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An Airborne Outbreak of Smallpox in a German Hospital and its Significance with Respect to Other Recent Outbreaks in Europe*

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Since 1960, smallpox has been introduced into 10 European countries on 28 separate occasions. Most commonly, the index case was infected in Asia and returned to Europe by air during the period December–May. Subsequent cases have occurred mainly among persons exposed by direct, face-to-face, contact in the household or hospital. Medical and hospital personnel, patients and visitors constituted approximately half of all cases in these outbreaks.

In a recent outbreak in Meschede, Federal Republic of Germany, detailed epidemiological studies have clearly indicated that 17 of the cases were infected by virus particles disseminated by air over a considerable distance within a single hospital building. Several features believed to be of importance in this unusual pattern of transmission were common to a similar outbreak in the Federal Republic of Germany in 1961 in which airborne transmission also occurred. These features include a source case with extensive rash and cough, low relative humidity in the hospital and air currents which caused rapid dissemination of the virus. While airborne transmission of this sort is rarely observed in smallpox outbreak, it is important to recognize that it may occur under certain circumstances.

Proper vaccination of travellers prior to their departure from their native countries and a regular programme for vaccination of medical and hospital personnel could have prevented at least half of the cases which occurred in Europe during the past decade. Although progress in the global smallpox eradication programme has been accompanied by a decreased frequency of importations into Europe, no country should relax its vigilance until smallpox has been eliminated everywhere.

During recent years the world-wide incidence of smallpox has declined sharply and in 1969 reached the lowest yearly total ever recorded. The number of countries experiencing smallpox has also decreased—from 54 in 1960 to 42 in 1967 and to 30 in 1969. Despite considerably increased air travel in recent years, outbreaks in the non-endemic countries have been less frequent. However, even a single case of smallpox imported into a country can cause considerable public concern.

In deciding upon appropriate measures that may be taken to prevent the importation of smallpox and to limit further transmission if the disease has been introduced, a knowledge of the epidemiological characteristics of recent outbreaks is of particular importance. The recent outbreak in Meschede, Federal Republic of Germany, in which it appears that airborne transmission of infection played an important role, is of special interest. The circumstances of this outbreak are described here in detail and discussed in relation to the characteristics of other outbreaks that have occurred in Europe during the last 10 years.

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MESCHEDE OUTBREAK, 1970

On 31 December 1969, a 20-year-old German electrician flew to Düsseldorf from Karachi, West Pakistan, and then returned to his home in Meschede by train. In September 1969, prior to departing for Pakistan, he had received a single dose of inactivated vaccine; in Turkey, *en route* to Pakistan, he was unsuccessfully vaccinated with live smallpox vaccine. He had not previously been vaccinated.

On 10 January 1970, he developed fever and on the following day was hospitalized in Meschede in an infectious diseases isolation ward, located on the ground floor of a 3-storey building, one of several buildings of a large general hospital. He was confined to a private room within the isolation ward. Isolation precautions were observed from admission since typhoid fever was initially suspected, and he was known to be convalescing from hepatitis.

From 11 to 14 January, the patient felt well enough to bathe himself at the sink in his room and amuse himself by sketching and painting. It is certain that during this period he remained strictly confined to his room; linen and towels were not changed during his few days residence in this unit. Toilet facilities were provided by an individual bedpan returned to his room after emptying. The patient had no direct contact with members of the religious order responsible for the hospital other than two nursing sisters, and he needed only minimal care during his stay in the hospital.

On 14 January, a rash was first noticed and the following day smallpox was suspected. On 16 January the diagnosis was confirmed by electron-microscopy and subsequently by isolation of the virus. The patient was then transferred to a recently constructed smallpox isolation hospital in nearby Wimbern, special precautions being taken to avoid the spread of infection. At the time of transfer on 16 January, the patient was seen to have extensive cutaneous and oral lesions and was coughing frequently.

For several days prior to the patient's admission to the isolation ward at Meschede, the entire hospital had been closed to all visitors because of an outbreak of influenza in the community. After the diagnosis of smallpox had been confirmed, the building in the general hospital which housed the isolation ward remained closed to all visitors for several weeks. All personnel known to have had direct contact with the patient were immunized against smallpox and transferred to the Wimbern isolation hospital or elsewhere for observation. All other staff and all patients in the isolation unit at Meschede, as well as those on the upper floors of the building, were also immunized and confined within the hospital building for the duration of the quarantine period. Health department personnel immunized patients and staff in the ground-floor isolation unit; hospital personnel immunized the first- and second-floor patients, using separate equipment and vaccines.

