

# Smallpox in the 19<sup>th</sup> century – lessons learned from a historical manuscript

“Dr. Frederick W. Barry’s Report to the Local Government Board upon an Epidemic Prevalence of Small-Pox in the Borough of Sheffield during 1887-88”.

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## Summary

Smallpox is said to have been eradicated by smallpox vaccination. However, the data in this historical report shows that the majority of those infected and almost half of those who died were vaccinated. Nevertheless, as the denominators varied widely, the vaccine was considered to be highly effective. In addition to vaccination rates, the report also describes other factors that influenced the transmission of the infection, such as population density and proximity to a smallpox hospital. It also describes the extensive isolation measures organised by Sheffield's residents themselves. Barry's report is a rich source of fascinating medical and epidemiological information and reflects the controversial debate about compulsory smallpox vaccination in the 19th century. This is the first time an approach to the document as a complex historical source has been presented in its entirety. The conclusion is that a revision of historical smallpox literature is essential.

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## Introduction

When smallpox broke out in Sheffield in 1887, the British government sent an extremely meticulous Medical Officer of Health to the northern English industrial city to help the local health administration combat the disease. He arrived when the epidemic was at its peak. In his report, Dr Frederick William Barry described exactly how the infection spread and how it was combated.<sup>1, a</sup>

“... it has been my object to set out all the facts respecting the recent epidemic in Sheffield, - to give a complete history of the behaviour there of the small-pox, and, as well, a wholly unbiassed account of every important condition capable of being thought of as having influenced the disease, ... I have abstained from any but the broadest inferences, - preferring rather that the competent student of details should draw his own conclusions from the abundant data thus placed at his disposal, which data I have, I can truly say, done my very best to render absolutely trustworthy.”

Barry's report is a panopticon of life and death in Victorian England and offers a historical insight into the epidemiology and eradication of the smallpox virus. It is worthwhile to analyse his manuscript out of pure historical interest, but equally important are the lessons to be learnt from a pathogen which has disappeared but which is still a prime example for epidemiological considerations.

The report was evaluated by the “Royal Commission Appointed To Inquire Into The Subject Of Vaccination”<sup>2</sup>, and was cited by contemporary authors.<sup>3</sup> Later on, the manuscript fell into oblivion. Only a few modern authors cited the report without going into detail.<sup>4,5</sup> The most detailed evaluation was a masters thesis translating Barry's data into actual geospatial models of smallpox spreading in Sheffield.<sup>6</sup> However, no one analysed the report as a whole.

## The Beginning

In the 1880s, smallpox vaccination was compulsory in England and Sheffield was a well-vaccinated city at the time of the outbreak. The debate about compulsory vaccination was omnipresent. In total, the city had been hit by four smallpox epidemics in the 30 years before the epidemic, each claiming more than 500 lives.

In this epidemic, Barry identified two index cases occurring in March 1887. Both suffered from *variolois*, a mild form of smallpox observed in individuals with partial immunity after vaccination or after previous smallpox disease.

In the following twelve months, Barry collected the data of smallpox cases in all sub-districts of Sheffield; 6023 citizens fell ill with smallpox (Table 1), and 590 persons died. He writes:

“... no statistics can estimate the amount of suffering caused by so wide-spread an epidemic. In many houses, especially those inhabited by the unvaccinated, where death has speared the inmates, a legacy of blindness, or permanent disfigurement, or weakened health and impaired usefulness, has been left behind...”

Why the infection spread in such a violent way is not clear until the end. Barry suspected that a highly virulent strain was circulating. At the same time, he observed that the disease was spread by people with unidentified smallpox of a modified type. For example, he found that a conductor on the Sheffield

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<sup>a</sup> If not marked differently, all following direct and indirect citations are found in the manuscript: “Dr. Frederick W. Barry's Report to the Local Government Board upon an Epidemic Prevalence of Small-Pox in the Borough of Sheffield during 1887-88”.<sup>1</sup>

and Hillsborough tram was infecting passengers on the tram travelling through the city. He noted that the city's reporting system did not work efficiently in the early stages of the outbreak.

