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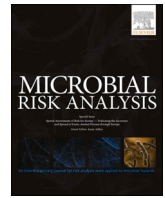
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## Risk of Monkeypox virus (MPXV) transmission through the handling and consumption of food

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### ABSTRACT

Monkeypox (MPX) is a zoonotic infectious disease caused by *Monkeypox virus* (MPXV), an enveloped DNA virus belonging to the *Poxviridae* family and the *Orthopoxvirus* genus. Since early May 2022, a growing number of human cases of Monkeypox have been reported in non-endemic countries, with no history of contact with animals imported from endemic and enzootic areas, or travel to an area where the virus usually circulated before May 2022. This qualitative risk assessment aimed to investigate the probability that MPXV transmission occurs through food during its handling and consumption. The risk assessment used “top-down” (based on epidemiological data) and “bottom-up” (following the agent through the food chain to assess the risk of foodborne transmission to human) approaches, which were combined. The “top-down” approach first concluded that bushmeat was the only food suspected as a source of contamination in recorded cases of MPXV, by contact or ingestion. The “bottom-up” approach then evaluated the chain of events required for a human to become ill after handling or consuming food. This approach involves several conditions: (i) the food must be contaminated with MPXV (naturally, by an infected handler or after contact with a contaminated surface); (ii) the food must contain viable virus when it reaches the handler or consumer; (iii) the person must be exposed to the virus and; (iv) the person must be infected after exposure. Throughout the risk assessment, some data gaps were identified and highlighted. The conclusions of the top-down and bottom-up approaches are consistent and suggest that the risk of transmission of MPXV through food is hypothetical and that such an occurrence was never reported. In case of contamination, cooking (e.g., 12 min at 70°C) could be considered effective in inactivating *Poxviridae* in foods. Recommendations for risk management are proposed. To our knowledge, this is the first risk assessment performed on foodborne transmission of MPXV.

### 1. Introduction

Monkeypox (MPX) is a zoonotic infectious disease caused by a *Monkeypox virus* (MPXV), an enveloped DNA virus belonging to the *Poxviridae* family (poxvirus) and the *Orthopoxvirus* genus. Since early May 2022, a growing number of cases of Monkeypox have been reported in non-endemic countries, outside Africa. In France, symptomatic

infections by this virus are subject to permanent surveillance through the mandatory reporting system. The first clinical case of Monkeypox in France was confirmed on 19 May 2022 in the Île-de-France region.

As of 17 August, 37,738 confirmed cases worldwide have been reported in 93 countries, including 12 deaths (World Health Organization, 2022). In France, as of 16 August 2022, 2,749 cases of Monkeypox have been confirmed. Out of the cases investigated by Santé publique France,

Abbreviations: CCID<sub>50</sub>, Cell Culture Infectious Dose<sub>50</sub>; PFU, Plaque-forming unit; TCID<sub>50</sub>, Tissue Culture Infectious Dose<sub>50</sub>.

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the French public health agency, 24% are secondary cases, *i.e.* previously identified and followed-up as at-risk contacts of biologically confirmed cases of Monkeypox (Santé publique France, 2022b). To date, in Europe, these cases have occurred without any history of contact with animals imported from endemic and enzootic areas, or travel to an area where the virus usually circulated before May 2022, and in the context of an outbreak with only human-to-human transmission.

Monkeypox is a localized or systemic disease, which may be associated with fever, headache, body aches, and asthenia. The characteristic vesicular rash may be present at the beginning, or appear after the general signs, or be isolated. The bullous lesions are mostly concentrated on the face, palms, and soles of the feet. The mucous membranes are also affected (mouth or anogenital region) (Cheema et al., 2022). These clinical features are important in the context of food contamination as the lesions are considered as infectious.

The incubation period of the disease is variable and estimated to be between 4 to 20 days (Miura et al. (2022) with 95% variability interval). The fever phase lasts about 1 to 3 days. The disease is usually mild and generally clears spontaneously after 2 to 3 weeks. Complications may occur as skin superinfection, keratitis in the case of ocular lesions, pulmonary, digestive, and neurological damage, and generalized infection, which can result in death, particularly in patients with severe comorbidities. A sick person is contagious as soon as symptoms appear and until the injured skin has completely healed. In 2020, Grant and co-authors pointed out that transmission in the absence of symptoms had not been documented (Grant et al., 2020), but some recent work may suggest this is possible (Adler et al., 2022; Hobson et al., 2021).

Poxviruses are characterized by a marked tissue tropism for skin and mucous membranes. MPXV can be transmitted directly, through the skin or mucosal contact with an infected individual, as well as through droplets contaminated by mucosal lesions (saliva, sneezes, sputum, kissing, etc.).

Another direct transmission route for MPXV is the respiratory route, which is also described for the *Variola virus* (VARV), the agent of smallpox, and other poxviruses (Diaz, 2021). There is a possible maternal-fetal-perinatal transmission with severe forms in the newborn (Mbala et al., 2017). MPXV can also be transmitted indirectly via the environment contaminated by the patient (bedding, clothing, crockery, bathroom linen, etc.) (Adler et al., 2022; Vaughan et al., 2020).

To prevent health risks associated with the transmission of MPXV in France, an emergency collective expert appraisal group was set up by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES). The aims of this work were first, to assess the risk of transmission of MPXV through food during handling and consumption, and, where appropriate, to issue recommendations about this risk.

## 2. Methods

This expert appraisal was carried out with the support of local French experts via an expert working group set up by the French Agency for Food, Environmental, and Occupational Health & Safety (ANSES). Two different approaches were used to assess the risk of transmission through the consumption of contaminated food. The first, the top-down approach is based on an analysis of epidemiological investigations conducted following zoonotic transmission. It aims to assess whether the food route is a potential route of transmission. The second, the bottom-up approach, aims at assessing the risk of foodborne transmission in the context of the 2022 multi-country outbreak.

### 2.1. Analysis of the literature for the top-down assessment

A top-down assessment was conducted, to evaluate the evidence of foodborne cases of Monkeypox (MPX) in humans. This assessment was based on two systematic reviews (Brown and Leggat 2016; Bunge et al. 2022) which respectively identified 2 and 14 publications on possible transmission through the consumption of contaminated food. After

checking the original publications 15 works were included. An additional literature search was also conducted on the PubMed database. The query paired the terms “monkeypox” or “monkey pox” with terms related to food or food transmission (*i.e.* bread, dairy products, eggs, fast foods, flour, fruit, meal, meat, raw foods, salads, vegetables, food, digestive tropism, gastrointestinal, intestine, digestive, feces, stool, fecal). This search was conducted on 10 June 2022 and identified 30 references. The references were exported to EndNote and were selected on the basis of the following inclusion criteria: a study on MPXV and a description of cases with suspicion or evidence of transmission through food, lesion, or replication in the digestive tract. Two publications were thus added, and two more by snowball search. In the end, nineteen publications were selected to list the cases where the role of contaminated food was suspected, and have been analyzed in Table 1.

### 2.2. Qualitative bottom-up assessment

A similar approach to that of EFSA in the bottom-up risk assessment of a zoonotic virus was applied (European Food Safety Authority, 2014). Fig. 1 summarizes the approach and the series of steps required for a single case of MPX to occur from food contaminated with MPXV.

The required chain of events involves many steps: (1) the raw meat from infected slaughtered animals must be naturally contaminated with MPXV while the raw food derived from non-animal sources and also raw meat from an uninfected animal must be contaminated by a food handler; (2) the food must contain viable virus when it reaches the consumer; (3) the person must be exposed to the virus (orally or by contact), and (4) the person must be infected after exposure. The different stages of this pathway are described below. It should be noted that all steps are necessary; if the answer to any of the questions in any of the steps is “no”, the probability of the MPX case occurring is zero.

This assessment was based on a bibliographical search on databases (including Scopus, PubMed), various keywords or combinations (such as “pox AND food”, “monkeypox AND bushmeat”, etc.), by the “snowball” method and by elements of the grey literature (reports, scientific communications, etc.).

The evaluation of the effect of temperature was based on literature research on a query of scientific bibliographical databases. The identified studies are provided in Table 2. Only some data were retained for modelling. The exclusion of some data was justified by the thermal inactivation condition, the strain used or the quality of the data.

The raw data from scientific publications (viral loads as a function of temperature) was collected from texts, tables, or figures into a numerical dataset. A manual collection of texts or tables was done. Figure data digitalization was performed for the raw data in figures according to the method described in Luong et al. (2022). An inactivation primary model was fitted on each kinetics to estimate the viral infectivity reduction parameter and its uncertainty. The decimal reduction times (D) (*i.e.* the time required at a specific temperature and under specified conditions for a 1 log<sub>10</sub> decrease of the microbial population) were adjusted for 36 kinetics over a temperature range of 30-65°C. The classical Bigelow model was fitted to the 36 D values. The parameters of this model were determined according to the method described in Guillier et al. (2020). Two parameters were determined, z<sub>T</sub> (the increase of temperature which leads to a 10-fold reduction of D) and log<sub>10</sub>(D<sub>ref</sub>) (the D values at a T<sub>ref</sub> of 70°C). The data of inactivation observed for MPXV were used to validate the model. All the data and models are available on a dedicated github repository (Guillier and Chaix, 2022).

