

## Smallpox

Smallpox is an acute infectious disease caused by the variola virus. Smallpox is believed to have emerged in human populations about 10,000 BCE. A description of smallpox first appeared in a Chinese text in the 4th century. The name variola was first used during the 6th century and is a derivative of the Latin *varius*, meaning spotted, or *varus*, meaning pimple. The first efforts to prevent smallpox occurred in China and India sometime before the year 1000 and involved intentional inoculation of a susceptible person with pustular or scab material from a person with smallpox. The term smallpox was first used in Europe in the 15th century to distinguish variola from the great pox (syphilis). In 1796, Edward Jenner demonstrated that smallpox could be prevented by inoculating a person with material from a cowpox lesion; this led to the first smallpox vaccine. The last case of smallpox in the United States was reported in Texas in 1949. In 1966, the World Health Organization initiated an intensified global smallpox eradication program. The last indigenous case of smallpox on earth occurred in Somalia in October 1977. The World Health Assembly officially certified the global eradication of smallpox in May 1980.

## Variola and Other Orthopoxviruses

Smallpox is caused by variola virus. Variola virus belongs to the genus *Orthopoxvirus*, family Poxviridae. Poxviruses are large brick-shaped viruses with a double stranded DNA genome. They are different from most other DNA viruses in that they replicate in the cytoplasm of the cell rather than in the nucleus. To do this, they produce a variety of proteins not produced by other DNA viruses (e.g., herpesvirus). Four orthopoxviruses are known to infect humans: variola, vaccinia, cowpox, and monkeypox. Variola virus infects only humans in nature, although primates and other animals have been infected in a laboratory. Vaccinia, cowpox, and monkeypox viruses can infect both humans and other animals in nature.

In laboratory experiments, 90% of aerosolized variola virus is inactivated within 24 hours. In the presence of ultraviolet light, this percentage would be even greater. In temperate climates, crusts from the skin lesions from smallpox patients, in which the virus is contained in a fibrin matrix, can retain viable virus for several years when held at room temperature. The virus survives longer at low temperature and humidity than at higher temperature or humidity. All poxviruses are rapidly inactivated by exposure to ultraviolet light, and chemical disinfectants such as bleach or Lysol®.

Some persons infected with variola major virus have particularly severe illnesses. This suggests that there could be differences

### Smallpox

- First described in Chinese text in 4<sup>th</sup> century
- Vaccine developed in late 18<sup>th</sup> century
- Last case in U.S. in 1949
- Last indigenous case on earth in 1977

### Variola Virus

- *Orthopoxvirus*
- Infects only humans in nature
- May remain viable in crusts for years at room temperature
- Rapidly inactivated by UV light, chemical disinfectants

in the virulence of strains of the virus. However, no laboratory test has been devised that correlates virus strains with virulence in humans. Physiologic factors in the host are probably the more important determinant of severity of the illness.

Smallpox vaccine contains vaccinia virus, not variola virus. Vaccinia is rarely isolated from animals outside the laboratory. There are multiple strains of vaccinia virus that have different levels of virulence for humans and animals. Vaccinia virus can also be genetically engineered to accept DNA and express other antigens, and has been used as a vector in laboratory experiments. Cowpox virus was probably the virus that Edward Jenner originally used as a vaccine for smallpox. The virus has many natural hosts, including cows, rodents, cats, elephants, and is found in nature primarily in Europe. Monkeypox was first found in monkeys and later in other animals such as rats, rabbits, and squirrels. It was reported in humans for the first time in 1970. It is found primarily in western and central Africa, although a cluster of monkeypox cases occurred in the United States in 2003 and was associated with pet prairie dogs from Africa.

## Smallpox Pathogenesis

- Virus contact with oropharyngeal or respiratory mucosa
- Virus replication in regional lymph nodes
- Viremia on about 8<sup>th</sup> day of infection
- Virus replication in oral and pharyngeal mucosa and skin

## Pathogenesis

Variola virus infection is initiated when the virus comes into contact with the oropharyngeal or respiratory mucosa of a susceptible person. The virus then multiplies in regional lymph nodes. An asymptomatic viremia develops 3 or 4 days after infection, which is followed by further virus replication, probably in the bone marrow, spleen, and lymphatics. A second viremia begins about 8–10 days after infection and is followed by the first symptoms of illness (prodromal stage), fever and toxemia. The virus localizes in small blood vessels of the dermis and in the oral and pharyngeal mucosa. In the skin, this results in the characteristic maculopapular rash, which evolves into vesicles, then pustules.

## Smallpox Clinical Presentations

- Variola major
  - severe illness
  - case-fatality rate of  $\geq 30\%$
- Variola minor
  - less severe
  - case-fatality rate of  $\leq 1\%$

## Clinical Features

Two clinical forms of smallpox have been described. While both forms are caused by variola virus, they are caused by different strains of the virus distinguishable by specific biologic properties (such as growth characteristics in cell culture and DNA structure). **Variola major** is the severe form of smallpox, with a more extensive rash, higher fever, and a greater degree of prostration. **Variola major** has a case-fatality rate of 30% or more. The last case of variola major occurred in Bangladesh in 1975. Variola minor was first described in South Africa and the United States in the late 19th century. Variola minor is a much less severe disease, with a case-fatality rate of 1% or less. Variola minor was endemic in some countries of Europe and of North and

South America and in many parts of Africa. The last case of variola minor occurred in Somalia in October 1977, and was the last case of indigenous smallpox on earth.

There are **four principal clinical presentations of variola major**, based on the Rao classification (1972). The relative vigor of the immune response to the infection probably determined the clinical presentation of the infection. The classification is based on the nature and evolution of the lesions: **ordinary** (most frequent), **modified** (mild and occurring in previously vaccinated persons), **flat**, and **hemorrhagic**. Flat and hemorrhagic smallpox are severe, uncommon forms and are usually fatal. In addition, variola sine eruptione (smallpox without rash) is a febrile illness occurring after the usual incubation period. It is seen generally in vaccinated persons and can be confirmed only by antibody studies or, rarely, by virus isolation. Subclinical (asymptomatic) infections with variola virus also occurred, but are not believed to be common.

The **incubation period** of smallpox averages 12 days, with a range of 7 to 17 days. During this period the patient is well. The **prodrome** or preeruptive stage of the illness then starts abruptly, with fever (usually 101°–104°F [38.3°–40°C]), malaise, headache, muscle pain, prostration, and often nausea and vomiting and backache. The person usually appears quite ill. The prodrome usually lasts 2–4 days. The person is not infectious until the end of the prodrome, when lesions develop in the mouth.

## Ordinary Smallpox

Ninety percent or more of smallpox cases among unvaccinated persons are of the ordinary type. The prodromal stage varies in severity. By the third or fourth day of illness, the temperature usually falls and the patient feels somewhat better. At this point the rash appears. The rash appears first as an **enanthem**—minute red spots on the tongue and oral and pharyngeal mucosa—about 24 hours before the appearance of rash on the skin. Lesions in the mouth and pharynx enlarge and ulcerate quickly, releasing large amounts of virus into the saliva about the time the cutaneous rash first becomes visible. Virus titers in saliva are highest during the first week of illness, corresponding with the period during which patients are most infectious.

The **exanthem** (skin rash) usually appears 2–4 days after the onset of fever as a few macules (known as “herald spots”) on the face, particularly on the forehead. Lesions then appear on the proximal portions of the extremities, then spread to the distal extremities and the trunk. Usually the rash appears on all parts of the body within 24 hours.

### Clinical Presentations of Variola Major

- **Ordinary** ( $\geq 90\%$  of cases in unvaccinated persons)
- **Modified** (mild; occurs in previously vaccinated persons)
- **Flat** (uncommon; usually fatal)
- **Hemorrhagic** (uncommon; usually fatal)

### Smallpox Prodrome

- **Incubation period 12 days** (range 7-17 days)
- **Prodrome**
  - abrupt onset of fever  $\geq 101^\circ\text{F}$
  - malaise, headache, muscle pain, nausea, vomiting, backache
  - lasts 2-4 days
  - not infectious until lesions develop in mouth

### Smallpox Rash

- **Enanthem** (mucous membrane lesions) appears approx. 24 hours before skin rash
- **Minute red spots on the tongue and oral/pharyngeal mucosa**
- **Lesions enlarge and ulcerate quickly**
- **Virus titers in saliva highest during first week of illness**

### Smallpox Rash

- **Exanthem** (skin rash) appears 2-4 days after onset of fever
- **First appears as macules, usually on the face**
- **Lesions appear on proximal extremities, spread to distal extremities and trunk**

# Smallpox

## Smallpox Rash Evolution

Stage	Days after Rash Onset
Macules	0-1
Papules	2-3
Vesicles	3-5
Pustules	6-12
Crusts	13-20
All crusts separated	21-28

## Smallpox Rash

- Vesicles often have a central depression (“umbilication”)
- Pustules raised, round, firm to the touch, deeply embedded in the skin
- Lesions in any one part of the body are in same stage of development
- Most dense on face and distal extremities (centrifugal distribution)
- Lesions on palms and soles ( $\geq 50\%$  of cases)

## Modified Smallpox

- Occurs in previously vaccinated persons
- Prodrome may be less severe
- No fever during evolution of rash
- Skin lesions evolve more quickly
- Rarely fatal
- More easily confused with chickenpox

By the second or third day of the rash, the macules become raised papules. By the third or fourth day the lesions become vesicular, containing first an opalescent fluid, which then becomes opaque and turbid within 24–48 hours. The skin lesions of smallpox typically are surrounded by a faint erythematous halo. The distended vesicles often have a central depression or dimple of varying size, referred to as “umbilication.” Umbilication often persists into the pustular stage, but as the lesion progresses it usually becomes flattened because of adsorption of fluid. Umbilication is less common in other vesicular or pustular rash illnesses, particularly in varicella.