The census was conducted in conjunction with a vigorous campaign aimed at complete vaccination coverage and re-vaccination of the population. Barry writes:

“... at the meeting of the health committee on Jan 18<sup>th</sup>, 1888, the Medical Officer of Health... strongly recommended the provision of additional facilities for securing vaccination and revaccination, and suggested a house to house visitation of the worst infected districts. Officers were charged... to personally urge vaccination... In carrying out these duties the services of these officers were utilized at my suggestion to make a vaccination census of the population of the borough. They were provided with books and forms.”

More than one million data were collected in over 50 000 questionnaires. Barry painstakingly listed this information and calculated the proportion of infected people in the vaccinated population and the proportion of infected people in the unvaccinated population.

### **Calculating Vaccine Efficacy (VE)**

Surprisingly, Barry's raw data show that more than 80% of those infected (4,995 out of 6,023, or 83%) and almost half of those who died (247 out of 590, or 42%) had been vaccinated. However, subsequent research calculated that the vaccine used in the Sheffield epidemic was 90% effective.<sup>4</sup>

These contradictory numbers are only understood when looking at the algorithm used for the determination of vaccine efficacy (VE). Up to today, VE is calculated comparing the rate of infected persons in the vaccinated population with the rate of infected persons in the unvaccinated population.

When this formula is applied to the data released by the Sheffield Health Office on the smallpox epidemic, a VE of 90% is obtained (see Table 1).<sup>4</sup> Barry's own data stem from the census carried out shortly after his arrival. The census data differed slightly from the Health Office data, with a VE of 84% (see Table 1).

Thus, the vaccine was considered highly effective because more than 97% of Sheffield's population was vaccinated, meaning that the high number of infected vaccinated individuals represented a small percentage. In contrast, since fewer people were unvaccinated, the smaller number of infected unvaccinated individuals represented a significantly higher percentage. This phenomenon, whereby the denominators diverge, could be termed the 'denominator effect' (see Table 1).

It is important to note that it is legitimate to calculate VE with divergent denominators. However, one condition must be met: The two groups must be comparable, differing only in their vaccination status. Whether this was the case in Sheffield in 1887/88 will be examined below.

### **Denominators, Numerators, and the “Royal Commission”**

Barry's report was assessed by a panel of experts appointed by the British government. The “Royal Commission Appointed To Inquire Into The Subject Of Vaccination” was tasked with investigating the controversial subject of smallpox vaccination. After eight years, 136 meetings and interviews with 187 experts and witnesses, the final report of the inquiry was published. The Royal Commission also reviewed and reinterpreted the Sheffield data and figures.<sup>2</sup> The following illustrates the modifications discussed by the Royal Commission and what VE would look like if the amended data were used to calculate it.

For example, the Royal Commission retrospectively reclassified some healthy, vaccinated people in Sheffield as unvaccinated, as it was proven that many healthy citizens had been incorrectly classified as vaccinated during the vaccination campaign. This was because they had only been vaccinated at the height of the epidemic or afterwards. Consequently, the number of unvaccinated individuals — referred to at that time as the 'unvaccinated class' — increased by 28%. When these figures are used in the VE formula, the vaccine's effectiveness is found to be 79% (see Table 1).

Barry himself suspected a further distortion of the denominator. He therefore presented an alternative approach. This time, he only included people who lived in houses where smallpox had occurred, rather than the entire urban population. People who were not exposed to the infection because they lived far away from areas affected by smallpox were thus no longer included. Consequently, the relative risk changed as the denominator changed, although the numerator remained the same. Following this change, the vaccine's effectiveness was found to be 69% (see Table 1).

When both adjustments - classification and exposition – are applied together, the effectiveness of vaccination is found to be 60% (see Table 1).