The uncertainty analysis was carried out according to internal methodology (ANSES, 2017). It consists for each step of the risk assessment of identifying the sources of uncertainty and then to qualify the magnitude of impact on output (three classes “minor”, “high” or “unqualifiable”) and the direction (“over”, “underestimated” or “unqualifiable”).

**Table 1**  
List of outbreaks in which food consumption was suspected. All studies identified only bushmeat consumption.

Country	Year	Case details	Suspected exposure			Reference
			sick human	contact with wildlife	bushmeat consumption of bushmeat	
Singapore (contracted in Nigeria)	2019	Ingestion of barbecued bushmeat that could have been contaminated. The patient had not handled raw meat, had not been exposed to wild animals or their products, and had no history of contact with rodents or people with smallpox-like diseases.			x	(Yong et al., 2020)**
United Kingdom	2018	The case reported contact with a person with an MPX-like rash at a large family event as well as the consumption of bushmeat during a visit to a rural area in Nigeria.	x		x	(Vaughan et al., 2018)**
Nigeria	2017-2018	Of the 122 confirmed cases, 2 patients reported contact with an unspecified wild animal as well as bushmeat consumption.		x	x	(Yinka-Ogunleye et al., 2019)**
Democratic Republic of Congo	2017	22 cases with three distinct clusters (Eyelle, Dongou, and Impfondo). In the Impfondo district, the first case had prepared bushmeat. The other three were family members.		x	x	(Doshi et al., 2019)**
Democratic Republic of Congo	2017	Risk factors determined by a retrospective study of two population groups, following the analysis of questionnaires (n=39) The authors indicate that populations frequently reporting risk factors for MPX, such as hunting and butchering of bushmeat and frequent contact with wildlife, are at greater risk of sylvatic zoonoses than the general population (IgM antigenic comparison).		x	x	(Guagliardo et al., 2020)***
Liberia	2017	Suspected consumption: two cases of MPX, one confirmed and one suspected. The confirmed case was an 8-year-old boy. His mother (one suspect/primary case) was a farmer married to a hunter. There was no clear information that the mother had been exposed to bushmeat. The mother and her child had not traveled outside their area of residence.			x	(Larway et al., 2021)***
Nigeria	2017	A total of 172 suspected and 61 laboratory-confirmed cases were reported from 14 states in Nigeria. The authors state that MPX in Nigeria may be linked to a lack of food safety and hygiene, as most people who consume wild animal meat as a “delicacy” have little knowledge of the virus (especially of hygienic meat preparation methods).		x	x	(Okareh and Morakinyo, 2018)***
Sierra Leone	2017	The patient had been hunting and eating squirrels for about 10 days before falling ill.		x	x	(Ye et al., 2019)**
Central African Republic	2016	The index case was a hunter and breeder. The consumption of squirrel meat ( <i>Xerus erythropus</i> ) found dead in the forest could be the source of contamination.		x	x	(Kalthan et al., 2018)**
Democratic Republic of Congo	2014-2015	The index cases of the two outbreaks investigated had consumed bushmeat. The index cases had consumed river hog ( <i>Potamochoerus porcus</i> ) and duiker ( <i>Cephalophus</i> ) meat. For both species, MPXV DNA was detected in animals collected in the region.			x	(Laudisoit et al., 2016)
Sierra Leone	2014	1 case (child) with no contact with people with monkeypox-like illness or animals within two weeks prior to the illness onset. Parents reported the regular preparation and consumption of meat from wild animals. Another potential lead is small rodents that may be present in the home.		x	x	(Reynolds et al., 2019)**
Democratic Republic of Congo	2011-2012	Of the three cases, case 1 noted contact with bushmeat before the onset of the disease; case 2 handled monkeys killed by local hunters and stored and ate monkey meat for his trip.			x	(McCollum et al., 2014)**
Central African Republic	2010	Two cases with lesions developed after hunting and eating a wild rodent		x	x	(Berthet et al., 2011)**
Central African Republic	2001	The authors report an episode (2 cases) observed in a family a few days after eating a dead monkey			x	(Nakouné and Kazanji, 2012) *
Democratic Republic of Congo	2001	Source of infection identified in 4 cases could be a monkey found dead in the forest that was handled and eaten by concerned family members.		x	x	(Meyer et al., 2002) **, **
Central African Republic	1984	In a Pygmy community, 6 cases observed in two families: five children and a young woman. The head of the family had hunted a monkey with pustules on its body, and an antelope with the same type of lesions, whose flesh had been shared between the different families of the clan.		x	x	(Chastel and Charmot, 2004)***
Democratic Republic of Congo	1983	Five cases (two of which allegedly ate a monkey and a Gambian rat) and their respective families.			x	(Jezek et al., 1986) **
Zaire	1972 - 1985	Transmission through food is mentioned as the main source of infection. The authors state that one of the factors of infection is “the method of food preparation”. In the Bumba area, 107 human cases of MPX were recorded from 1972 to 1985, while no cases were reported in the entire western region (Bas-Zaïre). The eating habits in the Bumba and Ikela areas differ from those		x	x	(Khodakevich et al., 1988)***

(continued on next page)

Table 1 (continued)

Country	Year	Case details	Suspected exposure			Reference
			sick human	contact with wildlife	consumption of bushmeat	
		in Tshela. In the first one, rodents, which are caught by children from the age of 5-6 years, account for 60-85% of all wild animals caught by the rural population and are sometimes eaten without cooking. After the age of 9-10 years, children copy their parents and cook the meat. In Bas-Zaïre, on the other hand, children start hunting wild animals at the age of 12-13 and small mammals are relatively rare targets. In addition, the consumption of raw meat is unusual.				
Liberia	1970	No evidence of consumption, mention of a case of MPXV in a child (9 years old) who occasionally consumed monkeys.			x	(Foster et al., 1972)**
Sierra Leone	1970	No evidence of consumption, mention of one case of MPXV (24 years old) who occasionally consumed monkeys.			x	(Foster et al., 1972)**

\* Referenced by Brown and Leggat (2016)

\*\* Referenced by Bunge et al. (2022)

\*\*\* Referenced in this current work

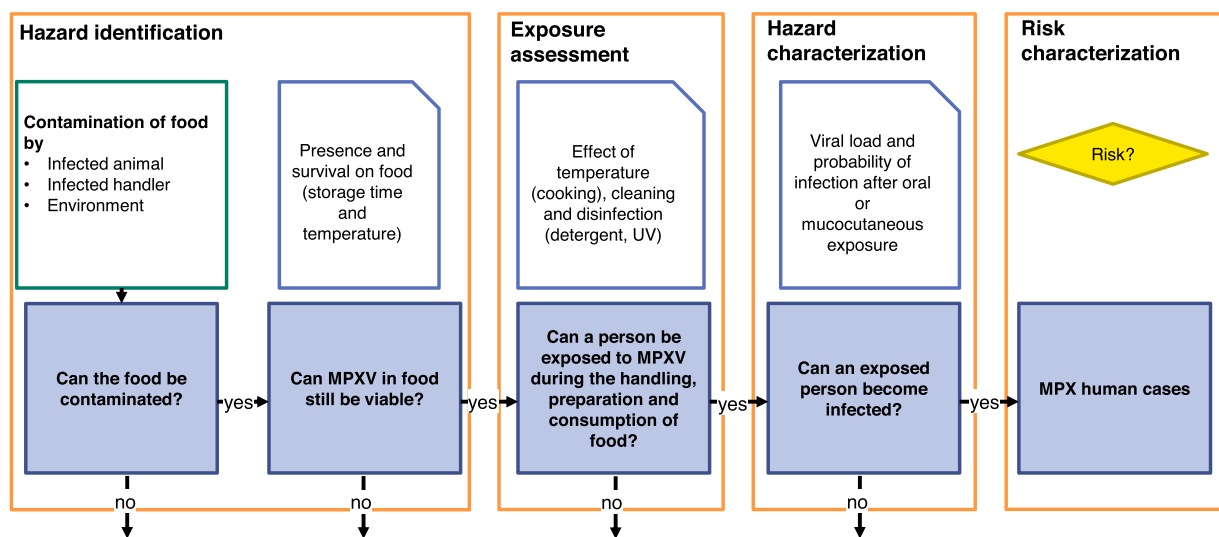


Fig. 1. Bottom-up risk assessment of MPXV transmission through handling or consumption of food.

### 3. Results and discussion

Two approaches were used to explore the possible foodborne aspect of *Monkeypox virus* transmission. Fig. 2 summarizes confirmed or possible transfer routes of MPXV, from wild animals to humans or from humans to humans. Our top-down and bottom-up approaches explore the possible food-borne transmission routes (highlighted in blue and orange, respectively).

