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Modelling the characteristics of the male injecting drug user population in England and Wales

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Abstract

Estimating characteristics of the injecting drug using (IDU) population is of major health importance. This study proposes a method to determine the age-specific rate at which individuals start injecting drugs, and the rate at which individuals leave the IDU population. A simple age-structured model describing the initiation of injecting and the removal of injectors from the IDU population and their evolution over time was fitted to data by maximum likelihood. The peak age at which males start injecting drugs is 21 years. The rate at which IDUs leave the surveyed IDU population (removal rate) increases linearly with age up to a maximum rate and is constant thereafter. The model suggests that the rate at which IDUs started injecting may have peaked during the early 1980s and has declined since. These results reflect the characteristics of a sample of IDUs in contact with services; they suggest that the incidence of injecting drug use has been broadly stable throughout the 1990s with possibly a slight drop in recent years. The actual IDU population may differ from the surveyed sample (in particular they may have a lower average age and length of career) and this must be investigated. Additional modelling work attempting to clarify the difference between the removal rates proposed here and the true cessation rates as they vary with age should also be undertaken.

Keywords: Modelling; Injecting; IDU; Incidence; Cessation; Male

Introduction

Understanding the characteristics of the injecting drug user (IDU) population is of major public health importance. Information on, for instance, the age-specific rates at which individuals start and stop injecting drugs can inform policy-making, particularly strategies aimed at the prevention of drug misuse (Home Office, 2002). The risks associated with injecting drug use include HIV, Hepatitis B, and Hepatitis C, in addition to fatal overdoses, etc.

Since 1990 voluntary unlinked anonymous (UA) saliva samples have been collected from injecting drug users in contact with specialist agencies throughout England and Wales (Health Protection Agency, 2003; Nicoll et al., 2000; Unlinked Anonymous Surveys Steering Group, 2002). These agencies provide a range of services from medical treatment to needle exchange and outreach work. Behavioral information is collected through a brief anonymous questionnaire unlinked to client identifying information. This includes questions on previous HIV testing and the sharing of injecting equipment. These samples have been collected on an annual basis leading to the availability of 12 complete surveys (1990–2001), although they do not extend to Scotland or Northern Ireland where other methods of surveillance are used.

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Various mathematical and statistical approaches have been made to gain information about the injecting drug user (IDU) population and its size (Frischer, Hickman, Kraus, Mariani, & Wiessing, 2001; Godfrey, Eaton, McDougall, & Culyer, 2002). Large surveys have also been undertaken (Frischer et al., 2001; Johnson et al., 2001; Johnson, Wadsworth, Wellings, & Field 1994) with the results extrapolated to draw conclusions about the wider drug using population (Johnson et al., 2001). Many smaller surveys have also been undertaken, but in many cases the size of the survey limits the generalisability of the results between different populations and through time.

The purpose of this work is to propose a method in which key parameters that contribute towards the characteristics of the IDU population can be estimated from a data set such as the UA surveys described in the following. These key parameters can then be taken forward and applied in both modelling applications and to inform policy-making. Of particular interest are the age-specific rates at which IDUs start and stop injecting drugs and how the incidence of injecting may have evolved over time. As the majority of IDUs are male (Hunter, Stimson, Judd, Jones, & Hickman, 2000) and the characteristics of male and female IDUs may differ considerably, only the male IDU population will be analysed, however, the techniques described here can be applied to the female injecting population so that formal comparisons can be made at a later date between the characteristics of male and female IDUs.

Methods

Data

A current IDU was defined as a person that injected non-prescribed drugs in the previous four weeks; all participating persons that had not injected within four weeks of the survey were excluded from the present analysis. Surveys from 1990 and 1991 were considered to be too small and so were discarded leaving 10 complete consecutive surveys 1992–2001. In each survey current male IDUs with data on their current age (at time of the survey) and the age of their first injection were considered. The data were further constrained by limiting the current age range to be from 16 to 49, and the age of first injection to be from 13 to 45. Data outside these ranges were sparse and deemed too unreliable to be used.