Despite the certainty that the original smallpox patient had not left his room during his hospitalization, all hospital patients and personnel were immunized as soon as the diagnosis of smallpox was made. On account of the advanced age or the serious illnesses or both of many of the patients on the two floors above the isolation unit, it was decided to immunize many of them with an inactivated smallpox vaccine or vaccinia-immune globulin (VIG) or with both. Some patients were vaccinated immediately with live smallpox vaccine while others received live vaccine a few days after inactivated vaccine or VIG had been administered.

Transmission of smallpox from the index case presumably occurred from 13 or 14 January, when the patient first developed a rash, until 16 January when he was removed to the Wimbern hospital. The infectiousness of the index case as early as 13 January is confirmed by the single, short interval of direct exposure of case No. 8 on that day only. Cases 2–18 all experienced the onset of illness well within one incubation period, i.e., between 7 and 17 days following the index patient's period of residence in the hospital (Table 1). The dates of onset of illness for all patients are shown graphically by date of onset of fever in Fig. 1; the two generations of the disease are indicated. Cases 19 and 20 clearly resulted from secondary spread within the hospital. Each of these latter patients had shared a room with an earlier smallpox patient; because of medical contraindications, neither had received live vaccine.

It is of interest to note the advanced age of most of the patients, their age distribution being similar to that of the remaining hospitalized patients who did not acquire smallpox infections. From the evidence of primary vaccination scars it appeared that all but 4 of the smallpox patients had been vaccinated successfully in the past but most of them had not been revaccinated during the 25 or more years prior to exposure, while many had not been revaccinated since their primary vaccination

TABLE 1

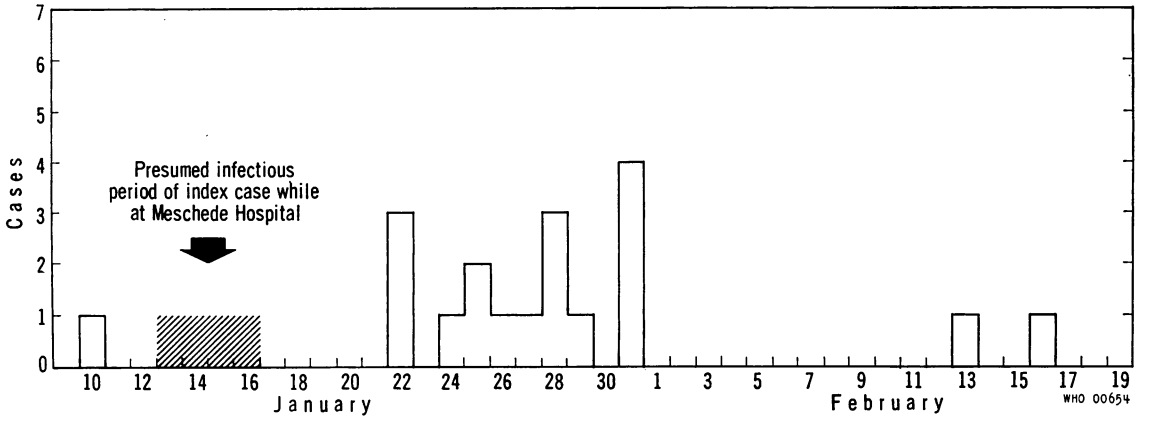
CASES OF SMALLPOX, MESCHEDE, FEDERAL REPUBLIC OF GERMANY, 1970, BY AGE, SEX, ONSET DATE AND IMMUNIZATION STATUS

Case No.	Age	Sex	Onset of:		Outcome	Previous vaccination		Recent re-vaccination			Comments
			Fever	Rash		Scar	Most recent vaccination	Killed vaccine	VIG [a]	Live vaccine	
1	20	M	10 Jan.	14 Jan.		No	1969	—	—	—	Index patient
2	5	F	23 Jan.	25 Jan.		No	—	16 Jan.	16 Jan.	—	Patient in R1
3	17	F	22 Jan.	25 Jan.	Death	No	—	16 Jan.	25 Jan.	17 Jan.	Nurse in R6
4	21	F	25 Jan.	28 Jan.		No	—	16 Jan.	25 Jan.	22 Jan.	Nurse in R3
5	57	M	22 Jan.	26 Jan.		Yes	1968	—	22 Jan.	19 Jan.	Patient in R6
6	50	F	25 Jan.	29 Jan.		Yes	1932	19 Jan.	19 Jan.	19 Jan.	Patient in R1
7	56	M	26 Jan.	29 Jan.		Yes	1942	17 Jan.	18 Jan.	—	Patient in R3
8	42	M	24 Jan.	26 Jan.		Yes	1946	—	—	—	Visitor
9	79	M	27 Jan.	29 Jan.	Death	Yes	1903 (?)	16 Jan.	18 Jan.	—	Patient in R3
10	89	M	28 Jan.	30 Jan.		Yes	?	21 Jan.	21 Jan.	—	Patient in R6
11	90	M	28 Jan.	30 Jan.		Yes	1892 (?)	16 Jan.	18 Jan.	—	Patient in R3
12	59	M	28 Jan.	31 Jan.		Yes	1930	17 Jan.	—	22 Jan.	Patient in R6
13	73	M	31 Jan.	1 Feb.		Yes	1909	17 Jan.	18 Jan.	30 Jan.	Patient in R6
14	59	F	29 Jan.	2 Feb.		Yes	1930	—	—	17 Nov.	Nurse in R6
15	65	F	31 Jan.	2 Feb.		Yes	1917	17 Jan.	30 Jan.	—	Patient in R5
16	69	F	31 Jan.	2 Feb.		Yes	1902	16 Jan.	18 Jan.	—	Patient in R1
17	60	M	31 Jan.	4 Feb.	Death	Yes	1917	17 Jan.	—	30 Jan.	Patient in R3
18	21	M	22 Jan.	None		Yes	1961	—	—	17 Jan.	Patient in R3
19	74	M	13 Feb.	15 Feb.		Yes	1907 (?)	17 Jan. 29 Jan.	18 Jan.	—	Patient contact, case 17
20	81	F	16 Feb.	17 Feb.	Death	Yes	1901 (?)	17 Jan.	17 Jan.	—	Patient contact, case 15