#### 3.1. Top-down assessment: evidence of foodborne cases of *Monkeypox virus* (MPXV) infection in humans

Analysis of the MPXV cases has identified two sources of infection for humans: animal or human. MPXV cases are historically initiated from one or several animal sources and can be followed by human-to-human transmission (Bunge et al., 2022). In both situations, a primary source of contamination may be the contact or the ingestion of meat from an infected animal.

Contact with animal reservoir(s) and/or animal spillover hosts (some primates, sciurids, rodents, or other species), alive or dead, often during hunting and preparation of bushmeat as food, is a presumed mode of infection with MPXV (Durski et al., 2018; Silva et al., 2021). There is very little evidence linking the preparation or consumption of the food to the onset of the disease (Simpson et al., 2020) but several studies

suggest that contamination through ingestion of meat from infected animals is possible (Reynolds et al., 2019; Yong et al., 2020).

Table 1 lists cases or outbreaks where the role of contaminated food was suspected. From 1970 to June 2022, 20 outbreaks were identified with possible transmission through contaminated food. Analysis of these data shows that no food, other than bushmeat, has been identified or suspected to be associated with human cases of MPXV. In the majority of the studies listed, it is difficult to distinguish the origin of contamination, as people may be infected by handling dead animals (direct contact, cross contamination, or inhalation) and/or by eating undercooked meat.

None of these references provided robust information to support the possibility of proven foodborne transmission of MPXV, nor its presence in foods other than bushmeat (sometimes obtained from visibly sick animals). It can therefore be concluded that foods other than bushmeat have never been documented as being associated with human cases of *Monkeypox* in any of the reported outbreaks. However, ingestion of other types of potentially contaminated food cannot be totally excluded as an exposure route in natural infections, although this has never been directly confirmed.

**Table 2**  
Summary of literature data (used or not used) to establish the effectiveness of heat treatments on Poxviridae

Virus species	Temperature	Studied matrix	Inoculum	Exclusion Criteria	Refs.
<i>Buffalopox virus</i> (BPXV) (4 strains)	56°C	Chick chorioallantoic membrane (CAM)	> 10 <sup>7</sup> pfu/ml (from inactivation observed)	None	(Baxby and Hill, 1971)
<i>Capripoxvirus</i>	56, 60°C	Cell culture media – 10% FCS	From 10 <sup>5.1</sup> to 10 <sup>6.9</sup> CCID <sub>50</sub> /ml	No data retained: there is insufficient information for determining the values in the kinetics (only wide ranges are available)	(Wolf et al., 2020)
<i>Cowpox virus</i> (CPXV)	56°C	CAM	> 10 <sup>7</sup> pfu/ml (from inactivation observed)	None	(Baxby and Hill, 1971)
<i>Cowpox virus</i> (CPXV) - 2 strains	50°C	0.1 M McIlvaines buffer	1.5.10 <sup>7</sup> pfu/ml	None	(Elzein, 1983)
<i>Myxoma virus</i> (MYXV)	50; 55; 52.5; 53; 57.5 and 60°C	Normal rabbit serum	10 <sup>6.5</sup> TCID <sub>50</sub> /ml	None	(Bronson and Parker, 1943)
Rabbitpox virus	55°C	Liquid culture medium	>10 <sup>7</sup> pfu/ml (from inactivation observed)	Inclusion of only kinetics with the initial strain	(Fenner, 1962)
<i>Variola virus</i> (VARV)	40, 45, 50, 55 and 56°C	Liquid culture media (0.85% saline, Phosphate buffered saline, Heart infusion broth) and 10% skim milk CAM	>10 <sup>7</sup> pfu/ml (from inactivation observed)	Data at pH 4.6 were not included (to avoid including data influenced by pH, as all other studies were conducted under near-neutral conditions)	(Hahon and Kozikowski, 1961)
<i>Vaccinia virus</i> (VACV)	56°C	CAM	> 10 <sup>7</sup> pfu/ml (from inactivation observed)	None	(Baxby and Hill, 1971)
<i>Vaccinia virus</i> (VACV)	56°C	Liquid culture medium	10 <sup>10</sup> pfu/ml	Insufficient information for other temperatures (only equations are proposed for 40, 45, 50, and 55°C and not the raw data) Fowlpox data were not retained due to inconsistencies between the figure and the text of the table	(Chambers et al., 2009)
<i>Vaccinia virus</i> (VACV)	65°C	Human protein solution	10 <sup>5.8</sup> TCID <sub>50</sub> /ml	Study not retained (data with LOQ censoring)	(Lelie et al., 1987)
<i>Vaccinia virus</i> (VACV)	65°C	Milk	10 <sup>3</sup> and 10 <sup>5</sup> pfu/ml	None	(De Oliveira et al., 2010)
<i>Vaccinia virus</i> (VACV)	40, 75, 85 and 95°C	Dulbecco's modified Eagle's medium (DMEM)	10 <sup>7</sup> TCID <sub>50</sub> /ml	Study not retained (dry heat on surfaces)	(Sauerbrei and Wutzler, 2009)
<i>Vaccinia virus</i> (VACV)	50; 52.5; 55 and 60°C	McIlvaines phosphate and citrate buffer	5.10 <sup>7</sup> pfu/ml	None	(Kaplan, 1958)
<i>Yaba monkey tumor virus</i> (YMTV)	30, 33, 35, 37 and 40°C	Phosphate buffered saline	10 <sup>5</sup> pfu/ml	None	(Yohn et al., 1966)
<i>Monkeypox virus</i> (MPXV)	56, 60, 70 and 90°C	DMEM +5% FCS	3.5 10 <sup>7</sup> pfu/ml	Dataset used for validation of the model. Only data observed at 56, 60°C and 70°C can be used. The data at 95°C as the temperature were dynamics during the experiments (95°C not reached before the end of the treatment)	(Batejat et al., 2022)

### 3.2. Bottom-up assessment of the risk of Monkeypox virus transmission through food

The “bottom-up” approach follows the virus through the food chain to predict the risk to human health in relation to other agents and/or foods. The different steps summarized in Fig. 1 (hazard identification, exposure assessment, hazard characterization, risk characterization) are presented below. This approach requires much data that is not always available, and expert opinion is often used to fill in the missing data.

#### 3.2.1. Potential sources of food contamination with MPXV

The first step in hazard identification is the possibility of food contamination. Food produced in areas where MPXV is circulating (either in wildlife or in the human population, or both) could be contaminated in several ways: at the source (infected animal), from the environment, or by an operator processing or preparing food.

##### 3.2.1.1. Food produced from an infected animal

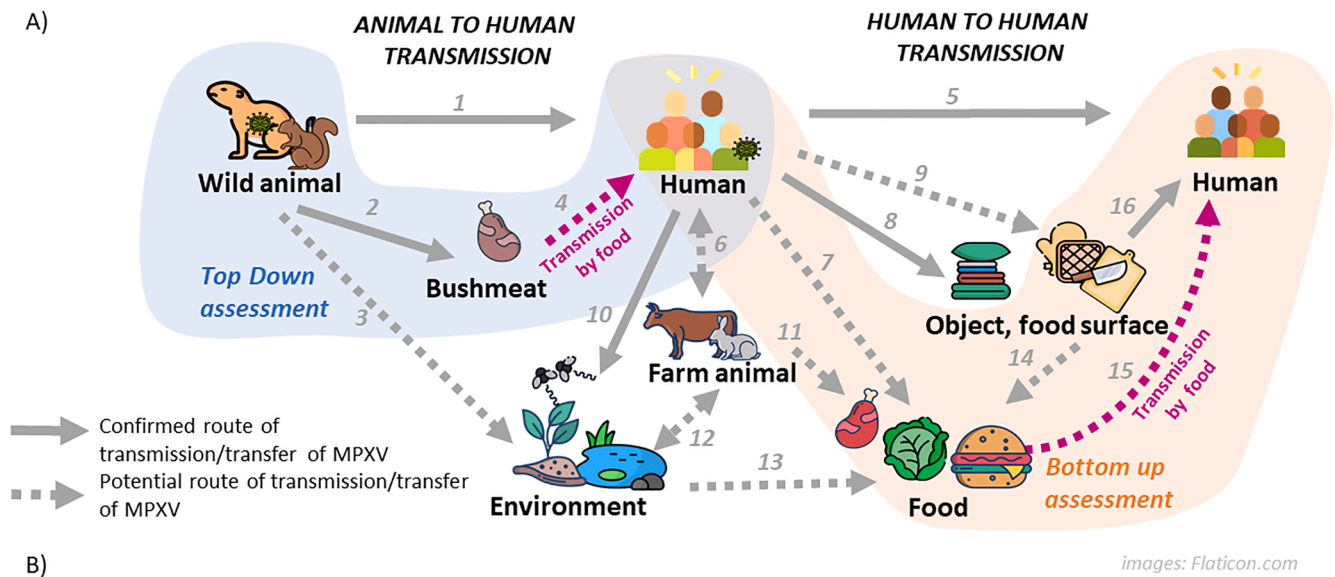
The analysis of the cases (Table 1) showed that some cases of MPXV could be attributed to exposure (by contact or ingestion) to meat from wild animals. It is therefore possible that MPXV could be present in the bushmeat. To illustrate, in France, bushmeat consumption is based on a deliberate or unintentional illegal introduction. Illegal imports of small

quantities by individuals may be for personal use, while larger quantities could be distributed by retailers or sold in markets for commercial purposes (Jansen et al., 2019). Border controls reduce the illegal inflow of food of animal origin into the EU, but cannot totally prevent it. Several studies have shown that among imported food of animal origin illegally imported, meat from animals that are potential reservoirs of zoonotic viruses was sometimes identified (Bair-Brake et al., 2014; Beutlich et al., 2015; Smith et al., 2012).