We investigated the sensitivity of the results obtained from the model and excluded injectors that began injecting before 1980 (approximately 12% of the records). These were a small population of older injectors whose data particularly on length of injecting career may be unreliable due to recall issues.

Model

C_{ijk} is the number of current IDUs in year k, aged i who started injecting at age j (e.g. $C_{30,20,1992}$ would be the number of 30-year-old current IDUs in 1992, who started injecting when they were 20 years old).

$$C_{ijk} = f_{jy} g_y S_{ijk}$$

where f_{jy} is the proportion of those persons who started injecting in year y that were aged j, g_y is the number of persons that started injecting in year y, S_{ijk} is the proportion of those persons that started injecting at age j, who are still injecting at age i in year k.

Those persons (S_{ijk}) continuing to inject one year later

$$S_i = S_{ijk}(1 - \lambda_{ijk})$$

where λ_{ijk} the removal probability, is the proportion of IDUs with current age i and start age j being removed from the surveyed injecting population in year k. This may be due to them stopping injecting, no longer reporting to services or because of deaths.

The proportion of IDUs in contact with services may vary with injecting career length, for example, it is known that IDUs with shorter injecting careers are likely to be under-represented compared to more experienced users (Godfrey et al., 2002). A measure of this under representation across all career lengths is incorporated in the model.

p_{i-j} is the proportion of persons with career length $(i - j)$ captured by a survey relative to a baseline career length.

The expected number of IDUs in survey year k of age i and start age j is

$$M_{ijk} = p_{i-j} C_{ijk}$$

Z_{ijk} is the probability that an IDU surveyed in year k, is of age i and start age j

$$Z_{ijk} = \frac{M_{ijk}}{\sum_j \sum_i M_{ijk}}$$

Parameterisation

It is assumed that both the proportion of persons starting injecting by age (f_{jy}) and the removal probability (λ_{ijk}) do not vary with time ($f_{jy} = f_j$ and $\lambda_{ijk} = \lambda_{ij}$). Both these assumptions will be examined during tests of sensitivity.

The absolute size of the male IDU population is not known and so it is not possible to calculate the number of males starting injecting each year. Therefore g_y is relative to some arbitrary fixed reference year detailed in the following.

As a starting point for analysis, an initial model was proposed with which to fit the data and this is defined as:

f_j is described by a gamma distribution at age a with an offset ω $f(a - \omega) = \text{gamma}(\mu, \sigma)$.
p_{i-j} is grouped into the following injecting career lengths; <1, 1–2, 3–4, 5–9 years, and calculated relative to a fixed injecting career length of 10+ years = 1.

g_y is grouped into 11 two-year groups (1980–1981, 1982–1983, etc.) and is calculated relative to year group 1988–1989 = 1000.
λ_{ij} is grouped into four age groups; 13–19 years, 20–24 years, 25–29 years, 30+ years.

The initial model was fitted to the data as follows:

Within each survey year k, the data, D_{ij} (count of the number of IDUs surveyed at age i, with starting age j) are assumed to follow a multinomial distribution. The log likelihood of the model given the data within year k is:

$$\log \text{lik}_k = \sum_{ij} D_{ijk} \log Z_{ijk}$$

each survey is independent, therefore

$$\log \text{lik} = \sum_k \log \text{lik}_k$$

Then, maintaining the gamma distribution describing f_j, backwards step-wise elimination was used to reduce the number of strata describing g_y, p_{i-j}, and λ_{ij}. Nested models were compared by the difference in deviance and the degrees of freedom, which can be tested using a chi-squared test with degrees of freedom equal to the difference in degrees of freedom between models. For comparisons between non-nested models, i.e. such as in a case where a function is changed from piece-wise constant to linear, a comparison between the resultant deviances was made. This process lead to a final parsimonious model containing less parameters than the initial model. Ninety-five percent confidence intervals were calculated using the profile likelihood method (Armitage & Colton, 1998).