By the sixth or seventh day, all the skin lesions are pustules. Between 7 and 10 days the pustules mature and reach their maximum size. The pustules are sharply raised, typically round, tense, and firm to the touch. **The pustules are deeply embedded in the dermis, giving them the feel of a small bead in the skin.** Fluid is slowly absorbed from the pustules, and by the end of the second week the pustules begin to form a crust. During the third week the crusts separate, leaving depigmented skin and, frequently, pitted scars. Fever usually rises again by the seventh or eighth day of the illness and continues to remain high throughout the vesicular and pustular stages, until crusts have formed over all the lesions.

The rash usually develops as a single crop. Consequently, **lesions in a particular part of the body are at about the same stage of development, although they may be different sizes.** The distribution of the rash is centrifugal: most dense on the face; more dense on the extremities than on the trunk; and on the extremities, more dense on the distal parts than on the proximal. The palms of the hands and soles of the feet are involved in the majority of cases.

In general, the severity of the clinical picture parallels the extent of the rash. In some cases, the pustular skin lesions on the extensor surfaces of the extremities and face are so numerous they became confluent. Patients with confluent smallpox often remain febrile and toxic even after scabs have formed over all the lesions. In one case series, the case-fatality rate in confluent smallpox was 62%.

## Modified Smallpox

Modified smallpox refers to the character of the eruption and the rapidity of its development. This form of smallpox occurs mostly in previously vaccinated patients. The prodromal illness occurs but may be less severe than in ordinary-type smallpox. Fever during evolution of the rash is usually absent. The skin lesions tend to evolve more quickly, are more superficial, and may not show the uniformity

characteristic of more typical smallpox. The lesions are often few in number, but even when they are numerous, or even confluent, they usually evolve rapidly. Modified smallpox is rarely, if ever, fatal. This form of variola major is more easily confused with chickenpox.

## **Flat (Malignant) Smallpox**

Flat-type smallpox is so called because the lesions remain almost flush with the skin at the time when raised vesicles form in ordinary-type smallpox. It is not known with certainty why some persons develop this type of disease. In a large series of persons hospitalized with smallpox in India, flat-type smallpox accounted for 5%–10% of cases, and the majority (72%) were in children. The prodrome is severe and lasts 3–4 days. Constitutional symptoms are severe and continue after the appearance of the rash. The fever remains elevated throughout and the patient has severe toxic symptoms. The rash on the tongue and palate is usually extensive. The skin lesions mature very slowly. By the seventh or eighth day the lesions are flat and appear to be buried in the skin. Unlike ordinary-type smallpox, the vesicles contain very little fluid and do not appear umbilicated. The lesions are soft and velvety to the touch, and may contain hemorrhages. Respiratory complications are common. The prognosis for flat-type smallpox is grave and most cases are fatal.

## **Hemorrhagic Smallpox**

Hemorrhagic smallpox is a severe and uncommon form of smallpox that is accompanied by extensive bleeding into the skin, mucous membranes, and gastrointestinal tract. In the large Indian series, hemorrhagic disease occurred in about 2% of hospitalized patients; the majority of cases were among adults, and pregnant women appear to be at increased risk. The prodromal stage, which can be prolonged, is characterized by fever, intense headache and backache, restlessness, a dusky flush or sometimes pallor of the face, extreme prostration, and toxicity. There is little or no remission of fever throughout the illness. Hemorrhagic manifestations can occur early or late in the course of the illness. In the early, or fulminating, form, hemorrhagic manifestations appear on the second or third day as subconjunctival bleeding, bleeding from the mouth or gums and other mucous membranes, petechiae in the skin, epistaxis, and hematuria. Death often occurs suddenly between the fifth and seventh days of illness, when only a few insignificant maculopapular cutaneous lesions are present. In patients who survive for 8–10 days the hemorrhages appear in the early eruptive period, and the rash is flat and does not progress beyond the vesicular stage.

### **Flat Smallpox**

- Severe prodrome
- Fever remains elevated throughout course of illness
- Extensive enanthem
- Skin lesions soft and flat, contain little fluid
- Most cases fatal

### **Hemorrhagic Smallpox**

- Prolonged severe prodrome
- Fever remains elevated throughout course of illness
- Early or late hemorrhagic signs
- Bleeding into skin, mucous membranes, GI tract
- Usually fatal

## Smallpox Complications

- Bacterial infection of skin lesions
- Arthritis
- Respiratory
- Encephalitis
- Death
  - 30% overall for ordinary smallpox
  - 40%-50% for children <1 year
  - ≥90% for flat and hemorrhagic smallpox

## Differential Diagnosis

The most important differentiating feature between smallpox and other rash illnesses is the presence of fever before rash onset

## Variola Sine Eruptione and Subclinical Infection

Febrile illness sometimes occurs among vaccinated contacts of smallpox patients, with the sudden onset of temperature of about 102°F (39°C), headache and sometimes backache. The attack often subsides within 48 hours and the temperature returns to normal. Although these symptoms could be caused by other infections, laboratory investigation may show a significant increase in variola antibody following such an attack. There is evidence of true subclinical infection with variola major virus (i.e., serologic evidence of infection with no symptoms), typically in recently vaccinated household contacts of smallpox patients. Persons with subclinical infections have not been shown to transmit the infection to contacts.

## Complications

**Secondary bacterial infection of the skin** is a relatively uncommon complication of smallpox. When this occurs, the fever usually remains elevated. **Arthritis** occurs in up to 2% of cases, most commonly in children. **Respiratory complications** (e.g., bronchitis, pneumonitis, or pneumonia) sometimes develop on about the eighth day of the illness and can be either viral or bacterial in origin. **Encephalitis** occasionally occurs and is indistinguishable from the acute perivascular demyelination observed as a complication of infection due to vaccinia, measles, or varicella.

In fatal cases, **death** usually occurs between the tenth and sixteenth days of the illness. The cause of death from smallpox is not clear, but the infection is now known to involve multiple organs. Circulating immune complexes, overwhelming viremia, or an uncontrolled immune response may be contributing factors. The overall case-fatality rate for ordinary-type smallpox is about 30%. However, the fatality rate for children younger than 1 year of age is 40%–50%. The fatality rate for flat-type and hemorrhagic smallpox is 90% or greater. The case-fatality rate for variola minor is 1% or less.

**Sequelae** of smallpox include scarring, which is most common on the face, blindness resulting from corneal ulceration and scarring, and limb deformities due to arthritis and osteomyelitis. There is no evidence of chronic or recurrent infection with variola virus.

## Differential Diagnosis

The disease that most closely resembles smallpox is varicella (chickenpox). The most important differentiating feature between smallpox and varicella, as well as other rash illnesses, is the presence of a prodrome with fever and

**other symptoms before rash onset.** A person with smallpox will have a severe, febrile prodrome that begins 1–4 days before the onset of the rash. The fever is high, usually 102°–104°F (38.8°–40°C), but always at least 101°F (38.3°C). Most children with varicella have a short, mild prodrome or no prodrome at all before onset of the rash and have little or no fever before rash onset. Adults, who may develop more severe varicella, are more likely to have fever or other symptoms before rash onset. **If there is no history of a febrile prodrome, smallpox is not likely.** In addition to fever, the prodrome of smallpox is associated with one or more additional symptoms, such as prostration, headache, backache, chills, abdominal pain or vomiting. Patients are frequently too ill to engage in normal activities and typically confine themselves to bed.