Interestingly, it was not only the denominators that were uncertain, but the numerators, too. Many of those who died from smallpox were automatically categorised as 'unvaccinated', even when their vaccination status was unclear or they had been vaccinated. In view of this, the Royal Commission discussed adjusting the numerators. Following such an adjustment, the effectiveness of vaccination would be found to be less than 60% (see Table 1).

Finally, Barry discovered that 18,121 people (more than 6% of the census population) had already contracted smallpox at some point in their lives. The denominator of the 'vaccinated class' was therefore subject to another error typical of retrospective studies in endemic areas, but difficult to assess. In modern analyses, these immunologically non-naïve individuals are excluded from efficacy studies because it is not possible to attribute their protection exclusively to the vaccine.

## **Geospatial Analysis and Exposition**

As presented so far, the first part of the manuscript contains important background information that was examined in detail by the 'Royal Commission'. However, the details hidden in the second part of the report on the comparability of vaccinated and non-vaccinated people are even more important than imprecise denominators and vague numerators.

Here, Barry analysed whether vaccinated and unvaccinated people were living in the same conditions. He identified cases of smallpox and tracked how the virus spread through the city. He entered each case of smallpox on precisely drawn maps of Sheffield, describing the spatial and temporal spread of the epidemic, just as thoroughly as in the first part (see Map 1).

Using a fine pen, he drew floor plans of workhouses and hospitals where smallpox patients had lived and died. In doing so, he took into account the fact that, unlike in earlier centuries, smallpox in the 19th century was a disease of poverty. 'Crowding' was the fate of the poor, as cities rapidly became overpopulated. Barry also used the term 'crowding' to describe living conditions in overcrowded working-class neighbourhoods, where many families lived together in one room.

Barry recorded remarkable differences in terms of population density in the city:

“Taking the whole area of the borough, the density of the population in 1881 was 14.5 persons per acre, but from what has already been stated with regard to the sparsely populated area included within the borough boundaries, it will be seen that this rate gives no

real idea of the density of the population in Sheffield proper. Some notion of the diversities in this respect in the different sub-districts may be derived from the fact that in North Sheffield the density reached a maximum of 244 persons per acre, whilst in Upper Halam there was only one person to every 2 ½ acres.”

Casually speaking, more than 200 people shared the space of half a soccer field in North Sheffield.

Under these conditions, Barry observed a striking lack of awareness of contagion:

“The population of Sheffield is, for so large a town, unique in its character, in fact it more closely resembles that of a village than of a town, for over wide areas each person appears to be acquainted with every other, and to be interested with that others concerns, a state of things leading to an amount of intercommunications... Further, as already stated, comparatively few women are employed in factories, and as their houses are as a rule small, and their domestic duties occupy no large fraction of their time, they have ample leisure for visiting their friends. Wherever a case of sickness is known to exist there they congregate, in some instances led by curiosity, but in the majority no doubt from a genuine desire to be of service. It is apparent that all this intercommunication could not fail to have exercised a great influence upon the spread of small-pox. Heedlessness of danger was almost universal. Whenever the ambulance went to remove a case to hospital, there the people crowded in scores to view the process, and frequently persons tried to get into the ambulance itself in order to have the pleasure of riding with the patient; in some cases actually succeeding in doing so. At funerals persons from infected and from non-infected houses mingled freely together, and it is said to have been a not uncommon practice for people to dare each other to visit small-pox patients.”

## **Winter Street Hospital**

The hospital in question was the Central District Hospital on Winter Street, which is mentioned in the second part of the manuscript. The 'back-to-back houses' of North Sheffield's most densely populated district are directly adjacent to the hospital building.

“This was for a considerable period the only hospital to which smallpox cases were removed, and shortly after it came into full operation a special incidence of small-pox in its immediate neighbourhood became so marked as to excite attention, and communications on the subject were addressed to the Local Government Board. I was accordingly especially instructed to inquire into the facts of the case.”