The reduced models used during the step-wise elimination process are described in the following (only changes from the initial model are noted):

1. The initial model.
2. λ is described by a linear function with age, $\lambda(a) = \max(\pi a + k, 0)$.
3. λ is described by a linear function with age up to a maximum and then constant thereafter. $\lambda(a) = \min((\max(\pi a + k, 0), \nu))$.
4. As model 3 above, except g_y is grouped into five 4-year groups (1980–1983, 1984–1987, 1990–1993, etc.) and is calculated relative to the fixed year group 1988–1989 = 1000.
5. As model 3 above, except p_{i-j} is grouped into the following injecting career lengths; <1, 1–2, 3–9, and is calculated relative to a fixed injecting career length of 10+ years.
6. As model 3 above, except p_{i-j} is grouped into the following injecting career lengths; <1, 1–9, and is calculated relative to a fixed injecting career length of 10+ years.

Sensitivity analysis

The sensitivity analysis of the final model proposed here took four approaches.

1. To test the assumption that the removal probability (λ_{ij}) and the function describing the proportion of persons starting injecting by age (f_j) are both constant over time. The data from surveys 1992 to 1996 and 1997 to 2001 were each modelled separately with the results compared to each other and that obtained from all surveys 1992 to 2001.
2. To test the impact of considering only injectors that injected in the previous four weeks, additional data from the UA surveys was also considered. Since 1998 the UA surveys included an additional field identifying injectors that had injected up to one year prior to being surveyed. Using this data a comparison was made between the characteristics of those injectors that had injected up to four weeks prior to being surveyed, and those that had injected in the previous year.
3. The impact of excluding injectors that claimed to have started before 1980 on the estimated expected injecting career length of an IDU was also considered.
4. To test the sensitivity of p_{i-j} and g_y, 95% confidence intervals were calculated for each of the parameters describing these functions.

Results

Data

Considering IDUs that started injecting from 1980 onwards, there were approximately 1500 male current IDUs in each annual survey with an overall total of 13,536 records analysed. The mean age of an IDU surveyed across all years was 27.9 years old, the mean age of first injection was 21.2 years, with a mode of 18 years of age. Across surveys 1992–2001 the average injecting career of an IDU calculated using the total injecting years and the total number of records was found to be 5.82 years. Including the injectors that started prior to 1980, for surveys 1992–2001, the mean age of an IDU surveyed across all years was 29.3 years, the mean age of first injection was 20.8 years, and the average injecting career was 8.56 years.

Model fit

The calculated model parameters for the parsimonious model are shown in Tables 1 and 2 with confidence intervals where appropriate. Table 3 shows the results of the fitting procedure. The deviance of the nth reduced model as described in the “Parameterisation section” is denoted D_n. Models 1, 2, and 3 examined the removal probability with model 3 using a linear removal probability up to a maximum being selected. As none of these models were nested, only a direct comparison between each deviance could be made. Model 4 considers a reduction in the number of parameters describing the function g_y, however, this was found to give a significantly less good fit than model 3 ($D_4 - D_3 = 112.9$, 5 d.f., $p < 0.001$). Model 5 considers a reduction in the number parameters

Table 1
Parsimonious model parameters describing functions $f(a-\omega)$ and $\lambda(a)$ when considering all data 1992–2001, data from 1992 to 1996, and data from 1997 to 2001

Model parameters	1992–2001	1992–1996	1997–2001
ω	12.58	12.92	12.32
μ	3.61	3.58	3.57
σ	3.32	3.19	3.53
π	0.020	0.027	0.016
κ	−0.353	−0.504	−0.287
ν	0.310	0.332	0.319