Another important differentiating feature of smallpox and varicella is the appearance, evolution, and distribution of the rash. Although there may be some similarity in the appearance of the lesions, particularly early after rash onset, classic smallpox looks very different from varicella. Smallpox lesions are deep in the dermis and feel hard to the touch, described as feeling like a pea under the skin. They are round and well circumscribed. As they evolve, they may become confluent or umbilicated. The varicella rash is superficial, and the lesions appear to be delicate and not as well circumscribed. Confluence and umbilication are uncommon in varicella. Smallpox rash lesions appear in a single crop, and lesions on any part of the body are in the same stage of development. Lesions are more dense on the extremities than on the trunk and often involve the palms and soles (i.e., centrifugal distribution). In contrast, the rash of varicella appears in several crops, so papules, vesicles, and crusts are seen simultaneously on the same part of the body and new lesions continue to appear for several days. Lesions are typically more dense on the trunk than on the extremities. In severe cases of varicella, rash distribution may not be a useful differentiating feature and rash may occur everywhere on the body, including the palms and soles.

For the first 2–3 days, the smallpox rash is maculopapular. At this stage of the illness smallpox could be confused with other febrile illnesses with maculopapular rash, such as measles, rubella, and other evolving vesicular rashes including varicella

Other common conditions that might be confused with smallpox are summarized in the table below. As the United States re-institutes smallpox vaccination, at least in limited groups, generalized vesicular rashes (generalized vaccinia and eczema vaccinatum) caused by vaccinia vaccine adverse reactions could be seen among persons with a history of recent smallpox vaccination or contact close with a vaccinee.

## Differential Diagnosis

### Smallpox

- Severe, febrile prodrome
- 1–4 days before rash
- $\geq 101^\circ\text{F}$
- Other symptoms:
  - prostration
  - headache
  - backache
  - chills
  - abdominal pain
  - vomiting

### Varicella

- Mild or no prodrome
- Little or no fever
- No associated symptoms

## Differential Diagnosis

### Smallpox

- Deep, hard lesions
- Round, well circumscribed
- Confluent or umbilicated
- Lesions at same stage of development

### Varicella

- Superficial lesions
- Not well circumscribed
- Confluence and umbilication not common
- Lesions at all stages of development

# Smallpox

In addition there are exceedingly rare causes of smallpox-like rash, such as rickettsial pox and monkeypox. A small percentage of smallpox cases present as hemorrhagic smallpox or a flat-type rash. Both variants are highly lethal. Hemorrhagic smallpox can be mistaken for meningococemia.

## COMMON CONDITIONS THAT MIGHT BE CONFUSED WITH SMALLPOX

CONDITION	CLINICAL CLUES
Varicella (primary infection with varicella-zoster virus)	Most common in children <10 years; children usually do not have a viral prodrome
Disseminated herpes zoster	Immunocompromised or elderly persons; rash looks like varicella, usually begins in dermatomal distribution
Impetigo ( <i>Streptococcus pyogenes</i> , <i>Staphylococcus aureus</i> )	Honey-colored crusted plaques with bullae are classic but may begin as vesicles; regional not disseminated rash; patients generally not ill
Drug eruptions	Exposure to medications; rash often generalized
Contact dermatitis	Itching; contact with possible allergens; rash often localized in pattern suggesting external contact
Erythema multiforme minor	Target, "bull's eye", or iris lesions; often follows recurrent herpes simplex virus infections; may involve hands & feet (including palms & soles)
Erythema multiforme (incl. Stevens-Johnson Syndrome)	Major form involves mucous membranes & conjunctivae; may be target lesions or vesicles
Enteroviral infection esp. Hand, Foot and Mouth disease	Summer & fall; fever & mild pharyngitis 1-2 days before rash onset; lesions initially maculopapular but evolve into whitish-grey tender, flat often oval vesicles; peripheral distribution (hands, feet, mouth, or disseminated)
Disseminated herpes simplex	Lesions indistinguishable from varicella; immunocompromised host
Scabies; insect bites (incl. fleas)	Itching is a major symptom; patient is not febrile & is otherwise well
Molluscum contagiosum	May disseminate in immunosuppressed persons

### Smallpox Major Criteria

- Febrile prodrome 1-4 days before rash onset; fever of  $\geq 101^{\circ}\text{F}$ , and at least 1 additional symptom\*
- Rash lesions are deep, firm/hard, round and well circumscribed
- On any one part of the body lesions in same stage of development

\*Prostration, headache, backache, chills, vomiting or severe abdominal pain

CDC has developed criteria that can be used to evaluate suspected smallpox cases and to categorize patients into high, moderate or low risk for smallpox. There are three major and five minor smallpox criteria:

### Major criteria

1. The patient has had a febrile prodrome (temperature  $101^{\circ}\text{F}$  [ $38.3^{\circ}\text{C}$ ] or higher) 1-4 days before rash onset and at least one of the following systemic complaints: prostration, headache, backache, chills, vomiting or abdominal pain.
2. Rash lesions are deep in the skin, firm or hard to the touch, round and well circumscribed, and may become umbilicated or confluent as they evolve.
3. On any one part of the body all the lesions are in the same stage of development (i.e., all are vesicles or all are pustules).

## Minor criteria

1. The distribution of the rash is centrifugal (i.e., the greatest concentration of lesions is on the face and distal extremities with relative sparing of the trunk).
2. The first lesions of the rash appear on the oral mucosa or palate, or on the face or forearms.
3. The patient appears toxic or moribund.
4. Lesions have progressed slowly (i.e., the individual lesions evolved from macules to papules to pustules, each stage lasting 1–2 days).
5. Lesions are present on the palms or soles.

A person is considered at **high risk** for smallpox if he or she meets all three major criteria. Immediate action should be taken to make sure that contact precautions and respiratory isolation are implemented. These patients should be reported to local and/or state health authorities immediately. Obtain digital photographs if possible, and consult with dermatology and/or infectious disease experts. Following such consultation, if the patient is still considered to be at high risk, the state health department will immediately report the case to CDC and arrangements will be made for laboratory testing for smallpox virus.

A person considered at **moderate risk** for smallpox must have a febrile prodrome and either one other major criterion or four or more minor criteria. These patients should be isolated and be evaluated urgently to determine the cause of the illness. Persons classified as high or moderate risk should be seen in consultation with a specialist in infectious diseases and/or dermatology whenever possible. Any person who did not have a febrile prodrome is considered at **low risk**, as are persons who had a febrile prodrome and fewer than four minor criteria. These patients should be managed as clinically indicated.

A case investigation worksheet and a poster that includes the rash illness algorithm, and information on differential diagnosis is available from the CDC smallpox website at <http://www.bt.cdc.gov/agent/smallpox/>

## Laboratory and Pathology Diagnosis

If a case is classified as high risk after evaluation using the algorithm, it fits the clinical case definition for smallpox and therefore should be considered a probable smallpox case until smallpox virus laboratory results are completed. For such a case, do not perform other laboratory testing for other diagnoses.

Currently, laboratory procedures for isolation of variola virus in clinical specimens should be done only by CDC in

### Smallpox Minor Criteria

- Greatest concentration of lesions on face and distal extremities
- Lesions first appear on oral mucosa/palate, face, or forearms
- Patient appears toxic or moribund
- Lesions evolve from macules to papules to pustules
- Lesions on palms and soles

### Risk of Smallpox by Clinical History and Examination

- High risk
  - febrile prodrome
  - classic smallpox lesions
  - same stage of development
- Moderate risk
  - febrile prodrome
  - 1 major OR  $\geq 4$  minor criteria
- Low risk
  - no febrile prodrome
  - febrile prodrome and  $<4$  minor criteria

### Laboratory Confirmation

- Rapid diagnostic testing for varicella zoster virus (DFA, IFA, PCR)
- Electron microscopy (may identify *Orthopoxvirus* but not specific for variola)
- Culture
- Nucleic acid-based testing
- Serologic testing

Atlanta. If the patient's clinical characteristics indicate a high risk for smallpox, the state health department should be contacted immediately. The diagnosis of an *Orthopoxvirus* infection can be made rapidly by electron microscopic examination of pustular fluid or scabs. Orthopox generic polymerase chain reaction (PCR) tests are available but do not distinguish between vaccinia, variola and other poxvirus infections. Differentiation of orthopoxviruses is made by nucleic acid-based testing, such as PCR. Serologic tests have also been developed to assist in the diagnosis of acute *Orthopoxvirus* infection, and direct antigen detection tests for variola virus are under development.

For a patient who meets the criteria for moderate risk, **the most important laboratory procedure is rapid diagnostic testing for varicella zoster virus (VZV)**. Laboratory testing should be done in consultation with an infectious disease or dermatology specialist. Smallpox virus testing is not indicated for cases that do not meet the clinical case definition. In the absence of smallpox (disease prevalence of zero), the predictive value of a positive laboratory test is extremely low (close to zero). Limiting requests for smallpox testing to cases that fit the clinical case definition will minimize the risks of a false-positive laboratory result, which would have extremely serious consequences.