[a] Vaccinia immune globulin.

FIG. 1

DATES OF ONSET OF SMALLPOX IN CASES OCCURRING AT MESCHEDE HOSPITAL, 1970



near the turn of the century. A smaller proportion of the younger patients and staff had been immunized previously.

Visitors were not permitted within the Meschede hospital on account of an outbreak of influenza in the area at the time. Patient No. 8, although designated as a visitor, was a relative of a ground-floor patient. He made an unsuccessful attempt to visit his relative, as described below.

The diagnosis in all cases except 18 and 20 was confirmed by virus isolation. Case 18 experienced fever and systemic symptoms but no rash. Since his haemagglutination-inhibiting antibody titre against vaccinia rose to over 1 : 500, he was believed to have *variola sine eruptione*. Case 20 was a fatal case; the virus was identified by electron-microscopy but was not isolated in chick-embryo culture.

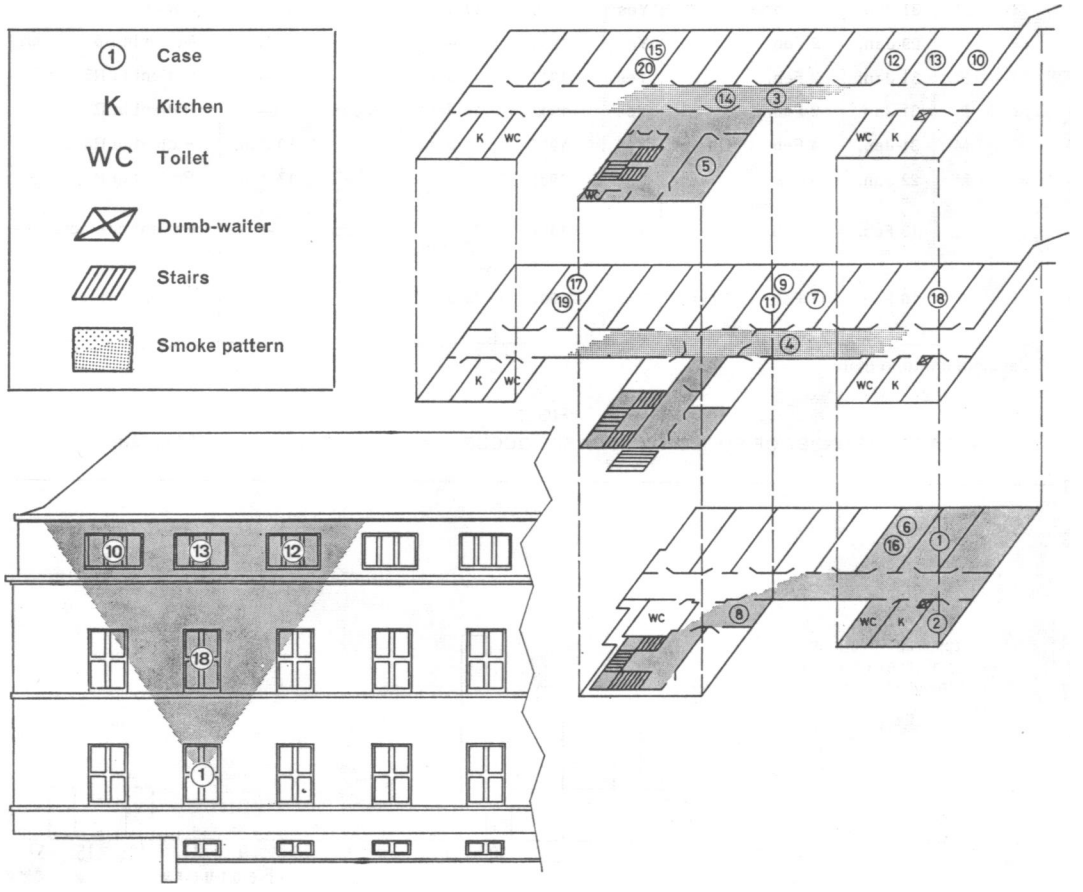
The floor plan of the hospital building in which the outbreak occurred and the location of all cases is shown in Fig. 2. The location of individual cases is indicated by numbers which correspond to those in Table 1 in which the other characteristics of the patients have been listed.

