it is 8.3 ($p < 0.000\,01$). For men the corresponding ORs are 7.6 ($p = 0.0001$) and 7.7 ($p = 0.0008$), respectively. Very few women are infected with HIV only. At 15 years of age, 98.4% (94.3–99.8%) were HSV-1 seropositive so that while this may contribute to the spread of HIV, these data cannot be used to investigate that association.

While the association between HIV and HSV-2 is strong, the extent to which each contributes to the spread of the other is more difficult to establish. There is evidence that the rise in the prevalence of HIV has coincided with an increase in the prevalence of HSV; between 1991 and 1998 when the prevalence of HIV among men attending STD clinics in Durban increased from 5 to 64%, the prevalence of HSV-2 increased from 10 to 41% (Kharsany *et al.* 2000).

(c) *Migration*

The HIV high-prevalence countries of southern Africa are bound together by their dependence on mining, especially hard rock mining for gold and other metals in South Africa and for diamonds in Botswana. In the 1980s and 1990s, for example, the South African gold mining industry employed half-a-million migrant mineworkers from rural areas in South Africa, and from Botswana, Malawi, Mozambique, Lesotho and Swaziland (Crush & James 1995). The regular and regulated supply of labour was maintained through a system of 'circular migration' whereby men from other countries were legally entitled to work in South Africa but had no right of permanent residence. To ensure that men did not remain in South Africa

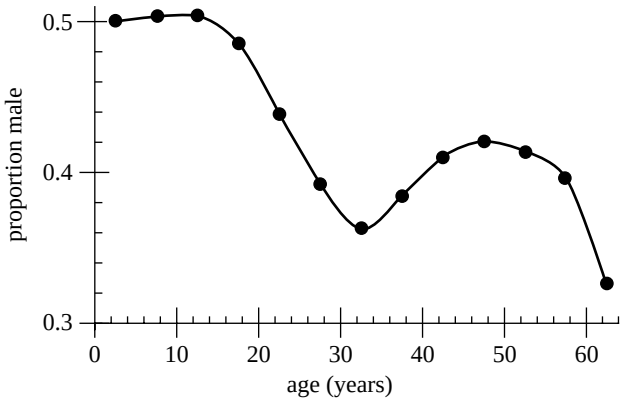

Figure 8. The proportion of men in Hlabisa in 1996 as a function of age (Statistics South Africa 1998).

they were not allowed to bring their families with them and were given annual contracts that obliged them to return home once a year with no guarantee of continued employment. An additional 2 million legal, and many more illegal, migrant workers seek employment on South Africa's factories or farms, or work in other mainly informal sector occupations (Zwi & Bachmayer 1990), creating ideal conditions for the wide and rapid spread of HIV and other STDs (Jochelson *et al*. 1991; Lurie *et al*. 1997).

The presence of about 70 000 single men living in mine hostels in Carletonville attracts large numbers of women who sell sex and alcohol (Campbell 2000) and the surplus of men in Carletonville is balanced by a deficit of men in rural areas such as Hlabisa where the proportion of men falls to *ca*. 35% at 32 years of age, as shown in figure 8, and then increases again as migrant workers return home, often with severe and debilitating diseases (Williams *et al*. 1998). A recent study of migrancy between Hlabisa and Carletonville (Lurie *et al*. 2000) found that HIV prevalence was higher among migrant than among non-migrant men (28 versus 14%; $p < 0.05$) but in 40% of discordant couples the woman was HIV positive, indicating that the wives of migrant men are at high risk of being infected locally.

(d) *Knowledge, condom use, perception of risk*

Knowledge of HIV and AIDS and the associated risk factors is good (Abdool Karim 1997; Williams *et al*. 2000*b*) but safe sex is not widely practised. Although condom distribution in the public sector increased from 6 million in 1994 to 172 million in 1997 in a total population of about 40 million people (Myer *et al*. 2001), condom use remains inconsistent. A nationwide, urban, survey in 1996 found that 62% of male and 79% of female adolescents had never used condoms (Richter 1996) and in the same year a study among rural adults in Hlabisa found that only 14% had ever used condoms (Colvin *et al*. 1998). In studies conducted between 1998 and 1999 among truck drivers (Ramjee & Gouws 2001), men from STD clinics and men from the general population (Ramjee *et al*. 2001), between 7 and 13% of men used condoms with their girlfriends or wives, while *ca*. 50% reported condom use with casual partners. In the 1998 survey in Carletonville, 23% of men and 17% of women said that they used a condom with their regular partner and 47% of men and 27% of women used a condom with their latest casual partner (Williams *et al*. 2000*b*).