Since varicella was the most common disease confused with smallpox in the past and the most common diagnosis in smallpox false alarms in the immediate posteradication era, rapid VZV diagnostic tests are important for evaluation of suspected smallpox cases. A variety of rapid methods are available for detecting VZV in clinical material. The most useful is direct fluorescent antibody (DFA). This method detects VZV directly in cells using anti-VZV antibody conjugated to fluorescein dye. DFA is very sensitive and specific but is critically dependent on careful collection of material from a lesion. Detection of VZV DNA by PCR testing of vesicular fluid or scabs can also be used for rapid detection of VZV in clinical material. Real time PCR assays take 4–6 hours to perform. Virus particles consistent with VZV can be detected using electron microscopy. Rapid diagnostic testing for VZV is generally available in at least one facility (private laboratories, academic hospital centers) in all large cities and in some local and in all state health department facilities. Other testing should be done as clinically indicated and may include testing for herpes simplex viruses (HSV), enteroviruses and syphilis.

Tzanck smear, although not diagnostic of VZV infection, is a rapid and easily performed test in hospitals with a pathology laboratory and is frequently available at the local level. A positive Tzanck smear confirms an alphaherpesvirus infection (either VZV or HSV).

Skin biopsies, if clinically indicated, can assist with a diagnosis on the basis of histopathology or can be confirmatory if immunohistochemistry tests are available.

## Medical Management

A suspected case of smallpox is a public health and medical emergency. Any person whose clinical characteristics meet the clinical case definition for smallpox must be isolated and reported immediately to the local and/or state health department.

**Strict respiratory and contact isolation of confirmed or suspected smallpox patients is critical to limit the exposure to the virus.** Smallpox patients are infectious until all crusts have separated. Although droplet spread is the major mode of person-to-person smallpox transmission, airborne transmission through fine particle aerosol can occur. Therefore, airborne precautions using a negative air pressure room with high-efficiency particulate air filtration should be initiated immediately for hospitalized high-risk or confirmed smallpox patients. This is the same isolation precaution that is taken for other infectious diseases with respiratory transmission, such as varicella.

All personnel who have contact with a patient with suspected or confirmed smallpox should use appropriate protective equipment. This includes properly fitted respirators (masks) of N95 quality or higher. In addition, personnel should use disposable gloves, gowns and shoe covers for all contact with patients. This precaution is to prevent inadvertent transmission of variola virus from clothing or other contaminated items to susceptible persons. Personnel should remove and correctly dispose of all protective clothing before contact with other people. Reusable bedding and clothing can be autoclaved or laundered in hot water with bleach to inactivate the virus. Persons such as laundry handlers, housekeepers, and laboratory personnel, who come into contact with materials potentially contaminated with smallpox virus, should use appropriate protective equipment. If a case of smallpox is confirmed, these personnel should be vaccinated before handling contaminated materials.

Medical management of a person with smallpox is primarily supportive. No antiviral drug is currently approved by the Food and Drug Administration for the treatment of smallpox. Recent studies suggest that the antiviral drug cidofovir might be useful as a therapeutic agent. However, the drug must be administered intravenously and can cause serious renal toxicity. Cidofovir administered for the treatment of smallpox would be an off-label use. Antiviral therapy with cidofovir or other drugs subsequently found to have antivariola activity might be considered but should be used under an investigational new drug (IND) protocol and by an infectious diseases specialist.

### Smallpox Medical Management

- Notify public health authorities **immediately** for suspected case
- Strict respiratory and contact isolation
- Supportive care
- Antiviral agents?

## Smallpox Epidemiology

- **Reservoir** Human (before eradication)
- **Transmission** Respiratory by large particles  
Can be airborne
- **Communicability** From onset of rash until  
all crusts separate

## Smallpox Epidemiology

- **Most transmission results from face-to-face contact with infected person (household and hospital contacts)**
- **Transmission most frequent during first week of rash**

## Epidemiology

### Reservoir

Although animals can be infected with variola in laboratory conditions, humans are the only natural host. There is no chronic carrier state and no known animal reservoir. Since the early 1980s (i.e., following global smallpox eradication), the only known locations of variola virus are at CDC in Atlanta and at the State Research Center of Virology and Biotechnology in Koltsovo, Russia.

### Transmission

Transmission of smallpox occurs through inhalation of airborne variola virus, usually droplets expressed from the oral, nasal, or pharyngeal mucosa of an infected person. Most transmission results from direct face-to-face contact with an infected person, usually within a distance of 6 feet, or from physical contact with a person with smallpox or with contaminated articles. Although variola virus could remain viable for years in dried crusts of skin lesions, transmission from crusts is uncommon, probably because virus is enmeshed in a fibrin matrix.

### Communicability

A person infected with variola virus is not infectious during the incubation period or the first day or two of the prodromal stage of the illness. The patient becomes infectious with the first appearance of the rash, which is often accompanied by lesions in the mouth and pharynx. The virus can be transmitted throughout the course of the illness (i.e., until all crusts separate). Transmission is most frequent during the first week of the rash, while most skin lesions are intact (i.e., vesicular or pustular). Virus is present in material draining from ruptured pustules and in crusts for a longer period, but infection from this source appears to be less frequent. In general, persons with a severe rash and involvement of the mouth and pharynx, and those with a cough are more infectious than those with a slight rash. Secondary attack rates among household members are generally 50%–60%.

Natural transmission of smallpox in a population is relatively slow. There is an interval of 2 to 3 weeks between each generation of cases. Smallpox generally spreads less widely and less rapidly than does varicella or measles, probably because transmission of variola virus does not occur until the onset of rash and generally requires close face-to-face contact for spread. At the time of rash onset, most patients are already confined to bed because of the high fever and toxemia of the prodromal stage of the illness. However, persons with severe prodromal illness may seek medical

attention; therefore, hospitals are a frequent source of infection because of transmission from hospitalized persons with unrecognized cases.

Secondary cases of smallpox are usually limited to those who come in contact with the infected person in the household or hospital. During the global eradication program, the chain of transmission of smallpox was interrupted by isolating smallpox patients in a setting in which they had contact only with adequately vaccinated or previously infected persons. This limited the next potential generation of cases to the household and close contacts of the index patient or patients. Contacts were identified and immediately vaccinated. Contacts who became ill were also isolated to establish a barrier to further transmission. This strategy was found to be effective even if community vaccination levels were low.

### Temporal Pattern

In temperate areas, the seasonality of smallpox was similar to that of measles and varicella, with incidence highest during the winter and spring. In tropical areas, seasonal variation was less evident and the disease was present throughout the year.

### Secular Trends

The last case of smallpox in the United States was reported in 1949. In the early 1950s, an estimated 50 million cases of smallpox occurred worldwide each year. Ten to 15 million cases occurred in 1966, when the disease had already been eliminated in 80% of the world.

### Smallpox Eradication

The intensified global smallpox eradication program began in 1966. The initial campaign was based on a twofold strategy: 1) mass vaccination campaigns in each country, using vaccine of ensured potency and stability, that would reach at least 80% of the population; and 2) development of surveillance systems to detect and contain cases and outbreaks. The program had to surmount numerous problems, including lack of organization in national health services, epidemic smallpox among refugees fleeing areas stricken by civil war and famine, shortages of funds and vaccine, and a host of other problems posed by difficult terrain, climate, and cultural beliefs. In addition, it was soon learned that even when 80% of the population was vaccinated, smallpox often persisted. Soon after the program began, it became apparent that by isolating persons with smallpox and vaccinating their contacts, outbreaks could be more rapidly contained, even in areas where vaccination coverage was low. This strategy was called **surveillance and containment**, and it became the key element in the global eradication program.

#### Smallpox Eradication

- Intensified Global Eradication program begun in 1966
- Initial strategy was mass vaccination
- Strategy evolved to "surveillance and containment"
- Last indigenous case in Somalia in October 1977

Although setbacks occurred, the surveillance and containment strategy was an enormous success. The last case of smallpox in Brazil was reported in 1971, and Indonesia's last case occurred in 1972. India, Pakistan and Bangladesh, with a population at that time of more than 700 million, were a particular challenge. But with intensive house-to-house searches and strict containment, the last case of variola major—the most deadly type of smallpox—occurred in Bangladesh in October 1975.

By the end of 1975, smallpox persisted only in the Horn of Africa. Conditions were very difficult in Ethiopia and Somalia, where there were few roads. Civil war, famine, and refugees made the task even more difficult. An intensive surveillance and containment and vaccination program was undertaken in the spring and summer of 1977. As a result, the world's last person with indigenous smallpox was a hospital cook in Merka, Somalia, on October 26, 1977. Searches for additional cases continued in Africa for more than 2 years, during which time thousands of rash illnesses were investigated. None proved to be smallpox.

The last cases of smallpox on earth occurred in an outbreak of 2 cases (one of which was fatal) in Birmingham, England in 1978. This outbreak occurred because variola virus was carried by the ventilation system from a research laboratory to an office one floor above the laboratory. In 1980 the World Health Assembly certified the global eradication of smallpox and recommended that all countries cease vaccination. The World Health Organization also recommended that all laboratories either destroy their remaining stocks of variola virus or transfer them to one of two WHO reference laboratories, the Institute of Viral Preparations in Moscow or CDC in Atlanta. All laboratories were believed to have complied with this request.