Table 2
Model parameters describing the parsimonious model for functions g_y and p_{i-j} for all data (1992–2001)

g_y	Best fit	95% Confidence interval
1980–1981	3479	3008–3734
1982–1983	2907	2696–3251
1984–1985	2069	1882–2139
1986–1987	1438	1326–1558
1988–1989	1000	Fixed
1990–1991	927	860–999
1992–1993	743	683–812
1994–1995	670	596–735
1996–1997	622	551–709
1998–1999	485	418–589
2000–2001	334	272–413
p_0	0.733	0.660–0.794
p_{1-2}	1.000	0.924–1.000
p_{3-9}	0.881	0.832–0.918
p_{10+}	1.00	Fixed

describing p_{i-j}, this was found to give a significantly better fit than model 3 ($D_5-D_3=1.9$, 1 d.f., $p=0.165$). A further reduction in the number of parameters describing p_{i-j} was also investigated (model 6), however, this was found to give a significantly less good fit than model 5 ($D_6-D_5=19.0$, 1 d.f., $p<0.001$). Model 5, therefore, was taken to be the parsimonious model.

Fig. 1 shows for each survey the complete data set (bars) and the model fit (lines) for the parsimonious model.

Under ascertainment (p_{i-j})

The values obtained for p_{i-j} (Table 2) suggest evidence of under ascertainment particularly in the new initiates, i.e. those injectors whose injecting starting age (j) is the same as their current age (i). Although there was also some evidence of under ascertainment for those injectors with injecting career lengths of up to 9 years.

Table 3
Goodness of fit of initial and reduced models

Model	d.f. ($n=3{,}051$)	Deviance (D_n)
1 (initial model)	3,030	5,553.2
2	3,032	5,586.4
3	3,031	5,514.9
4	3,036	5,627.8
5	3,032	5,516.8
6	3,033	5,535.8

Starting with age (f_j)

Over 50% of injectors are estimated to start injecting between 18 and 25 years of age and less than 15% start injecting over 30 years old (mean age of starting = 21 years) (Fig. 2). Considering separately the data for 1992–1996 and then 1997–2001 shows only a small difference in results and helps to confirm the validity of the assumption that the proportion of IDUs starting injecting with age does not change within this data set over time. Analysis of injectors that had injected within the previous year rather than just four weeks prior to being surveyed showed similar results (not shown).

The relative number of males starting injecting over time (g_y)

The relative number of males starting injecting each year, function g_y, is shown in Fig. 3. The graph compares the number of males starting injecting between each year assuming that 1000 injectors started in 1990. If, for example, in a given year the number of males starting injecting was 2000, then this would mean the model estimates that twice the number of males started injecting in that year compared to 1990. The result presented here shows a peak of persons starting injecting in the early 1980s. From then there was a drop in the number of males starting injecting until 1990 after which there has been a broad stabilization (or perhaps a small drop). Inclusion of injectors that started injecting before 1980 lead to erratic results for this function particularly prior to 1980 (results not shown). This could be because the injectors themselves gave erroneous information, or due to insufficient data being available to model the number of males starting injecting before 1980.

Removal probability

The removal probabilities for the parsimonious model were found to be linear with age up to a maximum and then constant thereafter. The initial piece-wise constant distribution as described by the initial model was found to give a much more inferior fit to the data. The results suggest that the older an IDU is, the more likely it is he will be removed from the IDU population up to around 30–35 years of age, thereafter removal probabilities appear to remain constant (Fig. 4). Although the removal probabilities for male injectors under 19 years of age are estimated to be zero, it is acknowledged that there is a chance that a younger IDU may leave the IDU population. For older data (1992–1996) the removal probability was found to be higher across all age groups aged 19 and above, this suggests a potential change in injecting behaviour through the 1990s. The removal probability for IDUs that injected within the previous year was found to be similar to the injectors that injected within four weeks of being surveyed