There are a limited number of suspected MPXV outbreaks to date in endemic and enzootic areas (despite the common consumption of bushmeat). For example, in France, the assumed consumption of bushmeat is low overall. Furthermore, the handling of bushmeat does not involve high-risk practices, such as hunting and butchering (Chastel and Charmot, 2004). The consumption of bushmeat involves preparation methods such as long cooking times. Based on this, the potential for introduction and transmission of MPXV through bushmeat in a country such as France is currently assumed to be very low. A better knowledge of the data associated with the importation of bushmeat (species involved, geographical origin and volume of bushmeat imported) could improve the estimation of this risk.

In the case of livestock, a limited study involved 120 small ruminants in an agroforestry setting where humans cases were present. The virus and/or anti-MPXV antibodies had been detected in humans and squirrels, with negative results in all small ruminants (Khodakevich et al.,





**Fig. 2.** A) Conceptual diagram of the *Monkeypox virus* transfer routes from animal to human and from human to human. To explore foodborne transmission, two assessment approaches were used: top-down assessment (blue), analyzing epidemiological data, and bottom-up assessment (orange), which explore the persistence of the virus along the food chain. B) Some examples of preventive measures according to different scenarios of MPXV contamination of foods is proposed (on the basis of the situation in France). \* The numbers in the column correspond to the arrows in Fig 2A.

1988).

For cattle, no information is available on infection under natural conditions according to Haddad (2022) and there are no experimental data on receptivity and susceptibility of ruminants to MPXV. Rabbits have been shown to be susceptible by cutaneous, subcutaneous and scarification routes, while recovering if they are adults, except in one study of albino rabbits, in which swelling occurred at the site of inoculation, followed seven days later by a rash with progression to death (Parker and Buller, 2013). Newborn rabbits are particularly susceptible to infection. However, no data on the infection of lagomorphs with MPXV under natural conditions are available.

In the absence of knowledge about transmission to livestock, it is recommended to apply preventive measures: sick humans should avoid contact with animals. If this is not possible, personal protective equipment is essential. Kitchen and table waste (peelings and other food scraps produced during meal preparation, and leftovers from plates after consumption) are considered by the regulation to be “category 3 animal by-products”, and therefore cannot be fed directly to animals without treatment (European Parliament, Council of the European Union 2009).

Based on current knowledge, the possibility of contamination of food of animal origin from an infected animal from France has been excluded.

### 3.2.1.2. Operator processing or preparing a food

In the context of this work, which concerns a virus actively circulating in human populations, one of the potential sources identified is the contamination of food by infected food handlers. It would then be possible for a human excreting MPXV involved in food processing or preparation to contaminate food with MPXV.

The risk of transmission would then depend on the stage of human disease in the infected food handler. Transmission is considered negligible before the onset of symptoms (Grant et al., 2020). Prolonged but low-level exposure could result in infection without visible clinical signs (Reynolds et al., 2010), and the virus may be transmitted by an asymptomatic person. Indeed, De Baetselier et al. (2022) in Belgium and Ferré et al. (2022) in France retrospectively analyzed 224 and 200 PCR samples, respectively, previously collected between May and July 2022 for gonorrhoea and chlamydia testing. MPXV DNA was found in 3/224 and 13/200 samples whose patients reported no symptoms at the time of collection. In the French study, only two initially asymptomatic patients presented symptoms after 7 and 9 days respectively, while in the Belgian study, all 224 patients remained asymptomatic at the date of follow-up clinical examination, performed 21 to 37 days after first examination

and sampling. Only the presence of MPXV DNA was tested in both studies, and further scientific investigations are needed to explore asymptomatic transmission.

In humans, the highest levels of viral shedding are found in vesicles and dry scabs, although the amount of virus excreted by sick people varies. During this outbreak, initial diagnostic information from recent French cases has shown Ct values between 20–32 (corresponding to  $10^{8.3}$  to  $10^{5.3}$  genome copies/ml or  $10^{6.6}$  to  $10^{3.6}$  PFU/ml), in skin lesion samples and in oral and nasopharyngeal samples (Personal communication from the French National Reference Center-Expert Laboratory for Orthopoxvirus, 2022). This information strongly supported shedding via the nasal and oropharyngeal routes.

In the crab-eating macaque, viral loads in blood increased rapidly during the course of the disease, from  $10^3$  to  $10^8$  genomes/g of tissue within 14 days (Jordan et al., 2009). Although viral loads in lesions were higher than in lesion-free skin, the latter still had high genome loads (Table 3). This was also found in goats infected with a *Capripoxvirus* (a different genus of virus in the *Poxviridae* family) (Bowden et al., 2008). In control macaques exposed to  $10^6$  and  $10^7$  PFU of MPXV intratracheally, viral loads in throat swabs increased rapidly, reaching peak levels on day 11, with loads of approximately  $10^3$  PFU/ml (Stittelaar et al., 2005).

Recently, the MPXV genome has been detected in the stools of patients (Antinori et al., 2022) which may suggest fecal shedding, even if the presence of viral DNA is not synonymous with the presence of viable virus. This hypothesis is strongly reinforced by Peiró-Mestres et al. (2022), who measured the viral DNA present in different secretions and excretions of 12 patients with MPX. Twenty-one of 23 rectal swabs samples (with Ct values ranging between 17.6 and 38.4), and 14 of 22 feces samples (17.8 to 31.4) were tested positive, without strict correlation in the same patient between the Ct of the two samples. Patrono et al. (2020) had already observed such fecal shedding of viral genome, but also viable virus, in chimpanzees in a situation of natural infection.

The 2022 outbreak also assumes transmission through intimate and sexual contact. Recent papers have even mentioned the presence of replicative MPXV in the semen of some patients (Lapa et al., 2022).

**Table 3**

Viral loads in tissues or secretions of animals infected with two different Poxviridae (MPXV and GTPV).

Species	Infecting strain exposure measures	Tissue / matrix	Tissue load	Refs.
Crab-eating macaque ( <i>Macaca fascicularis</i> )	MPXV - Zaire 79 Intravenous Dose: $5 \times 10^7$ PFU	Blood	$1.1 \times 10^4$ genomes/g tissue	(Jordan et al., 2009)
		Skin - Lesion	$1.4 \times 10^7$ genomes/g tissue	
	Dose: $10^6$ PFU	Skin - Normal	$1.5 \times 10^6$ genomes/g tissue	(Stittelaar et al., 2005)
		Throat swab	$< 3 \log_{10}$ PFU/ml	
	Dose: $10^7$ PFU		$\sim 3 \log_{10}$ PFU/ml	
Goat	<i>Capripoxvirus</i> (Indian GTPV) Intradermal Dose $10^{4.4}$ TCID <sub>50</sub> Measurements between 4 and 13 days after inoculation (control animals)	Skin - Normal	Between $2.7$ and $4.4 \log_{10}$ TCID <sub>50</sub> /g	(Bowden et al., 2008)
		Skin - Lesion (Macule)	$< 2.7 \log_{10}$ TCID <sub>50</sub> /g	
		Skin - Lesion (Papule)	Between $5.2$ and $> 7.2 \log_{10}$ TCID <sub>50</sub> /g	
		Nasal mucosa	Between $< 2.7$ and $3.2 \log_{10}$ TCID <sub>50</sub> /g	

Peiró-Mestres et al. (2022) also detected MPXV genome in 13/23 urine samples and 12/16 semen samples with ranges of Ct value between 19–20 to 40), which may suggest shedding in semen and urine. However, transmission through these fluids has not been established to date.

There is a lack of data on the viral loads shed by different tissues, and in view of the data in animals, there is uncertainty about shedding through the skin of a sick human without visible lesions. The lack of knowledge about the possible shedding of MPXV in pre- or post-symptomatic individuals, and the possible existence of excretion by asymptomatic cases, are also uncertainties to this analysis.