The building which houses the isolation unit was constructed in 1932; it has been well maintained and is in good repair. All patients' rooms are equipped with a sink and hot and cold running water. Heating is provided by steam radiators situated beneath the windows in each room. Ventilation for rooms and corridors is arranged by opening windows or doors.

The building is divided into four functional units as follows: (1) R.1, the isolation unit of the ground floor; (2) R.3, the entire first floor; (3) R.5, the

FIG. 2

FLOOR PLAN AND REAR ELEVATION OF MESCHEDE HOSPITAL SHOWING LOCATIONS OF ALL SMALLPOX CASES



eastern half of the second floor, which is used as a cloister for ailing nuns requiring hospital care; (4) R.6, the remaining half of the second floor.

Food is prepared in the main hospital kitchen and is supplied separately to each of the three floors. Food carts travel to the building along corridors connecting the two upper floors with corresponding floors of the main hospital bulilding and to the ground floor by an outside route. Dishes and eating utensils are kept on each of the three floors, separately for each of the five unit kitchens (Fig. 2). Linen is marked with identifying symbols for each floor and unit, and the linen from each of the four functional units is disinfected and washed separately in the hospital laundry. Linen from each room of the isolation unit is placed in individual laundry bags and subsequently inserted into a larger bag before leaving the unit.

A small service lift connects three of the ward kitchens in units R.1, R.3 and R.6. It is used infrequently to transfer bread or small kitchen items between R.1 and R.3 but is said not to have been used for similar transfers to the R.6 kitchen on the second floor. The doors to this lift were observed to close tightly on each floor. Lifts for personnel and patients, as well as for large or heavy equipment, are located within the main hospital.

The appearance of 17 cases of smallpox on three floors of the hospital during the second generation of disease was quite unexpected. Three possible mechanisms of transmission have been considered: (1) direct personal contact; (2) contamination of fomites with resultant indirect spread of infection; (3) airborne spread.

The index patient had no direct face-to-face or personal contact with any of the subsequent patients. Interviews with members of the hospital staff and many of the other patients all confirmed the statement of the index patient that he did not leave his room at any time following his admission to the isolation unit until his transfer to Wimbern on 16 January. At the time of transfer, he was encased in a protective plastic garment which was designed to prevent airborne, as well as contact, spread of infection. The doors to all other patients' rooms were closed and he was carried on a stretcher along the corridor of the isolation unit to a waiting ambulance. Thus there was no possibility that direct contact with the index case could have explained the extensive spread of infection seen in the first generation of cases within the hospital. The shape of the incidence curve (Fig. 1) also excludes the possibility that an early secondary case in a nurse could have resulted in the extensive dissemination observed among the staff and patients.

Transmission by contaminated fomites, while difficult to exclude with absolute certainty, seems most unlikely. None of the supplies or linen from R.1 were mixed with those of the upper floors or other parts of the hospital before, during or after the hospitalization of the index patient and linen from the isolation unit, as already mentioned, was separately disinfected before being washed. The absence of cases in the large general hospital adjoining the building housing the isolation unit, despite the sharing of food-preparing and laundry facilities and frequent movement of staff between the first and second floors of the isolation building and the main hospital building, suggests that contamination of linen, utensils and clothing did not play any role in transmission.

Apart from one night nurse who was responsible for patients throughout the building with the exception of patients in the cloister or R.5, nurses assigned to the isolation ward did not work on the other floors of the hospital building. The night nurse had at most very limited contact with the index patient as he required minimal, if any, care at night while he was in the isolation unit.

The possibility was also explored that a priest who routinely visited the patients might inadvertently have been a vector. Communion is offered to all patients in the hospital but the index patient refused communion. When the priest came to the door of his room on the day after his admission, the priest was advised that his services were not desired, and he did not again visit the patient. It was noted also that the priest, since he was elderly, customarily began his round of the building with the second floor. By so doing, he was able to ride up in the lift in the main hospital building, enter the isolation unit building *via* the corridor connecting the second floor, and then walk downstairs in the building after visiting the patients on each of the upper floors. Since he visited the second, first and ground floors in that order, the room of the index patient was one of the last he visited.