Barry drew a 4,000-foot radius circle around Winter Street Hospital and designated this area the 'Special Area' (see Map 1). He counted the houses and estimated that 91,020 people lived in this area, which was less than one square kilometre in size. He found that almost half of the houses affected by smallpox were located within this area. Therefore, those living outside this area could significantly reduce their risk of infection. The reduction in risk due to reduced exposure can be expressed using the same formula as vaccination protection, resulting in a value of 48% (see Table 1).

Risk reduction was even higher when looking at the initial period of the epidemic:

“In the 14 weeks from May 21st to August 27th, 1887, during which the hospital came into full operation, with an average daily number of 41 small-pox patients under treatment there, the incidence of small-pox on the special area became seven times as great as the incidence on the rest of the borough.”

Metaphorically speaking, the number of cases in the area around the hospital 'exploded' when it started accepting smallpox patients. Focusing on the initial period only, the risk reduction for people living outside the 'special area' would be 84% (see Table 1). Smallpox disappeared from the 'special area' around the hospital once it was relocated outside the city.

## **Multivariate Analysis**

Such a scenario would require multivariate statistical analysis today. Multivariate methods make it possible to assess which factors influenced the outcome and to what extent. In the case of the Sheffield outbreak, for example, it would be possible to determine the impact of vaccination and exposure (distance to hospital and population density), as well as socio-economic parameters and health education, on smallpox incidence, provided the data were collected in an appropriate manner.

In a multivariate analysis, parameters that initially seem important may turn out to be negligible by-products. Therefore, exposure and certain host factors may have determined smallpox risk to a greater extent, acting as better predictors of infection than vaccination. In other words, vaccination may have been the striking protective factor not only because of the large denominators and imprecise numerators, but also because it was negatively correlated with exposure levels, crowding, and other poverty-related host factors.

In fact, Barry himself highlights this negative correlation between exposure and vaccination status:

“The conflict between vaccination and small-pox in Sheffield as a whole has been of necessity a complex affair, so that it is open to anyone to contend that whereas unvaccinated persons have been generally and specially exposed there to the infection of small-pox, large groups of vaccinated persons have wholly escaped such exposure.”

This is probably why Barry paid particular attention to the situation in Sheffield's workhouses. In this scenario, all residents were at the same risk of infection, and his data show that both vaccinated and non-vaccinated people died from smallpox at the same rate (see Table 1).

Several other sections of the manuscript also point to exposure and host factors as crucial elements. For instance, Barry notes that individuals who had previously contracted smallpox naturally could still be afflicted by the disease a second time. He documented the cases of 23 individuals who experienced a second or even third attack of smallpox. For example:

“Elisabeth M. (aged 44), 68, Birley Street. Vaccinated in infancy at Crowland (Lincolnshire); two well-marked cicatrices of good class, aggregate area 1/8 square inch. Suffered from severe attack of small-pox in 1870 at Wakefield, in consequence of which she was blind for a time. Second attack of small-pox in January 1888, semi-confluent in character; ill eight weeks; much disfigured.”

The Health Officer also interviewed patients who had contracted smallpox in both the "vaccinated class" and the "unvaccinated class". He carefully counted the number of vaccination scars in children who contracted smallpox despite vaccination:

“Of the 358 children vaccinated by public vaccinators, 15, or 4.2 per cent, had either no visible cicatrix, or one cicatrix only; 36, or 10 per cent, had two cicatrices; 110, or 30.7 per cent, had three cicatrices; and 197, or 55.1 per cent, had four or more cicatrices;...”