In conclusion, a sick food handler may contaminate food by contact with soiled hands (e.g. in the presence of lesions) or in the case of poor hygiene practices (e.g. oro- or nasopharyngeal excretion, fecal and urine excretion).

### 3.2.1.3. Environment

A study showed that MPXV genetic material could be found in the regurgitation/defecation products of flies that landed or fed on the feces of naturally infected chimpanzees (including one sample out of ten analyzed with infectious virus) (Patrono et al., 2020). The good hygiene practices usually in place (insect and pest control) are sufficient to avoid theoretical contamination of food from this source.

It is assumed that contamination of the environment (in the food industry, catering industry, or at home) can only occur through shedding by infected persons, especially through contact with lesions, scabs, and nasal or oropharyngeal secretions. In France, confirmed cases are advised to isolate themselves at home, and may be given time off work for a period of 3 weeks from the date of onset of clinical signs (Santé publique France, 2022a). This could potentially allow to avoid food contamination by infected handlers (by contact and/or droplets), which could concern in this context any category of foods, including raw food and foods that have already been heat treated.

### 3.2.2. Presence and survival of MPXV in food

However, no information is available on the potential of MPXV to survive on the surface or inside food. There are no quantitative data on the initial viral loads of MPXV that could be found in food. In 2003, supported by epidemiological analyses, the CDC assumed that MPXV could remain infectious in bushmeat (Food and Drug Administration & Centers for Disease Control and Prevention 2003).

Regarding storage conditions, MPXV remains stable under refrigerated conditions ( $4^\circ\text{C}$ ) in laboratory media. By extrapolation, MPXV could remain viable in contaminated food stored under refrigeration.

In the absence of data on the survival of MPXV in food, the survival of other viruses of the *Poxviridae* family was explored.

#### 3.2.2.1. Survival of other viruses of the Poxviridae family in food matrices

Data on several viruses of the *Poxviridae* family show that infectious viruses remain stable over long periods at refrigeration temperatures. Essbauer et al. (2007) characterized the survival of *Vaccinia virus* (VACV) and *Variola virus* (VARV) in several food matrices (bread, sausage, and salad). Both viruses showed stable infectivity over 166 days at  $4.5^\circ\text{C}$ . In milk, VACV remains stable after 48 h of storage at  $4^\circ\text{C}$  (De Oliveira et al., 2010). In cheeses, it was shown that this virus was partially inactivated during ripening, but infectious viruses were found in cheeses even after 60 days of ripening (Rehfeld et al., 2017). De Oliveira et al. (2010) showed that freezing did not affect the infectivity of the viruses (milk samples at  $-20^\circ\text{C}$ ). Data on *Sheeppox virus* (SPPV) and *Goatpox virus* (GTPV) show that they are stable under freezing conditions (ILSI Europe Expert Group on Animal-Borne Viruses, 2009).

Thus, some of the examples presented above suggest the presence and survival of poxviruses in foods after storage. The persistence of viruses depends on their location (surface or internal), initial viral load



and storage conditions (e.g. duration, temperature, or exposure to ultraviolet rays from the sun). In addition, upstream food preparation steps (e.g. peeling, rinsing) could also influence the amount of infectious viruses remained in the food or finished product.

In conclusion, the initial viral loads of MPXV that could be found in food are not known. Data on other viruses of the *Poxviridae* family show that they can remain infectious in several food matrices under refrigeration conditions (4°C).

### 3.2.3. Food exposure assessment

This step concerns the survival of MPXV during the preparation of dishes made with contaminated food, as well as exposure to MPXV (probability of finding infectious viruses, and their quantities, through food contact or food ingestion). This relates to the handling and preparation of food (both by consumers and by food handlers in kitchens immediately prior to consumption), but also to the consumption of contaminated food.

There are no data on MPXV to assess exposure. However, it is likely that the survival of the virus depends on how and for how long food is transported and stored, how it is handled, and how the food is prepared. With regard to the latter, adequate cooking should inactivate MPXV, the conditions of application (i.e. time/temperature) of which are presented below. However, good hygiene practices should also be applied to avoid recontamination after cooking (by a sick food handler). Conversely, MPXV could survive in products consumed without further cooking (i.e. leafy vegetables eaten raw). Certain practices, such as drying/dehydration, washing or peeling of fruits and vegetables, could also reduce the degree of exposure to MPXV. In addition, the risk of cross-contamination should be taken into account.

In the absence of data on MPXV, we reviewed the available data on the *Poxviridae* family.

#### 3.2.3.1. Heat treatment efficiency

Analysis of the scientific literature identified several studies quantifying the impact of temperature on the inactivation of *Poxviridae* (Table 2). The raw data from these studies were digitized and the decimal reduction values (D) (i.e. the time required to divide the infectious load by 10) were adjusted for 36 kinetics over a temperature range of 30-65°C. Fig. 3 shows the 36 values of log<sub>10</sub>(D) as a function of temperature. Fig. 4 shows the fit of the secondary decimal reduction time model (Bigelow model). It quantifies the impact of temperature on the D values. The best fit and 95% bootstrap confidence intervals of parameters were 0.009 [-0.317, 0.293] for log<sub>10</sub> D70 and 14.5 [11.7, 18.2] for z<sub>T</sub>. The model was validated using the observed MPXV inactivation

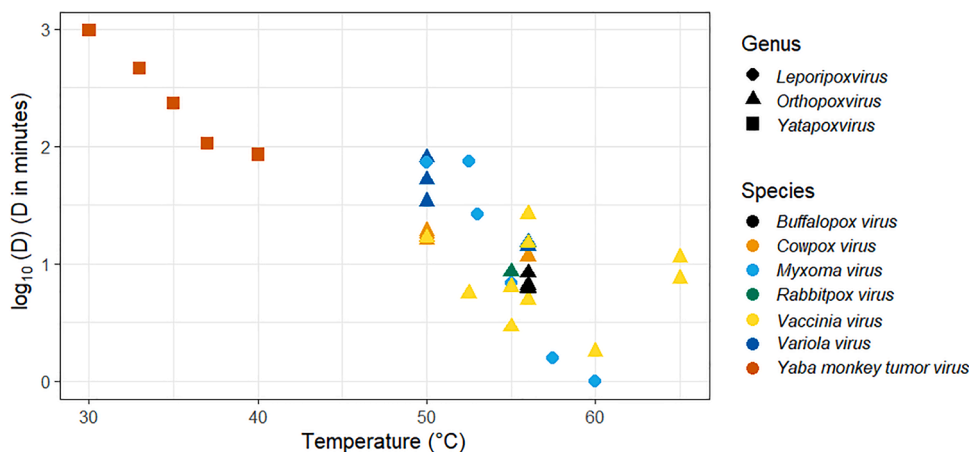


Fig. 3. Overview of data on decimal reduction time values (D) observed at different temperatures for three genera of viruses of the *Poxviridae* family. The associated studies are detailed in Table 2. Example of reading: for *Yatapoxvirus* (YMTV, pink square symbol), at a temperature of 40°C, a duration of about 2 log<sub>10</sub> min (i.e. 100 min) is required to reduce the infectious load of the virus by a factor of 10. The full dataset is accessible (Guillier and Chaix, 2022).

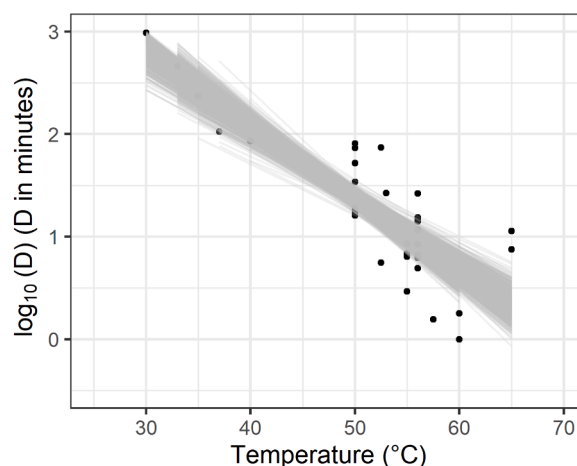


Fig. 4. Observed (dots) and fitted Bigelow model (grey lines corresponding to bootstrap resampling) values of decimal reduction time (logarithmic scale in minutes) as a function of temperature for viruses belonging to the *Poxviridae* family.

measured for two strains in two media and three time-temperature conditions recently published by Batéjat et al. (2022). The comparison between the predictions obtained with fitted parameter values and the observed inactivation is shown in Supplementary Figure 1. The model provides fail-safe predictions.

For a targeted performance criterion, i.e. a number of decimal reductions to be achieved, it is possible from the developed model to specify the time-temperature pair to be applied to achieve the target. Table 4 provides several examples of time-temperature pairs that achieve a 4-6 log<sub>10</sub> reduction in infectious viruses belonging to the *Poxviridae*. Cooking (i.e. 12 min at 70°C) could be considered effective in

Table 4

Time required (in minutes) at different temperatures to achieve decimal reduction targets of 4 to 6 log<sub>10</sub> in foods. Values were calculated from the fitted Bigelow secondary model. The upper value of the 95% bootstrap confidence interval was used for log<sub>10</sub> D70 (0.293) and the median z<sub>T</sub> (14.5°C).