## Case Definition

A clinical case of smallpox is defined as an illness with acute onset of fever (101°F [38.3°C] or higher) followed by a rash characterized by firm, deep-seated vesicles or pustules in the same stage of development without other apparent cause.

This case definition will not detect an atypical presentation of smallpox such as hemorrhagic or flat-type disease. In addition, given the extremely low likelihood of smallpox occurring, the case definition provides a high level of specificity (i.e., vesicular rash illness) rather than a high level of sensitivity (i.e., maculopapular rash illness). In the event of a smallpox outbreak, the case definition would be modified to increase sensitivity.

## Smallpox (Vaccinia) Vaccine

The first attempts to prevent smallpox were in China and India before the year 1000 century, and involved either nasal insufflation of powdered smallpox scabs, or scratching material from a smallpox lesion into the skin. This procedure was known as variolation and, if successful, produced lasting immunity to smallpox. However, because the person was infected with variola virus, a severe infection could result, and the person could transmit smallpox to others.

In 1796 **Edward Jenner**, a doctor in rural England, discovered that immunity to smallpox could be produced by inoculating a person with material from a cowpox lesion. Cowpox is a poxvirus in the same family as variola. Jenner called the material used for inoculation vaccine, from the root word *vacca*, which is Latin for cow. The procedure was much safer than variolation, and did not involve a risk of smallpox transmission. Vaccination to prevent smallpox was soon practiced all over the world.

At some time during the 19th century, the cowpox virus used for smallpox vaccination was replaced by vaccinia virus. Vaccinia is in the same family as cowpox and variola but is genetically distinct from both. The origin of vaccinia virus and how it came to be in the vaccine are not known.

## Characteristics

The smallpox vaccine currently available in the United States (Dryvax, produced by Wyeth) is a **live virus preparation of infectious vaccinia virus**. Smallpox vaccine does not contain smallpox (variola) virus. The current vaccine was prepared in the early 1980s from calf lymph with a seed virus derived from the New York City Board of Health (NYCBOH) strain of vaccinia virus. The vaccine is provided as a lyophilized (freeze-dried) powder in a 100-dose vial and contains the antibiotics polymyxin B, streptomycin, tetracycline and neomycin. The diluent used to reconstitute the vaccine is 50% glycerin and contains a small amount of phenol as a preservative.

Approximately 15 million doses of vaccine are available now in the United States. Testing has shown that existing supplies of vaccine could be diluted by a 1:5 ratio and still remain as effective and safe as full-strength vaccine. An additional 85 million doses of vaccine based on the NYCBOH strain have been found to be immunogenic at 1:5 or 1:10 dilution. This could potentially provide an additional 850 million doses.

The vaccine is administered by using a multiple puncture technique with a special bifurcated needle. Detailed information concerning reconstitution and administration

## Smallpox Vaccine

- 1796** Edward Jenner develops vaccine
- 1805** Use of cows to produce vaccine
- 1940s** Freeze-drying technology
- 1965** Licensure of bifurcated needle
- 1972** Routine vaccination stopped in U.S.
- 1983** Vaccine removed from civilian market

## Smallpox Vaccine

- Live vaccinia virus in calf lymph
- Contains trace amounts of polymyxin B, streptomycin, tetracycline, and neomycin
- Diluent contains glycerin and phenol
- New vaccine produced using cell culture technology does not contain antibiotics

## Response to Smallpox Vaccination

- Neutralizing antibody develops
  - 10 days after primary vaccination
  - 7 days after revaccination
- >95% of primary vaccinees develop detectable neutralizing antibody
- Antibody persists >10 years

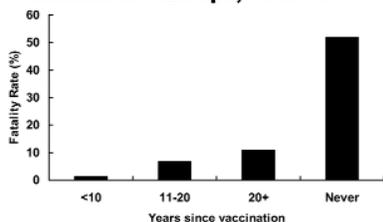
## Smallpox Vaccine Efficacy

- Clinical efficacy estimated in household contact studies
- 91%–97% reduction in cases among contacts with vaccination scar
- Studies did not consider time since vaccination or potency of vaccine

## Duration of Immunity Following Smallpox Vaccination

- High level of protection (~100%) for up to 5 years following vaccination
- Substantial but waning immunity for  $\geq 10$  years
- Reduction in disease severity among previously vaccinated persons

## Smallpox Fatality Rate by Time Since Vaccination—Europe, 1950-1971\*



\*Mack TM. *J Infect Dis* 1972;125:161-9.

of smallpox vaccine are available on the CDC smallpox website at <http://www.cdc.gov/smallpox>.

## Immunogenicity and Vaccine Efficacy

Neutralizing antibodies induced by vaccinia vaccine are genus-specific and cross-protective for other orthopoxviruses (e.g., monkeypox, cowpox, and variola viruses). Neutralizing antibodies are detectable 10 days after primary vaccination, and 7 days after revaccination. Although the level of antibody that protects against smallpox infection is unknown, after percutaneous administration of a standard dose of vaccinia vaccine, more than 95% of primary vaccinees (i.e., persons receiving their first dose of vaccine) will develop neutralizing or hemagglutination inhibition antibody at a titer of higher than 1:10. Neutralizing antibody titers of higher than 1:10 persist in 75% of persons for 10 years after receiving second doses and up to 30 years after receiving three doses of vaccine.

The efficacy of smallpox vaccine has never been measured precisely in controlled trials. However, protection has been determined in studies of persons exposed to a smallpox patient in their household. These studies indicated a 91%–97% reduction in smallpox among contacts with a vaccination scar compared with contacts without a scar. However, these studies did not always consider the time since vaccination or potency of vaccine, so they may underestimate protection.

Epidemiologic studies demonstrated that a high level of protection (nearly 100%) against smallpox persists for up to 5 years after primary vaccination, and substantial but waning immunity for 10 years or more. Antibody levels after revaccination can remain high longer, conferring a greater period of immunity than occurs after primary vaccination alone. Although smallpox vaccination received in the remote past may not completely protect against smallpox, vaccinated persons appear to have less severe disease. Studies of smallpox cases imported into Europe in the 1950s and 1960s demonstrated fewer fatalities among vaccinated persons compared with those who were unvaccinated. The fatality rate among persons vaccinated less than 10 years before exposure was 1.3%; it was 7% among those vaccinated 11 to 20 years prior, and 11% among those vaccinated 20 or more years prior to infection. In contrast, 52% of unvaccinated persons died.

Smallpox vaccination also provides protection if administered after an exposure to smallpox. **Postexposure efficacy** has been estimated in household contact studies in Pakistan and India. These studies indicate that rates of secondary cases in

households were up to 91% lower than rates among unvaccinated persons. The lowest secondary attack rates occurred in persons vaccinated less than 7 days after exposure. In these studies, smallpox was generally less severe (i.e., modified type) in persons who received postexposure vaccination.

Following vaccination, vaccinia virus replicates in the basal cells of the epidermis, resulting in the development of a lesion at the site of vaccination. A papule develops at the inoculation site 3–4 days after primary vaccination. Approximately 7 days following primary vaccination, a vesicle (a blister containing clear fluid) surrounded by erythema (a “Jennerian vesicle”) forms at the site. The vesicle becomes pustular by 7–11 days after vaccination. Maximum erythema occurs 8–12 days after vaccination. The erythema then subsides, the pustule dries, and a crust develops 2–3 weeks after vaccination. In the third week, the crust separates, leaving a permanent scar at the vaccination site. This response to vaccination is called a **major reaction**, and indicates that virus replication has taken place and vaccination was successful. **A person is considered protected with the development of a major reaction at the vaccination site.** A revaccinated person often develops a skin reaction similar to that after primary vaccination, but the lesion progresses faster than after primary vaccination.

Some persons do not develop a typical skin lesion after vaccination. All responses other than major reactions are referred to as **equivocal**. There are several possible causes of equivocal reactions. The person may be sufficiently immune to suppress viral replication or may be allergic to a component of the vaccine, leading to a hypersensitivity reaction at the site. An equivocal reaction could also be caused by insufficiently potent vaccine or incorrect administration technique. In general, a person who has an equivocal response to vaccination should be revaccinated using vaccine from another vial if possible. More information on interpretation of response to vaccination is available in the ACIP recommendations for smallpox vaccine, available at <http://www.cdc.gov/mmwr/PDF/rr/rr5010.pdf>.

Live vaccinia virus is present at the vaccination site beginning 3 to 4 days after vaccination and remains until the crust separates from the skin. Since the developing vaccinia lesion usually itches, care must be taken to avoid scratching, then touching other parts of the body, such as the eye, or other people. This could transfer the vaccine virus to these sites or individuals. Washing hands immediately after touching the vaccination site or dressing is very important in preventing this type of transmission.