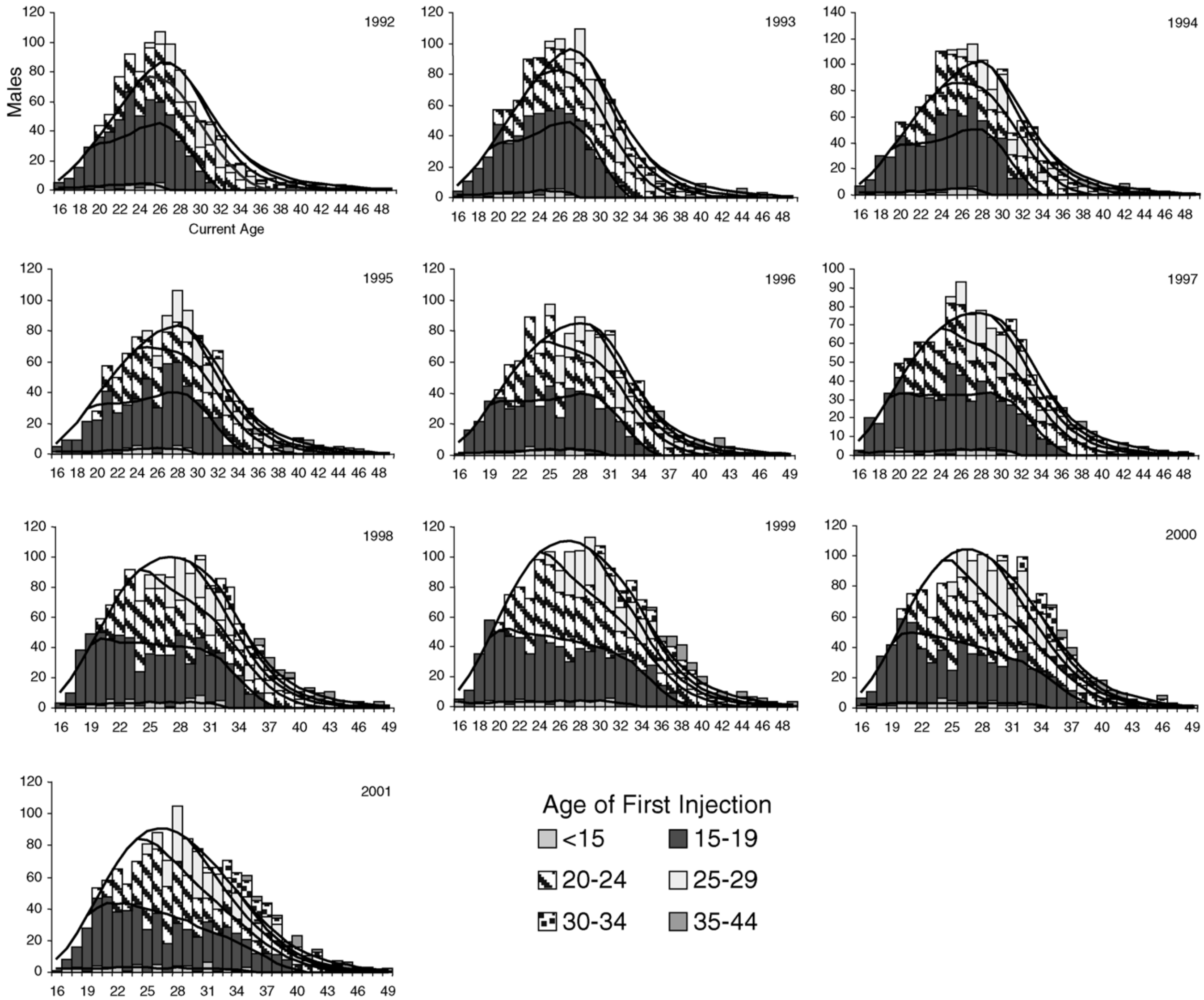

Fig. 1. The current age of surveyed male injecting drug users (injected within four weeks of being surveyed) broken down by the age of first injection for each survey 1992–2001. Also shown in each case is the model fit for each survey with an additional fit for each starting age.