## **Crowding and poverty**

By comparing cases of smallpox and other infections from different epidemics, Barry concluded that:

“... as regards the whole period of 27 years, rates of mortality from small-pox have been in excess of that of the borough in those sub-districts of Sheffield in which conditions of overcrowding and general unwholesomeness have been most pronounced”

His assumption that more factors than vaccination were decisive for the outcome of smallpox transmission was later confirmed by the Royal Commission. The final report of the Commission states that the severity and mortality of the disease, as well as the infection itself, were related to three factors: 1) high exposure, 2) poverty, and 3) unvaccinated status:

“We proceed to consider the explanations of the contrast between the fatality of smallpox in the case of the vaccinated and the unvaccinated... (the) unvaccinated are mostly to be found in the poorer and more neglected classes of the population, who would on that account be constitutionally weaker and less able to resist an attack of smallpox, and to escape a fatal result.”<sup>2</sup>

## **The Small-Pox-Associations**

At the very end of Barry's 300-page document, the reader finally comes across a startling piece of information. On only a few pages he describes the so-called "Small-pox Associations" in Sheffield. These were self-organised support associations with the aim of "ensuring the isolation of persons exposed to infection":

“... a certain money contribution should be made weekly by each member to a fund which was to be applied to a) the maintenance of such members as actually contracted small-pox, and b) the paying to members living in houses where there was small-pox a sufficient sum to enable them to remain away from work during the continuance of the disease at their homes”.

These smallpox protection associations were founded in the last quarter of 1887, several months after the start of the epidemic. The rules were strictly enforced.

“it was notorious that during a short period of the epidemic, men who were being paid out of these funds to isolate themselves, were frequenting public-houses, and places of amusement (especially theatres and the Mappin Art Gallery), and mixing freely with others. As soon as this came to the knowledge of the Association Committees, it was promptly put a stop to, and a rule was made that any workman, in receipt of pay from any Small-pox Association, who was known to go into any public place of amusement, or who in any other way mixed unnecessarily with healthy persons, should at once forfeit all benefit from the funds of his Association.”

By March 1888, there were 142 smallpox clubs, comprising 33,477 paying members. Assuming an average family size at that time, it is reasonable to conclude that the majority of Sheffield's working-class population participated in this city-wide isolation campaign. Barry recognised:

“The public-spirited action of the Sheffield workmen in forming the Associations above referred to did much to strengthen the hands of the Authorities in preventing free intercommunication between the healthy and the sick, and probably did more in this direction than could have been accomplished in other ways”.

At this point, the question arises as to the extent to which the epidemic was brought to a halt by the mass vaccination campaigns carried out by Sheffield's health authorities, or by the extensive isolation measures organised by Sheffield's residents.

## **The Introduction by George Buchanan**

Finally, it should be remembered that Barry wrote the manuscript amid fierce disputes between supporters and opponents of compulsory vaccination. Furthermore, public health was an emerging discipline and the debate surrounding contagious diseases was both heated and full of contradictions. When evaluating Barry's work, it is important to recognise that both sides of the vaccine debate have selected and distorted data in an unacceptable way to further their own agendas.<sup>7</sup>

In this context it is to be considered exceptional that Barry aimed for an objective and neutral viewpoint when collecting and reporting data:

“Herein I record all the facts, whether in favor of or opposed to belief in controlling power of vaccination over smallpox, which have come to my knowledge during the inquiry. In the following pages I propose to consider the effect exercised upon the Sheffield smallpox by 1) vaccination 2) general sanitary circumstances apart from hospitals 3) hospitals 4) various influences tending either to prevent isolation or to promote intercommunication between the healthy and the sick”.

This impartial view may have prompted George Buchanan — the United Kingdom's Chief Medical Officer and a staunch supporter of compulsory vaccination — to write a 30-page introduction to Barry's report. He mainly focused on the point that the positive effects of vaccination can be demonstrated by comparing different age groups affected by various epidemics and infections. The impact of exposure and the role of Winter Street Hospital are only mentioned briefly in a few lines:

“the one “sanitary circumstance” which could have caused inequalities in the incidence of smallpox was the greater or less degree of spaciousness or crowding, of houses upon area and of people within their homes”

The enormous self-organisation efforts of the 142 smallpox associations - to which, after all, a few pages were devoted in Barry's original report - were not mentioned in a single word in Buchanan's introduction.