Temperature	4 log <sub>10</sub>	5 log <sub>10</sub>	6 log <sub>10</sub>
50°C	188 min	235 min	282 min
65°C	17.4 min	21.7 min	26.1 min
70°C	7.9 min	9.8 min	11.8 min
80°C	1.6 min	2.0 min	2.4 min

inactivating *Poxviridae* (and by extension MPXV) in food. The Bigelow model, together with the above-mentioned values for its parameters, can be used to determine time and temperature conditions for other performance criteria. Thus, contaminated food that has not undergone sufficient heat treatment (temperature and duration) or that has been cooked but has not been protected against recontamination after cooking may be a source of exposure by oral or cutaneous routes.

### 3.2.3.2. Efficiency of other processes

Enveloped viruses are among the easiest to inactivate, as detergents damage their lipid envelope. *Poxviridae* are sensitive to common disinfectants (Kampf, 2022). Cleaning can be done with ordinary products, followed by disinfection with 1000 ppm available chlorine and, after removing the excess liquid, to let air dry. (European Centre for Disease Prevention and Control, 2022; Haut Conseil de la Santé Publique, 2022). This can be done by using a solution of sodium hypochlorite (NaClO), and for example, by diluting 1:25 household bleach (usually at an initial concentration of 2.6% in France). In its opinion of 24 May 2022, the French High Council for Public Health (Haut Conseil de la Santé Publique, HCSP) also specifies several recommendations concerning hand hygiene and cleaning procedures. For surfaces, standard household cleaners/disinfectants can be used in accordance with the manufacturer's instructions. Regarding utensils, it is specified that dishes and other kitchen utensils should not be shared. It is not necessary for the infected person to use dedicated utensils if they are properly washed, either in a dishwasher or by hand with warm water and detergent (Haut Conseil de la Santé Publique, 2022).

The usual measures for cleaning and disinfecting equipment and premises (especially hygiene rooms for staff) are effective against MPXV when the doses and action times required to achieve virucidal activity are applied.

Some materials in contact with sick people may be difficult to clean and disinfect (e.g. leather gloves for handling hot serving dishes), and are likely to be used by several people. These materials should not be used, and can be replaced by those that can be easily machine washed or soaked in disinfectant solutions (e.g. cloths, silicone potholders). Washing utensils and dishes in a dishwasher (> 60°C) and clothes in a washing machine (> 60°C) will eliminate the virus (Haut Conseil de la Santé Publique, 2022). It is worth mentioning in the context of dry-cleaning operation that viruses can show considerable thermal resistance after being dried on surfaces and exposed to dry heat (Sauerbrei and Wutzler, 2009).

UV has an effective virucidal action on viruses: it alters their genetic material. The UV dose required for 4-log removal of enveloped virus varies from 2 mJ/cm<sup>2</sup> to 60 mJ/cm<sup>2</sup> (Kong et al., 2021). UV treatment of clear liquids (or opaque liquids in turbulent flow) is particularly effective. For solid foods, the irregularity of the surface limits inactivation (Gómez-López et al., 2021). Regarding the effectiveness of UV, Orthopoxviruses are very sensitive to UV light (Centers for Disease Control and Prevention, 2022).

### 3.2.4. Hazard characterization and tropisms of MPXV

This step assesses the probability of a person becoming infected as a result of preparing or handling contaminated food or eating a meal prepared with such food.

The most susceptible populations, i.e., those with a higher-than-average probability of developing symptoms, or severe clinical forms of MPX after exposure to MPXV, are immunocompromised individuals, pregnant women, and young children (Doshi et al., 2019; Jezek et al., 1986; Santé publique France, 2022a). Children have more severe forms than adults (Huhn et al., 2005; Nakoune et al., 2017). This higher susceptibility of neonates and very young subjects is also found in animals experimentally infected with MPXV (Parker and Buller, 2013).

In the literature, the secondary attack rate (or the probability of transmitting MPXV to people living with an infected person) was

estimated in the order of 10%, with no indication of the exposure routes involved (Beer and Rao, 2019). This secondary attack rate might not be appropriate for the current outbreak as it concerns a different clade (clade I) for the majority of studies because the majority of studies focus on clade I (whereas the virus circulating in 2022 belongs to clade II). In addition, conditions of human-to-human exposure in the current outbreak (Northern countries involved, low density of people at home, urban zones, festive events bringing together many people, involvement of MSM with multiple sexual partners, absence of contact with wildlife, general health condition of the population, etc.) is very different from those that were present when and where this indicator was calculated.

Here, the oral route of exposure (the primary route of exposure in the case of contamination by food) will be considered. The mucocutaneous route of exposure will also be briefly considered, thus treating the food as an inert surface.

#### 3.2.4.1. Route of exposure through the digestive system

The digestive tropism of MPXV is not clearly established. Analysis of the literature shows that viable or replicating virus particles can be found in the digestive tract of sick humans or infected animals with or without clinical signs (Supplementary Table 1; Langohr et al., 2004; Müller et al., 1988; Patrono et al., 2020).

More generally, in patients, lesions may appear on the tissues of the digestive system. For example, Meyer et al. (2002) reported lesions in the mouths of three children (1, 8, and 9 years old) and one adult. In the context of the re-emergence of MPXV in 2017, oral ulcers are mentioned in about 36% of the 122 confirmed and probable cases notified in Nigeria between 2017 and 2018 (Yinka-Ogunleye et al., 2019). Patients mentioned specific symptoms of the digestive system, i.e. vomiting and nausea, in 21% of cases. In the 2003 US outbreak, among the 34 patients followed in the clinical study of Huhn et al., at least one third presented with gastrointestinal symptoms (Huhn et al., 2005). In France, during the current outbreak (May-July 2022), gastrointestinal symptoms were not particularly mentioned, but Thornhill et al. (2022) mentioned the existence of digestive manifestations associated with rectal lesions (61/528 patients).

Lesions in the digestive system are reported in experimental studies of MPXV inoculation in animals. A review of natural and experimental infections in animals between 1958 and 2012 was conducted by Parker and Buller (2013). Clinical signs related to the digestive system are mentioned after intravenous inoculation in rhesus macaques (*Macaca mulatta*). Lesions were found in various tissues of the digestive system, notably in the crab-eating macaque (*Macaca fascicularis*), in the stomach, intestine or liver, after exposure by aerosol, or in the stomach, small intestine, colon, rectum, and liver after subcutaneous exposure. In addition to this review, we identified additional experimental studies in rodents that also show lesions in the digestive system (Supplementary Table 2; Falendysz et al., 2017; Weiner et al., 2019).

A few experimental studies have also investigated the infection of animals with MPXV by the oral route (Table 5, from Hutson and Damon (2010)). Guinea pigs, golden hamsters, and adult rabbits did not show any apparent signs of disease. Newborn rabbits, white mice, and common squirrels developed signs of disease with up to 100% lethality.

When contaminated food is ingested and enters the gastrointestinal tract, the acidic pH of the stomach should inactivate MPXV. The effect of acidic conditions on the stability of MPXV was tested: a decrease of the order of 4 log<sub>10</sub> was reported in tissue cultures at pH 2 (<10<sup>1</sup> PFU/ml compared to 3.5x10<sup>5</sup> PFU/ml at pH 7) (Rouhandeh et al., 1967). The pH of the stomach may vary depending on the presence or absence of food intake. Food may nevertheless provide protection against the inactivation of the virus by gastric acids.

The evidence presented above suggests a possible spread of MPXV in the different organs of the digestive system in animals. It is not possible to characterize quantitatively the hazard of oral exposure to MPXV (lack of data such as the viral load excreted by sick people or the initial load

**Table 5**  
Experimental studies of MPXV inoculation into animals by the oral route (from [Hutson and Damon \(2010\)](#)).

Species	Exposure	Comment	Year	Refs.
Guinea pig	Strain: MPXV Copenhagen Unknown dose	Orally, guinea pigs, despite high doses of virus, showed no apparent signs of disease (lack of susceptibility).	1976	( <a href="#">Marennikova and Seluhina, 1976</a> )
Golden hamster	Strain: MPX Copenhagen Dose: 1.5 - 5.7x10 <sup>7</sup> PFU / 2 mL	Orally, golden hamsters, despite high doses of virus, showed no apparent signs of disease (lack of susceptibility).		
Rabbit	Strain: MPXV Copenhagen Dose: 1.4x10 <sup>9</sup> PFU / 2 mL	Adult rabbits showed no observable signs of disease after oral administration of MPXV (whereas acute disease and a generalized rash were observed intravenously). Ten-day-old rabbits infected with a virus dose of approximately 10 <sup>6</sup> -10 <sup>7</sup> PFU per ml developed an acute generalized illness with rash.		
White mice	Strain: MPXV Copenhagen Unknown dose	Twelve-day-old mice infected per os were ill and died in 14% of cases.		
Common squirrel	Strain: MPXV Z-249 Dose: 10 <sup>6</sup> PFU	Disease occurred earlier in animals infected orally or intranasally than in those infected by scarification. Infection was lethal in 100% of cases at 7-8 days after infection, regardless of the route of inoculation.	1989	( <a href="#">Marennikova et al., 1989</a> )

introduced in food or lack of knowledge of the dose-response relationship by the oral route). Data suggesting a digestive tropism of MPXV in humans are scarce; however, the possibility of oral transmission of MPXV cannot be excluded.