## Postexposure Vaccine Efficacy

- Secondary attack rates reduced up to 91% compared to unvaccinated contacts
- Lowest disease rates among persons vaccinated <7 days after exposure
- Disease generally less severe (modified-type) in persons receiving postexposure vaccination

## Clinical Response to Smallpox Vaccination\*

Symptom/Sign	Time after vac
Papule	3-4 days
Vesicle	5-6 days
Pustule	7-11 days
Maximum erythema	8-12 days
Scab	14 days
Scab separation	21 days

\*typical response in a nonimmune person

## Clinical Response to Smallpox Vaccination

- **Major (primary) reaction**
  - indicates viral replication has occurred and vaccination was successful
  - considered to be protected with the development of a major reaction
- **Equivocal reaction**
  - indicates immune suppression of viral replication, allergic reaction without production of immunity, incorrect vaccination technique, or impotent vaccine
  - revaccinate immediately

## Evolution of U.S. Smallpox Vaccine Recommendations

- **1972** Discontinue routine vaccination
- **1976** Discontinue vaccination of HCWs
- **1980** Vaccine recommended for lab workers
- **1990** Discontinue vaccination of military
- **1991** Consider vaccine for HCWs exposed to recombinant vaccinia
- **2001** Bioterrorism guidelines
- **2002** Smallpox Response Teams

## Smallpox Vaccine Indications in Nonemergency Situations

- Laboratory workers who handle cultures or animals infected with non-highly attenuated vaccinia
- Laboratory workers exposed to other Orthopoxviruses that infect humans
- Consider for other healthcare workers with contact with contaminated material
- Public health, hospital, and other personnel who may need to respond to a smallpox case or outbreak
- Persons who vaccinate others

## Smallpox Vaccine Indications in Emergency Situations\*

- Persons exposed to initial release
- Close contact with confirmed or suspected case
- Direct care or transportation of confirmed or suspected case-patient
- Laboratory personnel
- Persons with risk of contact with infectious materials from patient
- Other groups as recommended by public health authorities

\*following confirmation of a case of smallpox

## Vaccination Schedule and Use

Routine childhood smallpox vaccination was discontinued in the United States in 1972. Routine vaccination of healthcare workers was discontinued in 1976, and among military recruits in 1990. In 1980, smallpox vaccine was recommended for laboratory workers who were at occupational risk for exposure to vaccinia or other orthopoxviruses. In 1991, the Advisory Committee on Immunization Practices recommended that other healthcare workers who could be exposed to vaccinia or recombinant vaccinia be considered for vaccination. Guidelines for use of smallpox vaccine in the event of an intentional release of smallpox virus were first published in 2001.

For routine nonemergency use (i.e., in the absence of smallpox disease) **vaccination is recommended for laboratory workers who directly handle cultures or animals contaminated or infected with non-highly attenuated vaccinia viruses** (e.g., the NYCBOH, Temple of Heaven, Copenhagen, or Lister vaccinia strains), and recombinant vaccinia viruses derived from non-highly attenuated vaccinia strains. Vaccination is also recommended for laboratory workers exposed to other orthopoxviruses that infect humans (e.g., monkeypox or cowpox). Vaccination can be considered for other healthcare workers who come into contact with materials such as dressings that may be contaminated with vaccinia or recombinant vaccinia. This could occur, for example, in the course of a clinical trial in which humans were administered vaccines containing recombinant vaccinia viruses. **Vaccination is also recommended for public health, hospital, and other personnel who may need to respond to a smallpox case or outbreak, and for persons who administer the vaccine to others.**

**In the event of an intentional release of variola virus, vaccination would be recommended for those exposed to the initial release, contacts of persons with smallpox, and others at risk of exposure.** Persons at risk of exposure would include those involved in the direct medical or public health evaluation, care or transportation of confirmed or suspected smallpox patients; laboratory personnel who collect or process clinical specimens from confirmed or suspected smallpox patients; persons who may have contact with infectious materials, such as those responsible for medical waste disposal, linen disposal or disinfection, and room disinfection in a facility where smallpox patients are present; and other groups (e.g., medical, law enforcement, emergency response, or military personnel) as recommended by public health authorities.

The **schedule** for smallpox vaccine is one successful dose (i.e., a dose that results in a major reaction at the vaccination site). In routine circumstances the vaccine should not be

administered to persons younger than 18 years of age. In an emergency (postrelease) situation, there would be no age limit for vaccination of persons exposed to a person with confirmed smallpox.

Persons with occupational exposure to non–highly attenuated vaccinia viruses, recombinant viruses derived from non–highly attenuated vaccinia viruses, or other nonvariola orthopoxviruses should be revaccinated at least every 10 years. To ensure an increased level of protection against more virulent nonvariola orthopoxviruses (e.g., monkeypox), empiric revaccination every 3 years can be considered.

## Adverse Reactions Following Vaccination

A vesicular or pustular skin lesion at the site of inoculation indicates a successful vaccination, or “take.” In a 2002 study of old and new vaccines given to unvaccinated adults, the average size of the pustule at 2 weeks after vaccination was 12 millimeters. The average size of erythema surrounding the pustule was 16–24 millimeters, and average induration was 11–15 millimeters.

Some vaccinees may have larger degrees of erythema and induration that can be mistaken for cellulitis. These reactions generally improve within 24 to 48 hours without specific therapy but may require clinical evaluation to rule out bacterial cellulitis.

Forty to 47 percent of vaccinees reported mild pain at the site of inoculation. But 2%–3% reported the pain as severe. Axillary lymphadenopathy was reported in about one-third of recipients. Most lymphadenopathy was mild, but in 3%–7% it was considered moderate, i.e., bothersome to the vaccinee but not otherwise interfering with normal activities.

Fever is common after administration of smallpox vaccine. In a recent study of Dryvax given to unvaccinated adults, 5%–9% reported a temperature of 100°F (37.7°C) or higher, and 3% reported temperature of 102°F (38.8°C) or higher. Fever is most common 7–12 days after vaccination. In addition to fever, adult vaccinees also report a variety of constitutional symptoms, including headache, myalgias, chills, nausea, and fatigue on or about the eighth or ninth day after vaccination. One or 2 percent of recipients reported these symptoms as severe.

Historically, fever was more common among children. In past studies, about 70% of children experienced 1 or more days of temperature 100°F (37.7°C) or higher after primary vaccination. Fifteen to 20 percent of children experienced temperatures 102°F (38.8°C) or higher.

### Smallpox Vaccine

- **Schedule**
  - 1 successful dose
- **Revaccination**
  - 10 years (non-highly attenuated vaccinia and recombinants)
  - 3 years (more virulent Orthopoxviruses)

### Smallpox Vaccine Local Reactions Among Susceptible Adults

- **Pain, swelling, erythema at vaccination site**
- **Regional lymphadenopathy**
  - begins 3-10 days after vaccination
  - can persist for 2-4 weeks after vaccination site heals

### Smallpox Vaccine Reactions Among Susceptible Adults

- **Elevated temperature**
  - 5%–9%  $\geq 100^{\circ}\text{F}$
  - 3%  $\geq 102^{\circ}\text{F}$
- **Systemic symptoms (malaise, myalgia)**
- **36% sufficiently ill to miss work, school, or recreational activities or had trouble sleeping**

# Smallpox

## Smallpox Vaccine Adverse Reaction Rates\*

Reaction	Primary Vaccination
Inadvertent inoculation	25-529
Generalized vaccinia	23-242
Eczema vaccinatum	10-39
Progressive vaccinia	0.9-1.5
Postvaccinial encephalitis	3-12
Death	1

\*Rates per million primary vaccinations

## Inadvertent Inoculation

- Caused by transfer of vaccinia virus from site of vaccination to other areas of the body
- Most commonly on face, eyelid, nose, mouth, rectum, genitalia
- Most lesions heal spontaneously without specific treatment

## Generalized Vaccinia

- Results from viremia with implantations in the skin
- Occurs in the absence of eczema or other preexisting skin diseases
- Vesicles or pustules on normal skin distant from vaccination site
- Usually minor illness with little residual damage

Vaccinia virus is present at the site of vaccination beginning about 4 days after vaccination. Maximum viral shedding from the vaccination site occurs 4–14 days after vaccination, but vaccinia can be recovered from the site until the crust separates from the skin. **Inadvertent inoculation** (i.e., transfer of vaccinia from the vaccination site to another part of the body) is the most frequent complication of smallpox vaccination and accounts for approximately half of all complications of primary vaccination and revaccination. Studies in 1968 estimated the rate of inadvertent inoculation to be 529 cases per million primary vaccinations. The most common sites involved are the face, eyelid, nose, mouth, genitalia, and rectum. Most lesions heal without specific treatment. Involvement of the eye may result in scarring of the cornea and significant impairment of vision.