## **Haygarth and Leicester**

In Barry's time, the debate about "notification/isolation vs. mass vaccination" was conflictual. This conflict was fought not only with words, but also in the streets. For example, two years before the outbreak in Sheffield, many thousands of people — some sources say hundreds of thousands — marched in Leicester, 70 miles away, to protest against mass vaccination and support notification and isolation.<sup>8,9</sup>

At that time, Leicester was renowned for its efficient reporting and isolation system. Leicester City Hospital was built on the outskirts of the city and the Medical Officer of Health was notified of every case of smallpox. Contagious individuals were immediately isolated and all their contacts were quarantined. Those in quarantine received financial compensation for loss of wages. Later, the obligation to report cases was reinforced through active tracking, with a reward of two shillings and six pence offered for reporting a case of smallpox.<sup>8,9</sup> Four years after the outbreak in Sheffield, Leicester was also struck by smallpox. From 1892 to 1894, there were 358 cases in the town, 21 of which were

fatal (population: 174,624). Consequently, it appeared that fewer people died from smallpox in the Leicester epidemic than in the Sheffield epidemic. At this time, Leicester was an urban area that was referred to as 'unprotected' by infant vaccination.<sup>10</sup>

The strategy of notification and isolation was not invented by the people of Leicester. A century earlier, John Haygarth, a scientist from Chester and contemporary of Edward Jenner, had already published his "rules of prevention". He determined the radius of the exposure around an infected person to be between 18 inches and 1 yard<sup>11,12</sup> and stated that:

"The patient must not be allowed to approach a person liable to the distemper, till every scab is dropped off..."

Haygarth argued that mortality would be reduced by about 75% if his rules were followed, and by 97% if they were observed at all times.<sup>11</sup> He helped found the Smallpox Society of Chester and proposed a system for the worldwide elimination of smallpox. Other towns, such as London, Leeds and Liverpool, later adopted the Society's approach.<sup>13</sup>

## **Surveillance and containment**

The human variola virus is a pathogen with no animal hosts, transmitted through close contact with an infected person. Unlike respiratory viruses, such as influenza and SARS-CoV-2, which are transmitted by aerosols, transmission of this pathogen can be stopped effectively by reporting and isolating cases. Almost all infected carriers show symptoms. Historical archives provide ample evidence that this approach was pivotal in eradicating smallpox in Europe and around the world.

For example, the global smallpox campaign of the 20th century abandoned mass vaccination in favour of the "surveillance and containment" approach. Surveillance involves reporting cases, while containment involves vaccinating contacts and isolating the case simultaneously.

Bill Foege, one of the key figures in the WHO's smallpox eradication campaign, summed up the concept of isolation:

"The concept of a six-foot perimeter of no susceptible people around a smallpox patient proved to be a useful rule of thumb in stopping outbreaks"<sup>14</sup>

In 1880s Sheffield, the authorities seemed to have neglected notification and isolation rather too much. The mayor admitted as much at a heated town hall meeting:

"The authorities had as much the interests of the town at heart as the other portion of the inhabitants. But one of the great blots that had been in Sheffield was that they did not get a full and proper notification where that infectious disease existed (hear, hear). At Leicester, when a case of small-pox broke out, the medical men and others were obliged to send at once to the authorities and inform them of what had happened. The result was that the authorities could isolate the patients, and prevent the disease from spreading. But they had nothing of the kind in Sheffield."

When studying Barry's records, one might ask why the workers of Sheffield organised a city-wide isolation campaign when an extensive re-vaccination campaign had already been underway since the beginning of the epidemic. One might suspect that Sheffield residents copied Leicester's isolation and notification methods because, as Barry's records show, the vaccine was less effective than expected.