### 3.2.4.2. Exposure through mucocutaneous contact

Epidemiological observations show that objects contaminated by the patient (such as bedding, clothing, dishes, bath towels, etc.) can transmit indirectly MPXV ([Vaughan et al., 2020](#)). Given the elements presented above, contaminated food by a human shedding MPXV can be equated to a contaminated inanimate surface. This concerns in particular prepared food (raw or undercooked), or cooked food that may have been contaminated by an operator or a consumer who fails to comply with good hygiene practices.

ECDC recommends avoiding sharing any household items with others. If total isolation is not possible, then good hygiene practices should be rigorously applied: MPXV is able to survive on surfaces or other fomites for long periods (days to months) ([European Centre for Disease Prevention and Control, 2022](#)). At the current state of knowledge, there is insufficient data on contamination levels and on the infectivity decay rate in room conditions to provide precise recommendations.

The lack of data does not allow the characterization of the hazard by mucocutaneous exposure, in particular with regard to the viral load shed by sick people, the initial viral load on surfaces in contact with the sick persons (and in food in particular), or the dose-response by the cutaneous route. Outside the context of food preparation, these elements are essential to assess transmission indirectly, through inert surfaces.

### 3.2.5. Risk characterization

The purpose of this step is to estimate the probability of occurrence of at least one human case of MPX in France due to transmission of MPXV through contaminated food (other than bushmeat). The scope of the assessment was limited to the risk of transmission of MPXV to humans resulting from the handling and preparation (by consumers or food handlers immediately prior to consumption) and consumption of contaminated food for which cases of MPX have been confirmed.

The lack of data and knowledge at all stages of the bottom-up assessment leads to a very high degree of uncertainty. The sources of uncertainty are summarized in [Table 6](#). It is not possible to estimate the risk of foodborne transmission of MPXV through consumption of these foods, or even whether this mode of transmission can occur. However, there is no evidence to support the transmission of MPXV through food: in humans, no cases have been documented apart from suspicions linked to the consumption of bushmeat.

## 4. Conclusion

This risk assessment combines the “top-down” (the episode monitoring approach) and “bottom-up” (following the virus through the food chain to assess the risk to human health) approaches. The “top-down” approach first concluded that bushmeat was suspected as a source of MPXV in human cases of MPX. Food was never identified as being associated with human cases of MPX in any of the recorded cases.

The “bottom-up” approach then concluded that the chain of events required for a human case to become ill after handling or consuming food involves several conditions: i) the food must be contaminated with MPXV; ii) the food must contain viable virus when it reaches the handler or consumer; iii) the person must be exposed to the virus and; iv) the person must be infected after exposure. Each of these steps is necessary for a case of the disease to occur. The conclusions of the top-down and bottom-up approaches are consistent and suggest that the risk of transmission of MPXV through food (other than bushmeat) is still only hypothetical and that such an occurrence was never reported. Due to the lack of data and knowledge, which leads to a very high degree of uncertainty, it is not possible to quantify the risk of MPXV transmission from handling or eating contaminated food. New scientific facts, which will add to the knowledge about this virus, may change this uncertainty.

Isolation measures for confirmed human cases, as well as the application of good hygiene practices, could decrease the probability of the MPXV transmission through food. Cooking (e.g. 12 min at 70°C) could be considered effective in inactivating MPXV in food. Moreover, a few measures and the application of good hygiene practices can preventively limit contamination of food in food-production areas or at home (see summary in [Fig. 2](#)).

It should also be emphasized that good hygiene practices in the restaurant or food industry are also based on the health status of the operators. Anyone who is ill should be aware of the importance of not handling food if they have symptoms of gastroenteritis (diarrhea, fever, vomiting, headache) but also of any kind of infected skin lesions. In the current context of the MPX outbreak, raising awareness of symptoms and lesions suggestive of MPX among contact persons working in the catering and food industry could limit the initial contamination of the food.

If foodborne transmission of MPXV were to be confirmed in the future, the risk of becoming infected through handling or consumption of contaminated food would be considered higher if food were produced or consumed under conditions that increase the likelihood of

**Table 6**  
Analysis of sources of uncertainty in the steps of the bottom-up risk assessment of MPXV transmission through food.

Risk assessment phase	Sources of uncertainty	Choice made	Information available explaining the choice	Magnitude of impact on outcome (minor, strong or not quantifiable)	Direction (over/under estimated or not quantifiable)
Potential sources of food contamination	Transmission via a food vehicle is not proven but only suspected. The viral loads shed by a sick person are unknown. Unknown information on possible pre- or post-symptomatic shedding.	We considered that MPXV was potentially transmissible through food, despite the lack of evidence to this effect	Table 1 lists studies that suggest the possible foodborne transmission of MPXV (bushmeat animals)	Strong	Overestimation
Exposure assessment	Lack of specific data on the behavior of MPXV (on the new strain in particular) in food (under food storage or preparation conditions).	We explored data on other viruses belonging to the <i>Poxviridae</i> family	In microbiological risk assessment, it is usual to consider data from micro-organisms similar to the one being assessed (here only data from viruses from the same Genus, i.e. <i>Orthopoxvirus</i> , are considered)	Not quantifiable	Not quantifiable
Hazard characterization	No dose-response relationship available for MPXV in oral or mucocutaneous routes	As no dose-response is available, we focused on the potential exposure via food and the effect of mitigation strategies (preventive measures)	Experimental studies listed in section "Hazard characterization"	Strong	Not quantifiable
Risk characterization		We remained with a qualitative risk assessment	Impact of the other three components of the risk assessment	Strong	Overestimation

contamination (Fig. 2).

To conclude, the relationship between food consumption and MPXV transmission has never been demonstrated. The lack of data does not allow a quantitative assessment of the risk of foodborne transmission of MPXV. This expert appraisal showed the need to acquire data useful for assessing the risk of transmission of *Monkeypox virus*, in particular through food.

#### CRedit authorship contribution statement

**Estelle Chaix:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Visualization, Writing – review & editing, Supervision, Project administration. **Mickaël Boni:** Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Laurent Guillier:** Conceptualization, Methodology, Investigation, Formal analysis, Software, Writing – original draft, Visualization, Writing – review & editing. **Stéphane Bertagnoli:** Formal analysis, Writing – review & editing. **Alexandra Mailles:** Formal analysis, Writing – review & editing. **Catherine Collignon:** Formal analysis, Writing – review & editing. **Pauline Kooch:** Methodology, Formal analysis, Writing – review & editing. **Olivier Ferraris:** Formal analysis, Writing – review & editing. **Sandra Martin-Latil:** Formal analysis, Writing – review & editing. **Jean-Claude Manuguerra:** Formal analysis, Writing – review & editing. **Nadia Haddad:** Investigation, Formal analysis, Writing – original draft, Supervision, Writing – review & editing.

#### Declaration of Competing Interest

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#### Supplementary materials