A variety of **erythematous or urticarial rashes** can occur approximately 10 days after primary vaccination. The vaccinee is usually afebrile with this reaction, and the rash resolves spontaneously within 2–4 days. In rare instances, bullous erythema multiforme (Stevens-Johnson syndrome) occurs.

**Generalized vaccinia** is another type of rash following smallpox vaccination. This condition is believed to result from a vaccinia viremia with implantations in the skin in persons without eczema or other preexisting skin disease. It consists of vesicles or pustules appearing on normal skin distant from the vaccination site. Most rashes labeled as generalized vaccinia produce only minor illness with little residual damage. The rash is generally self limited and requires minor or no therapy except among patients whose conditions might be toxic or who have serious underlying immunosuppressive illnesses. In the 1968 studies, rashes diagnosed as generalized vaccinia occurred at a rate of 242 per million primary vaccinations.

Moderate and severe complications of vaccinia vaccination include eczema vaccinatum, progressive vaccinia, and postvaccinial encephalitis. These complications are rare but occur at least 10 times more often among primary vaccinees than among revaccinees and are more frequent among infants than among older children and adults. It is estimated that 14–52 persons per million primary vaccinations will experience potentially life-threatening adverse reactions.

**Myopericarditis** is the inflammation of heart muscle and/or the membrane that surrounds the heart. There were reports of this condition following smallpox vaccination in the 1950s and 1960s, but these cases were associated with vaccine strains not currently used. Myopericarditis was not an anticipated adverse reaction to the smallpox vaccine when the National Smallpox Vaccination Program began in

December 2002. During January–October 2003, 31 serious cardiac adverse events were reported among approximately 38,000 civilian recipients of smallpox vaccine (21 myopericarditis and 10 ischemic events).

**Eczema vaccinatum** is a localized or systemic dissemination of vaccinia virus in persons who have eczema or atopic dermatitis or a history of either of these conditions, or among contacts of vaccinees with eczema or atopic dermatitis or a history of these skin conditions. **Eczema vaccinatum can occur regardless of whether the skin disease is active or quiescent.** Usually the illness is mild and self limited, but it can be severe or fatal. The most serious cases among vaccine recipients occur among primary vaccinees. Severe cases have been observed after recently vaccinated persons have been in contact with persons who have active eczema or atopic dermatitis or a history of these skin conditions. In the 1968 studies, eczema vaccinatum was estimated to occur in 10–39 persons per million primary vaccinations.

**Progressive vaccinia**, also known as vaccinia necrosum, is a severe illness characterized by progressive necrosis in the area of vaccination, often with metastatic lesions. It occurs almost exclusively among persons with cellular immunodeficiency, but it can occur in persons with humoral immunodeficiency. In the 1968 studies, it occurred in approximately 1–2 persons per million primary vaccinations. Progressive vaccinia was almost always fatal before the introduction of vaccinia immune globulin and antiviral agents. Progressive vaccinia may be more common now, with human immunodeficiency virus (HIV) and post-transplant immunosuppression widely prevalent. Therapy includes aggressive treatment with vaccinia immune globulin and possibly antiviral drugs.

**Postvaccinial encephalitis** has been reported in 3–12 persons per million primary vaccinations. In the majority of cases, postvaccinial encephalitis affects primary vaccinees younger than 12 months of age or adolescents and adults receiving a primary vaccination. It presents with any of a variety of central nervous system signs, such as ataxia, confusion, paralysis, seizures, or coma. Most cases are believed to result from autoimmune or allergic reactions rather than direct viral invasion of the nervous system. Approximately 15%–25% percent of affected vaccinees with this complication die, and 25% develop permanent neurologic sequelae. There is no specific therapy for postvaccinial encephalitis.

**Fetal vaccinia** is a rare complication of smallpox vaccination. Fewer than 50 cases of fetal vaccinia infection have been reported, usually after primary vaccination of the mother in early pregnancy. Fetal vaccinia usually results in stillbirth or death of the infant soon after delivery. Smallpox vaccine is not known to cause congenital malformations.

## Eczema Vaccinatum

- Generalized spread of vaccinia on skin of patients with eczema or atopic dermatitis, or past history of eczema or atopic dermatitis
- Occurs in vaccinees and contacts
- Can occur whether eczema is active or quiescent
- May be severe or fatal

## Progressive Vaccinia

- Progressive necrosis at site of vaccination, often with metastatic lesions
- Occurs in patients with impaired immunologic function, particularly cellular immunodeficiency
- Frequently fatal

## Postvaccinial Encephalitis

- Highest risk among children <12 months of age and older persons receiving primary vaccination
- Believed to result from autoimmune or allergic reaction
- Frequently fatal or neurologic sequelae

## Fetal Vaccinia

- <50 fetal vaccinia cases reported in world literature
- Most result from primary vaccination of mother early in pregnancy
- Usually results in stillbirth or death of infant soon after delivery
- Congenital malformations not reported

**Death** resulting from smallpox vaccination is rare, with approximately one death per million primary vaccinations and one death per 4 million revaccinations. Death is most often the result of postvaccinial encephalitis or progressive vaccinia.

Guidelines for the evaluation and management of adverse reactions following smallpox vaccine were published in 2003 in the *Morbidity and Mortality Weekly Report* (MMWR). These guidelines are available on the CDC smallpox website at <http://www.bt.cdc.gov/agent/smallpox/>

## Contraindications and Precautions to Vaccination

As with all vaccines, smallpox vaccine is contraindicated for persons who have experienced a severe allergic reaction to a prior dose of vaccine or to a vaccine component. Calf lymph vaccine (Dryvax) contains trace amounts of polymyxin B, streptomycin, tetracycline, and neomycin. The diluent contains glycerin and phenol. The vaccine does not contain sulfa-type antibiotics or penicillin. The new cell-culture vaccines do not contain antibiotics.

Persons with significant **immunosuppression** or those who have an **immunosuppressed household contact** should not receive smallpox vaccine in a nonemergency situation. Replication of vaccinia virus can be enhanced among people with immunodeficiency diseases and immunosuppression. Significant immunosuppression can be caused by many diseases, including leukemia, lymphoma, or generalized malignancy; solid organ or stem cell transplantation; and cellular or humoral immunity disorders, including HIV infection. Some autoimmune conditions and/or drugs used to treat autoimmune conditions may cause significant immunosuppression. Therapies that can cause immunosuppression include alkylating agents, antimetabolites, radiation, or high-dose corticosteroid therapy. Many experts suggest that prednisone doses of 2 milligrams per kilogram of body weight per day or higher, or 20 milligrams per day or higher for 14 days or more be considered immunosuppressive for the purpose of live virus vaccination. As with other live vaccines, those receiving high levels of these drugs should not be immunized for 3 months after their last dose.

Persons with physician-diagnosed **heart disease** should not receive the smallpox vaccine. This recommendation is based on findings of cardiac symptoms such as chest pain, palpitations and shortness of breath that were first detected in late March 2003, and is further supported by the recognition of myopericarditis as an adverse reaction. In addition to physician-diagnosed heart disease, persons with three of the

### Smallpox Vaccine Contraindications and Precautions (Nonemergency Situations)

- Severe allergic reaction to a vaccine component or following a prior dose
- Immunosuppression in the recipient or household contact
- Physician-diagnosed heart disease or risk factors for heart disease
- Pregnancy in the recipient or household contact
- Breastfeeding

five heart disease **risk factors** (hypertension, hyperlipidemia, current smoker, diabetes or a first degree relative with a heart condition before the age of 50) are contraindicated from receiving the smallpox vaccine.

Live viral vaccines are contraindicated during **pregnancy**. For nonemergency indications, smallpox vaccine should not be administered to pregnant women or persons with a pregnant household contact. Pregnancy should also be avoided for at least 4 weeks after vaccination. Women who are breastfeeding should not be vaccinated because the close contact that occurs during this activity could increase the chance of transmission of the vaccine virus to the breastfeeding infant.

Because of the increased risk for eczema vaccinatum, smallpox vaccine should not be administered to persons with **eczema or atopic dermatitis or a past history of these conditions**. Persons who have a household contact with eczema or atopic dermatitis or a history of these conditions should also not be vaccinated.

Persons with other types of **acute, chronic, or exfoliative skin conditions** (e.g., burns, varicella, herpes zoster, impetigo, severe acne, or psoriasis) may be at increased risk of inadvertent inoculation. People with exfoliative skin conditions should not be vaccinated until the condition is controlled or resolves. In addition, persons with household contacts with acute, chronic, or exfoliative skin conditions should not be vaccinated until the skin condition in the household contact is controlled or resolves.

**Children younger than 12 months of age** should not be vaccinated. All vaccinated persons should take precautions to prevent virus transmission to young children and other household contacts. Since smallpox vaccine is currently recommended only for persons with occupational risk of exposure to vaccinia or recombinant vaccinia viruses, and for healthcare and public health response team members, vaccination is not indicated for infants or children younger than 18 years of age.