## Conclusion and Outlook

The historiography of the Sheffield epidemic illustrates how factors other than the vaccine that were important for smallpox transmission were increasingly overlooked. Although the original document written by Barry contains a wealth of detail, data and observations, the official introduction by health official Buchanan omits key elements of the story. Modern sources refer to the Sheffield vaccine as being 90% effective, making no mention of the impact of other influencing factors.<sup>3</sup>

For those familiar with the subject, there are several factors besides the vaccine that contributed to the eradication of smallpox in Europe and worldwide: 1) Sutton's method of variolation marked the early decline in the 18th century. 2) Host factors, such as improved nutritional conditions, reduced susceptibility to infectious agents. 3) The emergence of less virulent variola minor strains displaced the more aggressive variola major strains. 4) Governments were prompted by class conflicts to introduce social standards for living conditions, resulting in a gradual decline in overpopulation in the second half of the 19th century. 5) Reporting systems improved drastically as states were formed and medicalisation took place in Europe. 6) During the global smallpox eradication campaign of the 20th century, mass vaccination was replaced by the concept of 'surveillance and containment'.

Nevertheless, the story of smallpox eradication is widely regarded as nothing more than a triumph of the vaccine. The fact that the efficacy of the smallpox vaccine has never been demonstrated in controlled clinical trials is ignored, as are 1970s records indicating low vaccine efficacy when exposure was high.<sup>15,16</sup> The role of exposure in smallpox eradication — in Chester, Leicester, Sheffield and ultimately globally — is rarely discussed. To date, factors leading to lower exposure to pathogens in general tend to be neglected.<sup>17</sup>

An unbiased reading of Barry's report leads to the conclusion that revising the historical smallpox literature is essential. The impact of political disputes over compulsory vaccination on the quality of historical data must also be evaluated. Documents and archives must be examined for bias, errors and weaknesses. The simplistic narrative that 'the vaccine eradicated smallpox' should be critically reviewed, and an evidence-based history of smallpox and its eradication should be created.

Due to the complexity of the topic, this project would pose a significant challenge and require an interdisciplinary approach encompassing various academic disciplines from the natural and social sciences.

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**Table 1: Smallpox rates in Sheffield calculated with different raw data sets from Barry's report**

|                     | Individuals with vaccination |        | Individuals without vaccination |      | Risk reduction presumed to be caused by vaccine (VE) |
|---------------------|------------------------------|--------|---------------------------------|------|--|
|                     | Smallpox                     | All    | Smallpox                        | All  |  |
| Health office data  | 4995                         | 307966 | 1028                            | 6556 | 90   |
| Census (WP)         | 4151                         | 268397 | 552                             | 5715 | 84   |
| Census (WP, DC)     | 4151                         | 266797 | 552                             | 7316 | 79   |
| Census (IH)         | 4151                         | 18020  | 552                             | 736  | 69   |
| Census (IH, DC)     | 4151                         | 17843  | 552                             | 940  | 60   |
| Census (IH, DC, EC) | 4206                         | 17843  | 497                             | 940  | 55   |
| Workhouses          | 40                           | 1658   | 3                               | 108  | 13   |

  

|                  | Houses outside special area |       | Houses inside special area |       | Risk reduction living outside special area (EXP) |
|------------------|-----------------------------|-------|----------------------------|-------|--|
|                  | Smallpox                    | All   | Smallpox                   | All   |  |
| Whole epidemic * | 2866                        | 45034 | 2230                       | 18204 | 48   |
| Initial phase ** | 87                          | 45034 | 249                        | 18204 | 86   |

WP: Whole population; DC: Denominator corrected as proposed by the Royal Commission; IH: Invaded houses; EC: Enumerator corrected as proposed by the Royal Commission; VE: Vaccine efficacy; EXP: Exposition; \* 3/1887 – 3/1888; \*\* 5/1887 – 7/1887

**Map 1: Portion of the town of Sheffield, showing smallpox cases in the whole of the most densely populated area in November 1887**