The most reasonable explanation for the spread of smallpox appears to be the airborne route. In addition to the fact that no alternative mechanisms of transmission could be elicited, two incidents and the distribution of cases within the hospital appear to confirm strongly this hypothesis. The first incident relates to the circumstances of the exposure of

patient No. 8. It is certain that this patient had visited the hospital only once on the evening of 13 January, 11 days before onset of illness, and had remained in the building for 15 minutes. After entering the hospital by the front door on the first floor, he spoke briefly with a physician at the site designated "8" in Fig. 2. As the hospital was closed to visitors, he was not permitted to enter the patient-care areas, nor did he enter the isolation unit corridor. Patient No. 8 had no known contact with any patient or any other member of the hospital staff but he subsequently developed typical smallpox with onset of fever on 24 January.

The second incident relates to the circumstances of exposure of patient No. 15, who was confined to the cloister on the second floor. This patient, who was one of the nursing sisters, had been hospitalized for many months with severe arthritis and had not left her room for any purpose during the month of January. No hospital personnel other than the nuns, the priest, and physicians caring for the nuns were permitted to enter this area. This patient developed smallpox on 31 January.

Additional strong support for the hypothesis of airborne transmission is the uniformity of attack rates by floor within the hospital as recorded in Table 2. Such uniform rates would seem most unlikely if transfer of infection had occurred by direct contact or through fomites or indirectly by hospital personnel, since the relative degree of exposure within the cloister, the other upper floors and the isolation unit was different for all items considered.

Since the airborne route seemed to be the method of transmission which would explain this incident most satisfactorily, patterns of air flow within the building were examined. Meteorological conditions on 10 April, a cold day selected for the test, were similar to those of mid-January. A smoke-generating device was released in the room which had housed the index patient. The patterns of air currents observed inside and outside the buildings are shown approximately in Fig. 2; the denser shading indicates a greater concentration of smoke. Within the building, dense smoke entered the corridor and rooms adjacent to that of the index patient. The smoke then passed down the corridor, through a door normally kept ajar by means of a special device and then into the entrance hall. (Smallpox case No. 8 had waited in this entrance hall.) The smoke, after passing through this entrance area, flowed directly to the central stairwell which served effectively as a chimney and conducted a dense cloud of smoke to the first and second floor levels where it drifted into the corridors and adjacent rooms. It is important to note that access to the upper units of the building involved passing through this stairwell area.

The smoke from the index patient's room also flowed out of the partially opened window as a thin layer and then directly up the exterior surface of the building, as shown in Fig. 2. When windows were opened in the rooms above that occupied by the index patient, smoke readily entered these rooms. This flow pattern into the upper windows appeared to be caused by convection currents generated by radiators located below the windows. It is interesting to note that the flow pattern coincided closely with the distribution of smallpox cases within the hospital. Smoke was not seen to enter or leave the service lift shaft in the kitchen areas of R.1, R.3, or R.6, although a slight air current within the shaft could be demonstrated. The smoke did not reach the lift in the main building.

TABLE 2

ATTACK RATES OF SMALLPOX AMONG HOSPITALIZED PATIENTS[a] BY FLOOR IN HOSPITAL, MESCHEDE 1970

Location	Total no. of patients	No. of cases	Attack rate (%)
Ground Floor	15	3	20
1st Floor	34	5	15
2nd Floor	25	5	20
Total	74	13	18

[a] Second-generation cases among patients.

IMPORTATION OF SMALLPOX INTO EUROPE

Since 1960, smallpox has been introduced into 10 European countries on 28 separate occasions. The United Kingdom and the more northern of the continental countries have been most frequently affected; whether because of more frequent travel between these countries and endemic areas or for other reasons is not known. As may be seen in Table 3, the sources of infection in 20 of the 28 introductions were Asian countries; the infection came from Africa in 5 instances; and in one, from another European country. In 2 instances, the source was uncertain, although the 1963 introduction into Hungary may have been related to the immediately preceding outbreak in Poland. The 1966 out-