Low levels of perceived risk of contracting HIV may contribute to low levels of condom use. In 1998, only 20% of men and 17% of women in Carletonville thought that they had a good chance of being infected and of those who thought that they were at no risk of infection, 28% were already infected (Williams *et al*. 2000*b*).

(e) *Mother-to-child transmission of HIV*

Studies conducted at King Edward VIII hospital in Durban reported vertical transmission rates of *ca* 34%, while 60% of infected infants showed HIV-related symptoms by three months, and 77% of the HIV-positive children were symptomatic by 1 year; the case fatality rate was 35% over 2 years (Bobat *et al*. 1998). Although extensive trials have been done in the use of drugs to prevent vertical transmission of HIV (McIntyre & Gray 2000), antenatal care and testing programmes are limited, proven interventions are not implemented in the public sector, and prevention of postnatal transmission through breast-feeding remains problematical (Mofenson & McIntyre 2000).

(f) *Tuberculosis*

The incidence of tuberculosis in South Africa is among the highest in the world; a recent estimate puts the case rate at 392 per 100 000 population (Dye *et al*. 1999) and this is increasing rapidly as a result of the epidemic of HIV.

Between 1991 and 1995 the annual incidence of tuberculosis in Hlabisa increased from 154 to 413 per 100 000 and 44% of cases were attributable to HIV infection (Wilkinson & Davies 1997). At Rietfontein Hospital in Gauteng the prevalence of HIV infection among tuberculosis patients increased from 5% in 1991 to 80% in 1997 (Abdool Karim & Abdool Karim 1999).

Silicosis increases the risk of tuberculosis (Williams *et al*. 1998) and in a recent study of gold miners in Welkom, 25% had silicosis and 34% were HIV positive. The incidence of tuberculosis increased by 4.1 times if men were HIV positive and by 3.3 times if men had silicosis; among men with both diseases the incidence of tuberculosis between 1995 and 1997 was 16.1% per annum (Corbett *et al*. 2000).

5. PROJECTIONS AND MODELS

Demographic models have been developed to predict trends in infection rates, adult and infant mortality, the number of orphans and life expectancy, at a national level. The Doyle (1991) model is widely used for advocacy and the predictions have generally been borne out. A model developed by the Actuarial Society of South Africa (ASSA) (Dorrington 1998) has been used to model the macro-economic effects of HIV and AIDS (Barings 2000). These models rely on the national ANC data (figure 1) for their calibration and validation and more detailed data are needed not only concerning HIV but also other STDs (which increase transmission of HIV), infectious diseases (which are associated with HIV), and

social factors, especially migrancy and poverty (which place people in a situation of high risk).

(a) *Current prevalence and future deaths*

About 25% of women attending ANCs are currently infected with HIV (figure 1), which gives a reasonable estimate of the prevalence in adult women aged 15–49 years, while the rates of infection in men are *ca.* 75% of the rates in women (Williams *et al.* 2000*d*). About half of the South African population is between 15 and 49 years old, so that *ca.* 10% of the entire population, or 4 million people, are infected with HIV.

Between 1998 and 1999 the prevalence of infection among women attending ANCs increased from 21 to 24% (fit in figure 1) and *ca.* 15% of those infected in 1998 will have died 1 year later. Approximately 6% of adult women were therefore newly infected between 1998 and 1999 and if the proportion of men who were newly infected was *ca.* 75% of this, there are currently about 3000 new infections per day. From the number of new infections per day and using a gamma-function survivorship curve with a median life expectancy of 7 years (Kamali *et al.* 1998; UNAIDS 1996) it is probable that about 60 000 adults died of AIDS-related diseases in the year 2000 and that nearly half-a-million will die in the year 2007. Direct evidence for increasing mortality was obtained in a demographic and health survey carried out in the rural northeast of South Africa where mortality increased significantly between 1992 and 1995 with the greatest increase in adults between 20 and 49 years of age due mainly to AIDS-related diseases including tuberculosis (Tollman *et al.* 1999).