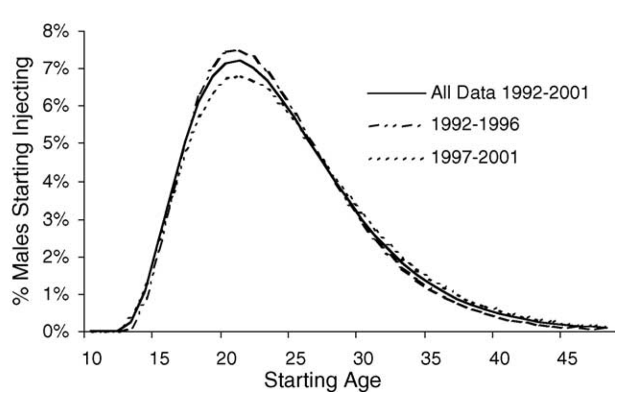

Fig. 2. Function f_j. The proportion of IDUs starting injecting by age. Using data from all surveys, surveys 1992–1996 and 1997–2001.

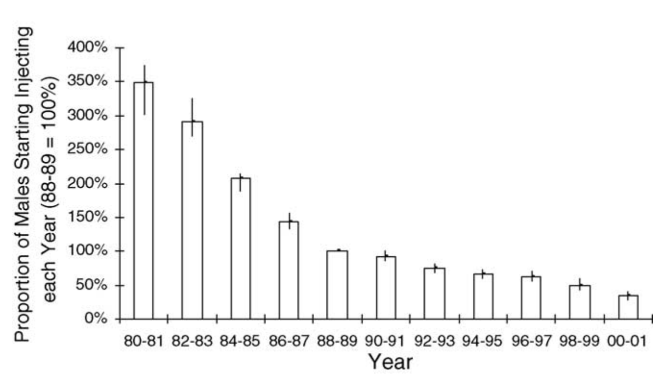

Fig. 3. Function g_y. The relative proportion of males starting injecting each year (assuming 100% in 1988–1989) with 95% confidence intervals.

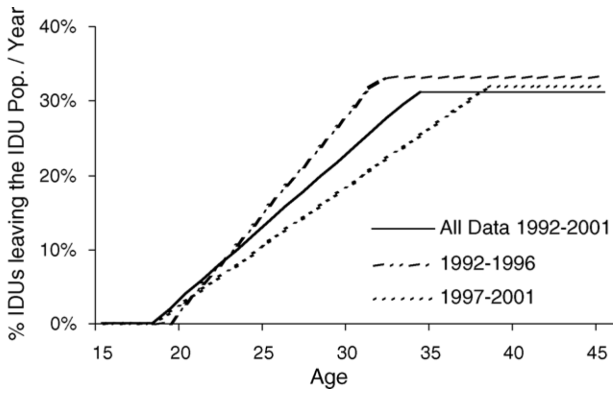

Fig. 4. The age-specific proportion of IDUs leaving the IDU population per year (λ_i). Using data from all surveys, surveys 1992–1996 and 1997–2001.

(results not shown). If it is assumed that the removal probabilities accurately reflect the probability that IDUs either stop injecting or die, the results obtained from the removal probability (λ_{ij}) and the function describing the age of starting (f_j) can be used to calculate the average injecting career of an IDU. From the parsimonious model the average injecting career was found to be 5.97 years (5.56–6.60 years; 95% confidence interval).

Discussion

The work proposes a method in which key parameters that contribute towards an increased understanding of the characteristics of the IDU population can be estimated from a data set consisting of a sequence of IDU surveys. In this case the data set was 10 consecutive unlinked anonymous surveys (1992–2001) of current IDUs with information on their current age, age at the time of the survey, and their age at first injection.

As a starting point for analysis an initial model was proposed consisting of a number of parameters describing each model function. It is normal for a full model to be used at this stage and it is acknowledged that the initial model could have been described by many more parameters; this was not done for two reasons. The computing power required to manipulate such a model would have been prohibitive and there is a danger that a 'many parameter' model may lead to 'over fitting' of the data.