TABLE 3. IMPORTATIONS OF SMALLPOX INTO EUROPE, JANUARY 1961–JUNE 1970

Import No.	Year	Month	Country	Total of cases	Subsequent infections acquired in hospitals or by medical personnel	Origin of imported infection	Method of transport of index case	References
1	1961	Jan.	Spain	17	13	India	Air	
2	1961	March	Federal Republic of Germany	4	1	India	Air	Herrlich (1961)
3	1961	April	USSR	1	—	India	Air	
4	1961	Oct.	Belgium	1	—	Democratic Republic of the Congo	Air	
5	1961	Dec.	Federal Republic of Germany	5	2	Liberia	Air	Anders (1962)
6	1961	Dec.	Federal Republic of Germany	33	19	Pakistan	Air	Anders (1962)
7	1961	Dec.	United Kingdom	3	—	Pakistan	Air	Ministry of Health, United Kingdom (1963)
8	1961	Dec.	United Kingdom	2	1	Pakistan	Air	Ministry of Health, United Kingdom (1963)
9	1961	Dec.	United Kingdom	14	13	Pakistan	Air	Ministry of Health, United Kingdom (1963)
10	1962	Jan.	United Kingdom	1	—	Pakistan	Air	Ministry of Health, United Kingdom (1963)
11	1962	Jan.	United Kingdom	47	26	Pakistan	Air	
12	1962	March	Poland	29	4	India	Sea	Kostrzewski (1964)
13	1962	July	United Kingdom	3	—	India	Sea	
14	1963	March	Sweden	27	15	Asia (country unknown)	Air	Stroin (1966)
15	1963	May	Poland	99	46	India	Air	Kostrzewski (1964)
16	1963	Aug.	Switzerland	1	—	Gabon	Air	
17	1963	Unknown	Hungary	2	1	Unknown	Unknown	
18	1965	Oct.	Federal Republic of Germany	1	—	United Rep. of Tanzania	Air	Anders (1966)
19	1966	Unknown	United Kingdom	72	1	Unknown	Unknown	Ministry of Health, United Kingdom (unpublished data)
20	1967	Feb.	Federal Republic of Germany	1	—	India	Air	
21	1967	March	Czechoslovakia	1	—	India	Air	
22	1967	March	Federal Republic of Germany	1	—	India	Air	
23	1967	Oct.	United Kingdom	2	—	Pakistan	Air	Gordon (1969)
24	1968	Feb.	United Kingdom	1	—	Pakistan	Air	
25	1968	Aug.	Belgium	1	—	Democratic Republic of the Congo	Air	Courtois (unpublished data)
26	1970	Jan.	Federal Republic of Germany	20	19	Pakistan	Air	
27	1970	Aug.	Denmark	1	—	Afghanistan	Air	
28	1970	Sept.	Norway	1	—	Denmark	Sea	
Total cases				391	161			

break of variola minor in the United Kingdom probably originated in South America or South Africa.

Introductions of smallpox into European countries have occurred less frequently in recent years. While 17 introductions occurred between 1960 and 1964, only 11 have been recorded during the past 6 years. As smallpox incidence declines throughout the world, such importations should become even less frequent.

It is of particular interest that this decrease in importations has occurred despite a considerable increase in the amount of air travel. However, 23 of the 26 importations for which the mode of travel is known were associated with air travel. Of 3 outbreaks in which the infective source travelled by ship, 2 were recognized on, or before, the arrival of the ship in port; control measures were promptly instituted and outbreaks were rapidly contained. In a third outbreak, the patient was an already known contact of a case in another European country. Although in the largest of these outbreaks, 29 cases were recorded, 25 of these were among members of the ship's crew; only 4 cases occurred among inhabitants of the port. Following the two other importations by ship, 0 and 2 secondary cases were reported. In contrast, travel by air frequently includes further travel within the country during the incubation period of the disease, presenting special problems. Recognition and notification of smallpox by physicians is often greatly delayed since they may not suspect the disease or may be in doubt regarding the correct diagnosis, being unfamiliar with the clinical picture. Delays in diagnosis of 2 or more weeks have been frequent and in at least three instances more than 4 weeks elapsed before smallpox was diagnosed.

As in the recent outbreak at Meschede, the index patient in all previous outbreaks in the Federal Republic of Germany has been a German citizen returning from abroad. In outbreaks occurring in Czechoslovakia, Poland, Spain, Sweden and Switzerland, nationals of these countries were likewise responsible for introducing the disease into their own countries. Since cases of smallpox are exceptionally rare among persons successfully vaccinated within the preceeding 3 years, it is reasonable to conclude that many of these outbreaks might have been prevented if persons travelling abroad had been adequately protected prior to their departure.

Once the disease is introduced into a country further transmission usually occurs in the home or, more often, in the hospital, as in the Meschede outbreak. Of the 391 cases listed in Table 3, 27 represent index cases infected abroad; an additional 24 (outbreak 12) occurred among members of a ship's crew while in quarantine. Of the remaining 340 cases, 161 (47%) were infected in a hospital or during the course of medical or nursing duties. The role of hospitals in the further dissemination of infection and the risk to both other patients and personnel cannot be overemphasized since, as clearly seen in the Meschede outbreak, the hospital staff, patients and visitors are at considerable risk.