Estimates of age-specific incidence (figure 5) can be used to estimate the long-term impact of HIV on life expectancy and suggest that the life expectancy for women in KwaZulu/Natal could fall to 30 years. Assuming that the incidence among men is *ca.* 75% of that for women and is shifted to older ages by about 5 years the life expectancy for men could fall to 34 years. In practice it is likely that the incidence of infection will decline over the next 10 years as people change their behaviour and better interventions are put in place. These calculations do not, however, include the dramatic impact that AIDS is already having on infant mortality (Taylor 1998).

More extensive models (Doyle 1991; Dorrington 1998), bear out these simple calculations, although some of the earlier predictions underestimated the rate of growth of the epidemic. In 1997 the Doyle model predicted that by the year 2000 *ca.* 15% of adults would be infected with HIV, reaching a peak of *ca.* 22% only in the year 2010. The model predicted about 100 000 excess deaths in the year 2000 increasing to about 500 000 in the year 2010 and about 200 000 AIDS orphans in the year 2000 rising to about 2 million in the year 2010 (Taylor 1998). The ASSA model predicts that HIV infection rates will peak at *ca.* 17% of the total population in 2006, that AIDS-related deaths will peak about 5 years later when about 720 000 people will die of AIDS-related disease each year. Because these deaths will be concentrated in the 25- to 50-year-old age groups the labour force will be disproportionately affected with severe repercussions for the economy of the country (Barings 2000).

6. DISCUSSION

While the prevalence of HIV infection in South Africa is among the highest in the world, the infection rates among women attending ANCs suggest that the prevalence of infection is levelling off in all provinces and that the prevalence in the Western Cape, for example, is likely to remain substantially below that in KwaZulu/Natal. Because the population of South Africa is unevenly distributed more extensive data and more detailed spatial mapping are needed to properly plan and coordinate an effective response to the epidemic.

The incidence of infection is particularly high among young women between the ages of *ca.* 15 and 20 years, but to protect them from infection will require a much more detailed understanding of the social context of sexual transactions among young people than is currently available (MacPhail & Campbell 2001; Campbell & MacPhail 2001).

The high prevalence of curable STDs suggests that much progress could be made through effective syndromic management and the provision of periodic presumptive treatment to groups at high risk. Viral STDs, and in particular HSV-2, are more difficult to manage but trials of symptomatic treatment or potential vaccines for HSV-2 should be done. There is increasing evidence that male circumcision is associated with significantly lower rates of infection (Szabo & Short 2000) and consideration should be given to promoting male circumcision as a public health measure.

Dealing with the health consequences of migration is important but problematical as the economy of South Africa as well as its neighbours depends on migrant labour and the remittances that migrant workers send home. The lack of differences in the infection rates in urban and rural areas testifies to the role of migration in the spread of infection, and the relative constancy in the age-prevalence of infection among mineworkers and truck drivers shows that, unlike those living in more stable communities, migrant workers remain at high risk of infection throughout their working lives. However, just as migration has contributed to the spread of HIV it could be used to spread information concerning HIV and AIDS, and associated diseases and programmes targeting migrant workers and dealing with the specific social, psychological and health problems that they face should be given a high priority.

Before the advent of the HIV epidemic South Africa had one of the highest rates of tuberculosis in the world, although rates were falling. HIV has reversed this trend and on the gold mines, where the high prevalence of silicosis contributes to the epidemic of tuberculosis, there have been dramatic increases in the incidence of tuberculosis, mainly among men with HIV. Mass treatment with isoniazid is being considered by some gold mines to bring the situation under control (G. Churchyard, personal communication).

Scientists working on the South African AIDS Vaccine Initiative (Galloway 2000) are collaborating internationally to develop a subtype C HIV vaccine (Williamson *et al.* 2000) and trial sites are being developed by the MRC (Gouws *et al.* 2000). Given the urgency of the situation the provision of universal access to free antiretroviral

therapy (ART) should be considered drawing on the experience of Brazil and Argentina (UNAIDS 2000). While bulk purchase would reduce drug costs by an order of magnitude or more, the greater difficulties will be those of delivery, care, monitoring, safety, drug resistance and so on. However, ART cannot only save the lives of infected people but may also have a dramatic public health impact through reductions in transmission.

While much is known, much is still to be learned about the epidemic of HIV and AIDS in South Africa and, in particular, we need to know why the prevalence rates are so much higher in this region than elsewhere. Those interventions that have proved effective in other settings need to be widely implemented as rapidly as possible and new interventions need to be tried and tested. There remains a need for sound epidemiological modelling, which will provide a more coherent and quantitative framework within which such interventions can be planned, carried out, tested and evaluated.

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