As with all vaccines, vaccination should be deferred for persons with **moderate or severe acute illnesses**.

In the event of an exposure to smallpox, there would be no contraindications to vaccination. In this situation, the benefit of vaccination would outweigh the risk of a complication from the vaccine. In a postrelease situation, contraindications and precautions for use of smallpox vaccine in a person who has not been exposed to smallpox would be the same as those in a nonemergency situation.

### **Smallpox Vaccine Contraindications and Precautions (Nonemergency Situations)**

- Eczema or atopic dermatitis (current or past history) in the recipient or household contact
- Acute, chronic, or exfoliative skin conditions (until improved or resolved) in the recipient or household contact
- Children <12 months of age
- Moderate or severe acute illness

### **Smallpox Vaccine Contraindications and Precautions Emergency (Postrelease) Situations**

- Exposed persons—no contraindications
- Unexposed persons—same as nonemergency situations

## **Vaccinia Immune Globulin Intravenous**

- Immunoglobulin fraction of plasma from persons vaccinated with vaccinia vaccine
- Effective for treatment of eczema vaccinatum, progressive vaccinia, severe generalized vaccinia, and ocular vaccinia
- Not effective in postvaccinal encephalitis

## **Vaccinia Immune Globulin Intravenous**

Vaccinia immune globulin intravenous (VIGIV) is the only product currently available for treatment of complications of vaccinia vaccination. VIGIV is a solvent/detergent-treated sterile solution of purified gamma globulin (IgG) fraction of human plasma containing antibodies to vaccinia virus. It is manufactured from plasma collected from healthy, screened donors with high titers of anti-vaccinia antibody. Each plasma donation used for the manufacture of VIGIV is tested for the presence of hepatitis B virus and antibodies to human immunodeficiency viruses 1 and 2 and hepatitis C virus.

VIGIV is indicated for treatment or modification of eczema vaccinatum, progressive vaccinia, and severe generalized vaccinia. It should also be used for vaccinia infections in persons who have skin conditions such as burns, impetigo, varicella zoster, or poison ivy; or for persons who have eczematous skin lesions when it is warranted because of either the activity or extensiveness of such lesions. It is also indicated for aberrant infections induced by vaccinia virus, which include its accidental implantation in eyes (except in cases of isolated keratitis), mouth, or other areas where vaccinia infection would constitute a special hazard. Since postvaccinal encephalitis is not due to virus multiplication, VIGIV is not likely to be effective in treating this adverse reaction. Immune globulin products have no role in the treatment of smallpox.

Supplies of VIGIV are stored in the Strategic National Stockpile. All releases of VIGIV from the stockpile must be approved by CDC.

## **Antiviral Drugs**

**Cidofovir** is an antiviral medication that is currently licensed for the treatment of retinitis. In vitro and animal studies with this drug have shown some activity against vaccinia virus, but it is unclear how well it would work in treating vaccinia infections in humans. Because it is not licensed for this indication, use of cidofovir for treating vaccinia infections should be done through an investigational new drug (IND) protocol with careful monitoring. Cidofovir is a second-line treatment for complications of smallpox vaccination. VIGIV is still considered the standard treatment. CDC is developing the investigative protocol for use of this drug.

## **Vaccine Storage and Handling**

Lyophilized smallpox vaccine is stable indefinitely at temperatures of  $-4^{\circ}\text{F}$  ( $-20^{\circ}\text{C}$ ) or less. Unreconstituted vaccine should be stored at refrigerator temperature  $35^{\circ}\text{--}40^{\circ}\text{F}$  ( $2^{\circ}\text{--}8^{\circ}\text{C}$ ). The vaccine should be used within 90 days of reconstitution. Because the vaccine vial must be opened in

## **Vaccine Storage and Handling**

- Stable indefinitely at  $-4^{\circ}\text{F}$  ( $-20^{\circ}\text{C}$ )
- Store unreconstituted vaccine at  $35\text{--}46^{\circ}\text{F}$  ( $2^{\circ}\text{--}8^{\circ}\text{C}$ )
- Reconstituted vaccine must be used within 90 days
- Avoid contamination after opening vial

order to prepare a dose for administration (i.e., the bifurcated needle is dipped into the vaccine), care must be taken to avoid contamination. A needle should never contact the vaccine in a vial more than once.

## Smallpox Preparedness and Response Planning

A smallpox response plan has been in place in the United States since the early 1970s. In 1999, efforts were begun to update the response plan in the context of an intentional release of smallpox virus as an act of terrorism. Following the anthrax attacks in 2001, the plan was revised further to provide detailed information on surveillance and response to a smallpox virus release.

The interim plan is intended to assist with local and state response planning by identifying actions that must be taken in the event of a suspected smallpox case. **The key elements of preparedness for smallpox response are surveillance and diagnosis to achieve early detection of an introduced case; isolation of the case or cases; and identification and vaccination of the contacts of the case-patient or patients.** Sections of the plan provide detailed information on these critical aspects of the plan, including surveillance and contact tracing, smallpox vaccine, isolation guidelines for both confirmed and suspected cases and febrile contacts of patients, specimen collection and transport, decontamination, and communication.

In December 2002, the President announced a plan to better protect the American people against the threat of smallpox attack. The Department of Health and Human Services will work with state and local governments to form volunteer Smallpox Response Teams, which can provide critical services in the event of a smallpox attack. To ensure that Smallpox Response Teams can mobilize immediately in an emergency, healthcare workers and other critical personnel may be asked to volunteer to receive the vaccine. The Department of Defense will also vaccinate certain military and civilian personnel who are or may be deployed in high-threat areas. Some U.S. personnel assigned to certain overseas embassies may also be offered vaccination. The plan does not include a recommendation for vaccination of the general public.

### Selected References

Casey CG, Iskander JK, Roper MH, et al. Adverse events associated with smallpox vaccination in the United States, January–October 2003. *JAMA* 2005;294:2734–43.

### Smallpox Response Plan

- **Key elements:**
  - surveillance and investigation of cases
  - contact tracing
  - isolation guidelines
  - specimen collection and handling
  - communications
  - decontamination

### Smallpox Response Teams

- Emergency, healthcare workers and other critical personnel may be asked to volunteer to receive the vaccine
- Department of Defense will also vaccinate certain personnel who are or may be deployed in high threat areas
- Some personnel assigned to certain overseas embassies may be offered vaccination
- Does not include a recommendation for vaccination of the general public

CDC. Vaccinia (smallpox) vaccine: recommendations of the Advisory Committee on Immunization Practices (ACIP). *MMWR* 2001;50(No. RR-10):1–25.

CDC. Notice to Readers: Supplemental recommendations on adverse events following smallpox vaccine in the preevent vaccination program: recommendations of the Advisory Committee on Immunization Practices. *MMWR* 2003;52:282–84.

Fenner F, Henderson DA, Arita I, et al. (eds). *Smallpox and its eradication*. Geneva: World Health Organization, 1988. Available at <http://www.who.int/emc/diseases/smallpox/Smallpoxeradication.htm>

Frey S, Couch RB, Tacket CO, et al. Clinical responses to undiluted and diluted smallpox vaccine. *N Engl J Med* 2002;346:1265–74.

Halsell, J, et al. Myopericarditis following smallpox vaccination among vaccinia-naïve U.S. military personnel, *JAMA* 2003;289:3283–9.

Henderson DA, Inglesby TV, Bartlett JG, et al. Smallpox as a biological weapon: medical and public health management. *JAMA* 1999;281:2127-37.

Henderson DA, Borio LL, Lane JM. Smallpox and vaccinia. In: Plotkin SA, Orenstein WA, eds. *Vaccines*. 4th ed. Philadelphia: Saunders;2003:123–153.

Lane JM, Ruben FL, Neff JM, Millar JD. Complications of smallpox vaccination, 1968: national surveillance in the United States. *N Engl J Med* 1969;281:1201–8.

Lane JM, Ruben FL, Neff JM, Millar JD. Complications of smallpox vaccination, 1968: results of ten statewide surveys. *J Infect Dis* 1970;122:303–39.

LeDuc JW, Jahrling PB. Strengthening national preparedness for smallpox: an update. *Emerg Infect Dis* 2001;7. Available at <http://www.cdc.gov/ncidod/eid/vol7no1/leduc.htm>

Mack TM. Smallpox in Europe, 1950–1971. *J Infect Dis* 1972;125:161–9.

Rosenthal SR, Merchlinsky M, Kleppinger C, Goldenthal KL. Developing new smallpox vaccines. *Emerg Infect Dis* 2001;7. Available at <http://www.cdc.gov/ncidod/eid/vol7no6/rosenthal.htm>

World Health Organization. Smallpox eradication: temporary retention of variola virus stocks. *Wkly Epidemiol Record* 2001;19:142–5.