The period from December to May is of particular importance. These months coincide with the usual seasonal increase in smallpox in countries in the northern hemisphere, from which the majority of importations originate, and travellers obviously have a greater probability of becoming infected during this time. Following the introduction of infection, further transmission in a European country also occurs more frequently if the introduction takes place during the period from December to May. The summary in Table 4 shows that importations during these months of increased

TABLE 4
SIZE OF OUTBREAK BY MONTH OF IMPORTATION OF SMALLPOX IN EUROPE, 1960-SEPTEMBER 1970

Month of importation	No. of importations	No. of cases in each outbreak [a]				Cases resulting from spread of infection	Average no. of subsequent cases per outbreak
		1	2–4	5–9	⩾10		
Dec.–May	18	6	3	1	8	288	16.0
June–Nov.	8	6	2	0	0	3	0.4
Total	26	12	5	1	8	291	11.2

[a] Two outbreaks not included. In one (2 cases), the dates are unknown; in the other (72 cases) no source case was found, although the first indigenous case was recognized in February.

prevalence gave rise to 40 times as many secondary cases as importations occurring in the period June–November.

Extensive studies in both endemic and non-endemic countries have clearly indicated the necessity for close, and often prolonged, personal contact before transmission of infection occurs. A single patient rarely infects more than a few persons, and only infrequently have cases been reported in which there was no direct or " face-to-face " contact with an earlier case (Ministry of Health, United Kingdom, 1963). The Meschede outbreak in which the index patient infected 17 others is clearly an exception. In European outbreaks of the past decade, two other notable episodes have been reported in which a substantial number of persons was infected by a single patient—in Poland (Kostrzewski & Madgzik, 1964) and in the Federal Republic of Germany (Anders & Posch, 1962). In the Polish outbreak, 25 persons became infected as a result of contact with a patient, a very popular young nurse suffering from haemorrhagic smallpox, incorrectly diagnosed as leukaemia. During her illness and even after her death, many—perhaps several hundred—staff members, patients and friends visited her room. Transmission in this case occurred as a result of face-to-face contact with an undiagnosed patient whose illness was very severe.

In the outbreak in the district (" Kreis ") of Monschau, Federal Republic of Germany, in 1961, a second-generation case was the source of infection for 19 additional cases, only 9 of whom, however, had face-to-face contact with the patient. The patient was a 9-year-old girl admitted to the hospital with severe confluent disease, an ulcerative pharyngitis and a continual barking cough. Although the ward to which she was admitted had been cleared of other patients, a number of patients remained in a neighbouring ward at the end of a common corridor until the following day when they were transferred or discharged. Eventually, 10 persons, none of whom had direct face-to-face contact with the source case, developed smallpox; they were: 7 patients, 2 members of the staff of the adjoining ward and a carpenter who had erected a wooden partition in the corridor. Infection appeared to have spread by air over a considerable distance along the common corridor, along which air flowed from the isolation unit to the neighbouring ward.

Although in several of the outbreaks a few cases have been noted in which no face-to-face contact with a previous case was recorded, the Monschau and the Meschede outbreaks are the only episodes in which a large group of cases at a considerable distance from the index patient appears to have been infected as a result of transmission of the virus by air.

DISCUSSION

Smallpox outbreaks, although not detected until two or three generations of cases have occurred, have been reasonably rapidly and effectively contained when well-defined procedures of isolation, protective immunization and surveillance of close contacts of smallpox patients have been instituted. Since smallpox outbreaks usually develop comparatively slowly and many weeks normally elapse before a substantial number of persons becomes infected, it is not surprising that outbreaks may be effectively contained despite delays in clinical recognition of the disease. The comparatively slow spread of smallpox, observed both in endemic and non-endemic countries, is attributed to the fact that infection is almost invariably transmitted during face-to-face contact with a patient after the rash has begun to develop. Patients with classical smallpox, unmodified by vaccination, are usually confined to bed during this period and are therefore not normally in contact with many susceptible persons. While previously vaccinated persons may experience a very mild, highly modified form of smallpox and remain ambulatory, such persons excrete fewer organisms and are less efficient transmitters of infection (Rao et al., 1968).

The Meschede outbreak and the earlier Monschau outbreak are unusual in the extent of transmission that took place from a single smallpox case and in the fact that a number of cases occurred in persons who had no face-to-face contact with the patient.

The Meschede outbreak probably resulted from an unusual combination of at least three important factors. The patient had a densely confluent rash with severe bronchitis and cough; Rao et al. (1968) have shown that patients with more serious smallpox infections transmit infection more effectively than those with a mild or modified illness. This is attributed to the fact that such patients are likely to have a greater number of lesions on the mucous membranes, thus shedding larger quantities of virus into the saliva and subsequently into the air. At Meschede, virus dissemination was undoubtedly accentuated by coughing and the virus particles undoubtedly survived in the air for unsually long periods since the relative humidity in the hospital was very low.