The model predicts the most likely starting age of a male IDU to be 21 years old (Fig. 2) and this result compares well with the observed mean age of first injection of 21.2 years. It was also found that over 50% of injectors are estimated to start injecting between 18 and 25 years of age. It was assumed in the model structure that this function did not change over time. The similar results obtained when the model was fit to data from two separate time periods, i.e. 1992–1996 and 1997–2001 gives confidence to the validity of this assumption.

The removal probabilities obtained from the model (Fig. 4) show that as an injectors age increases his chance of leaving the IDU population increases up to a plateau at around 30–35 years of age, after which the rate is constant. In the case of the data examined here, an IDU may leave the IDU population because he has died, stopped injecting, or stopped reporting to services. While it is impossible to know which, the results here do point to an increasing injecting cessation rate with age followed by constant cessation behaviour in older injectors. It is acknowledged that the natural death rate increases with age and the constant removal probability in the older age groups do seem to contradict this. However, the small increase in the death rate for ages 35–49 is insignificant compared to the high constant removal probability across the same age group.

Assuming the removal probability is a reasonable approximation of the probability that IDUs either stop injecting or die, the average expected injecting career length from the parsimonious model was found to be 5.97 years (5.56–6.60 years; 95% confidence interval). This is similar to the average injecting career length obtained from the crude data of 5.82 years. To clarify whether the removal probabilities presented here are a reasonable approximation of the probabilities that current IDUs stop injecting drugs, further information is required on the proportion of surveyed IDUs continuing to inject after giving up contact with services.

The number of males starting injecting each year shows a high incidence of injecting in the early 1980s followed by a sharp decline (Fig. 3). This fits well with the effects of individual and social concern following the sudden emergence of AIDS and HIV infection in IDUs. Throughout the 1990s there appears to have been a fairly stable incidence of new male injectors. This is also in agreement with other studies. For instance, Hickman, Seaman and de Angelis (2001) estimated the incidence of heroin use from 1991 to 1998, and found a stable incidence during this period. The slight reduction in the number of males starting injecting in 2000–2001 coupled with an increase in the average injecting career length of an IDU in more recent years (1997–2001) may be indicative of a change in the nature of the IDU population with more 'problem' rather than casual users.

It is acknowledged that the data here is likely to be representative of IDUs that are in contact with services (Hope et al., 2002). The main caveat of this study is whether the results obtained here are also representative of the total male IDU population in England and Wales. Surveys of injectors that are in contact with services will inevitably lead to some bias; IDUs that have short careers will be under sampled whereas older injectors will be over represented and this can lead to a bias in the results and conclusions obtained from the model. Comparisons have been made between IDUs both in and out of drug treatment. IDUs that report to services are generally older (Cook, McVeigh, Syed, Mutton, & Bellis, 2001) and have a longer average injecting careers than those that do not (Godfrey et al., 2002). Work has also been done to estimate the lag from the time of heroin use initiation until the time of first reporting(Hickman et al., 2001). It has been speculated that the average delay from the time a person starts problematic drug use to receiving treatment is 5 years (Coid, Carvell, Kittler, Healey, & Henderson, 2000; Godfrey et al., 2002) or more.

The implications of selecting IDUs that injected up to four weeks prior to being surveyed were examined during sensitivity analysis. The similarity in results for those that have injected in the last four weeks and those that report having injected in the last year suggests the choice of definition of a current IDU is not critical, however, further work may have to be undertaken on IDU injecting patterns to confirm this.

The methods described here provide a technique by which key parameters can be obtained that will contribute towards a greater understanding of the IDU population and its characteristics. As has been shown here, in each given moment the population of active IDUs is a mix of injectors who have been injecting for a different numbers of years and this range is very relevant in terms of the implementation of targeted prevention strategies.

The knowledge of the parameters obtained here enables us to take forward work on the relationship between the IDU population and the spread of blood-born viruses such as Hepatitis B, Hepatitis C, and HIV. Additional data on the IDU population will always be useful, although the possibility of obtaining a completely unbiased survey of the current IDU population seems unlikely.

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