Experimental studies (Harper, 1961) have shown that vaccinia virus can survive for long periods when the relative humidity is low and presumably variola virus behaves similarly. Finally, the design of the hospital building seems inadvertently to have led to relatively strong air currents being set up when the building was heated. These currents would have disseminated virus particles throughout the building while the low relative humidity would have favoured their survival.

In the Monschau outbreak, in which airborne transmission also occurred, there were similar features; specifically, a source case with extensive rash and cough, transmission during a period of low relative humidity and a hospital design favouring the occurrence of air currents.

In considering future vaccination policy in countries presently free from smallpox, the frequency of importation of the disease by returning nationals should be studied. Interruption of this source of infection by the proper immunization of all travellers prior to their departure from their native country seems to be indicated. This measure, together with a regular programme of vaccination of hospital personnel (Arita, 1970), should substantially reduce both the number and size of outbreaks.

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RÉSUMÉ

ÉPIDÉMIE DE VARIOLE PROPAGÉE PAR VOIE AÉRIENNE DANS UN HÔPITAL D'ALLEMAGNE; SA SIGNIFICATION AU REGARD D'AUTRES ÉPIDÉMIES SURVENUES RÉCEMMENT EN EUROPE

Depuis 1960, on a enregistré dans 10 pays d'Europe 28 cas d'importation de variole. Il s'agissait généralement de personnes qui avaient contracté la maladie en Asie, ou plus rarement en Afrique, et qui arrivaient en Europe par avion. La majorité d'entre elles étaient des Européens revenant d'un voyage à l'étranger; au Royaume-Uni, cependant, les cas indicateurs étaient des ressortissants de pays d'endémicité. Les deux tiers des importations ont eu lieu entre les mois de décembre et de mai, et c'est aussi durant cette période que l'éclosion de cas secondaires a été la plus intense. L'infection s'est propagée essentiellement par contacts directs entre le malade et d'autres personnes, dans le milieu familial ou à l'hôpital. Près de 40% des cas secondaires se sont déclarés parmi le personnel médical et hospitalier, des malades hospitalisés pour d'autres affections et des visiteurs dans les hôpitaux.

Dans les régions d'endémicité, comme dans les pays normalement indemnes de variole, la propagation du virus se fait habituellement par contact direct entre sujet infecté et sujets réceptifs et le primo-cas n'engendre généralement qu'un petit nombre de nouvelles infections. L'épidémie qui s'est déclarée à Meschede (République fédérale d'Allemagne) en janvier 1970 représente à cet égard une remarquable exception. Un malade admis à l'hôpital de cette ville pour une atteinte de variole (contractée au Pakistan occidental) a été à l'origine de 17 cas de deuxième génération dus à la propagation du virus par voie aérienne à l'intérieur de l'hôpital. Une enquête a permis d'élucider le concours de circonstances responsable de l'épidémie: le cas indicateur présentait une forte éruption confluente, avec bronchite et toux sévères; l'atmosphère de l'hôpital était caractérisée par un faible degré d'humidité relative; l'établissement présentait une architecture particulière qui a facilité la dissémination des particules virales par voie aérienne.

Bien que la propagation de la variole par l'air soit une éventualité peu fréquente, l'épidémie de Meschede — tout comme celle de Kreis Monschau en 1961 — montre qu'elle représente néanmoins un risque non négligeable. Une vaccination adéquate des voyageurs internationaux avant le départ du pays d'origine et des mesures assurant une immunisation efficace du personnel médical et hospitalier auraient permis de réduire de moitié au moins le nombre des cas de variole enregistrés en Europe pendant la dernière décennie.

REFERENCES

Anders, W. (1966) *Bundesgesundheitsblatt*, **2**, 21

Anders, W. & Posch, J. (1962) *Bundesgesundheitsblatt*, **17**, 265

Arita, I., Shafa, E. & Kader, M. A. (1970) *Amer. J. publ. Hlth* (in press)

Gordon, H. & Lewis, J. T. (1969) *Publ. Hlth (Lond.)*, **83**, 97

Harper, Q. J. (1961) *J. Hyg. (Lond.)*, **69**, 479

Herrlich, A., Diesfeld, H. J. & Schmidt, H. (1961) *Dtsch. med. Wschr.*, **86**, 1413

Kostrzewski, J. & Magdzik, W. (1964) *Epidem. Rev.*, **18**, 44

Ministry of Health, United Kingdom (1963) *Reports on Public Health and Medical Subjects*, No. 109, p. 1

Rao, A. R., Jacob, E. S., Kamalakshi, S., Appaswamy, S. & Bradbury (1968) *Ind. J. med. Res.*, **56**, 1826

Stroin, J. & Zetterburg, B. (1966) *Acta med. scand. (suppl.)*, vol. 164, p. 1