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#### References

- Adler, H., Gould, S., Hine, P., Snell, L.B., Wong, W., Houlihan, C.F., Osborne, J.C., Rampling, T., Beadsworth, M.B.J., Duncan, C.J.A., Dunning, J., Fletcher, T.E., Hunter, E.R., Jacobs, M., Khoo, S.H., et al., 2022. Clinical features and management of human monkeypox: a retrospective observational study in the UK. *Lancet Infect. Dis.* 22 (8), 1153–1162. [https://doi.org/10.1016/S1473-3099\(22\)00228-6](https://doi.org/10.1016/S1473-3099(22)00228-6).
- ANSES, 2017. Illustrations et actualisation des recommandations pour l'évaluation du poids des preuves et l'analyse d'incertitude à l'Anses.
- Antinori, A., Mazzotta, V., Vita, S., Carletti, F., Tacconi, D., Lapini, L.E., D'Abramo, A., Cicalini, S., Lapa, D., Pittalis, S., Puro, V., Rivano Capparuccia, M., Giombini, E., Gruber, C.E.M., Garbuglia, A.R., et al., 2022. Epidemiological, clinical and virological characteristics of four cases of monkeypox support transmission through sexual contact, Italy, May 2022. *Eurosurveillance* 27 (22), 2200421. <https://doi.org/10.2807/1560-7917.ES.2022.27.22.2200421>.
- Bair-Brake, H., Bell, T., Higgins, A., Bailey, N., Duda, M., Shapiro, S., Eves, H., Marano, N., Galland, G., 2014. Is that a rodent in your luggage? A mixed method approach to describe bushmeat importation into the United States. *Zoonoses Public Health* 61 (2), 97–104. <https://doi.org/10.1111/zph.12050>.
- Batéjat, C., Grassin, Q., Feher, M., Hoinard, D., Vanhomwegen, J., Manuguerra, J.C., Leclercq, I., 2022. Heat inactivation of the Monkeypoxvirus - Preprint. *bioRxiv*. <https://doi.org/10.1101/2022.08.10.502482>, 2022.08.10.502482.
- Baxby, D., Hill, B., 1971. Characteristics of a new poxvirus isolated from Indian buffaloes. *Arch Gesamte Virusforsch* 35 (1), 70–79. <https://doi.org/10.1007/BF01249754>.
- Beer, E.M., Rao, V.B., 2019. A systematic review of the epidemiology of human monkeypox outbreaks and implications for outbreak strategy. *PLoS Negl. Trop. Dis.* 13 (10), e0007791. <https://doi.org/10.1371/journal.pntd.0007791>.
- Berthet, N., Nakouné, E., Whist, E., Selekon, B., Burguière, A.M., Manuguerra, J.C., Gessain, A., Kazanji, M., 2011. Maculopapular lesions in the Central African Republic. *Lancet* 378 (9799), 1354. [https://doi.org/10.1016/S0140-6736\(11\)61142-2](https://doi.org/10.1016/S0140-6736(11)61142-2).
- Beutlich, J., Hammerl, J.A., Appel, B., Nöckler, K., Helmuth, R., Jöst, K., Ludwig, M.-L., Hanke, C., Bechtold, D., Mayer-Scholl, A., 2015. Characterization of illegal food items and identification of foodborne pathogens brought into the European Union via two major German airports. *Int. J. Food Microbiol.* 209, 13–19. <https://doi.org/10.1016/j.ijfoodmicro.2014.10.017>.



- Bowden, T.R., Babluk, S.L., Parkyn, G.R., Copps, J.S., Boyle, D.B., 2008. Capripoxvirus tissue tropism and shedding: A quantitative study in experimentally infected sheep and goats. *Virology* 371 (2), 380–393. <https://doi.org/10.1016/j.virol.2007.10.002>.
- Bronson, L.H., Parker, R.F., 1943. The inactivation of the virus of infectious xymatosis by heat. *J. Bacteriol.* 45 (2), 177–181. <https://doi.org/10.1128/jb.45.2.177-181.1943>.
- Brown, Katy, Leggat, Peter, 2016. Human monkeypox: current state of knowledge and implications for the future. *Trop. Med. Infect. Dis.* 1 (1) <https://doi.org/10.3390/tropicalmed1010008>.
- Bunge, E.M., Hoet, B., Chen, L., Lienert, F., Weidenthaler, H., Baer, L.R., Steffen, R., 2022. The changing epidemiology of human monkeypox—A potential threat? A systematic review. *PLoS Negl. Trop. Dis.* 16 (2), e0010141 <https://doi.org/10.1371/journal.pntd.0010141>.
- Centers for Disease Control and Prevention, 2022. Disinfection of the Home and Non-Healthcare Settings.
- Chambers, A.E., Dixon, M.M., Harvey, S.P., 2009. Studies of the suitability of fowlpox as a decontamination and thermal stability simulant for variola major. *Int. J. Microbiol.* <https://doi.org/10.1155/2009/158749>, 2009.
- Chastel, C., Charmot, G., 2004. [Bacterial and viral epidemics of zoonotic origin; the role of hunting and cutting up wild animals]. *Bull. Soc. Pathol. Exot.* 97 (3), 207–212, 1990.
- Cheema, A.Y., Ogedegbe, O.J., Munir, M., Alugba, G., Ojo, T.K., 2022. Monkeypox: a review of clinical features. *Cureus* 14 (7), e26756. <https://doi.org/10.7759/cureus.26756>.
- De Baetselier, I., Van Dijk, C., Kenyon, C., Coppens, J., Michiels, J., de Block, T., Smet, H., Coppens, S., Vanroye, F., Bugert, J.J., Gird, P., Zange, S., Liesenborghs, L., Brosius, I., van Griensven, J., et al., 2022. Retrospective detection of asymptomatic monkeypox virus infections among male sexual health clinic attendees in Belgium. *Nat. Med.* <https://doi.org/10.1038/s41591-022-02004-w>.
- De Oliveira, T.M.L., Rehfeld, I.S., Siqueira, J.M.F., Abrahao, J.S., Campos, R.K., Dos Santos, A.K.R., Cerqueira, M.N.O., Kroon, E.G., Lobato, Z.I., 2010. Vaccinia virus is not inactivated after thermal treatment and cheese production using experimentally contaminated milk. *Foodborne Pathog. Dis.* 7 (12), 1491–1496. <https://doi.org/10.1089/fpd.2010.0597>.
- Diaz, J.H., 2021. The disease ecology, epidemiology, clinical manifestations, management, prevention, and control of increasing human infections with animal orthopoxviruses. *Wilderness Environ. Med.* 32 (4), 528–536. <https://doi.org/10.1016/j.wem.2021.08.003>.
- Doshi, R.H., Guagliardo, S.A.J., Doty, J.B., Babeaux, A.D., Matheny, A., Burgado, J., Townsend, M.B., Morgan, A.S., Satheshkumar, P.S., Ndakala, N., 2019. Epidemiologic and ecologic investigations of monkeypox, Likouala Department, Republic of the Congo, 2017. *Emerg. Infect. Dis.* 25 (2), 273. <https://doi.org/10.3201/eid2502.181222>.
- Durski, K.N., McCollum, A.M., Nakazawa, Y., Petersen, B.W., Reynolds, M.G., Briand, S., Djingarey, M.H., Olson, V., Damon, I.K., Khalakdina, A., 2018. Emergence of monkeypox in West Africa and Central Africa, 1970–2017/Emergence de l'orthopoxvirose simienne en Afrique de l'Ouest et en Afrique centrale, 1970–2017. *Wkly. Epidemiol. Rec.* 93, 125–132. <https://apps.who.int/iris/handle/10665/260499>.
- Elzein, E., 1983. Study of the thermal inactivation kinetics of the red cowpox virus and its white mutant. *Sudan J. Vet. Sci. Anim. Husband.* 4, 13–18. <http://sudanjvr.net/journal/1624.pdf>.
- Essbauer, S., Meyer, H., Porsch-Özürümec, M., Pfeffer, M., 2007. Long-lasting stability of vaccinia virus (Orthopoxvirus) in food and environmental samples. *Zoonoses Public Health* 54 (3–4), 118–124. <https://doi.org/10.1111/j.1863-2378.2007.01035.x>.
- European Centre for Disease Prevention and Control, 2022. Monkeypox multi-country outbreak –23 May 2022. Stockholm.
- European Food Safety Authority, 2014. An update on the risk of transmission of Ebola virus (EBOV) via the food chain. *EFSA J* 12 (11), 3884. <https://doi.org/10.2903/j.efsa.2014.3884>.
- European Parliament, Council of the European Union, 2009. Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation), in: European Parliament, Council of the European Union (Eds.).
- Falendysz, E.A., Lopera, J.G., Doty, J.B., Nakazawa, Y., Crill, C., Lorenzsonn, F., Kalemba, L.S.N., Ronderos, M.D., Mejia, A., Malekani, J.M., Kareem, K., Carroll, D.S., Osorio, J.E., Roche, T.E., 2017. Characterization of Monkeypox virus infection in African rope squirrels (*Funisciurus* sp.). *PLoS Negl. Trop. Dis.* 11 (8), e0005809 <https://doi.org/10.1371/journal.pntd.0005809>.
- Fenner, F.J., 1962. Interactions between pox viruses, *Proceedings of the Royal Society of London, Series B. Biological Sciences* 156 (964), 388–414. <https://doi.org/10.1098/rspb.1962.0047>.
- Ferré, V.M., Bachelard, A., Zaidi, M., Armand-Lefevre, L., Descamps, D., Charpentier, C., Ghosn, J., 2022. Detection of Monkeypox Virus in Anorectal Swabs From Asymptomatic Men Who Have Sex With Men in a Sexually Transmitted Infection Screening Program in Paris, France. *Ann Intern Med.* <https://doi.org/10.7326/m22-2183>.
- Food and Drug Administration & Centers for Disease Control and Prevention, 2003. Control of communicable diseases; restrictions on African rodents, prairie dogs, and certain other animals. Interim final rule; opportunity for public comment. *Fed. Regist.* 68 (213), 62353–62369.
- Foster, S.O., Brink, E.W., Hutchins, D.L., Pifer, J.M., Lourie, B., Moser, C.R., Cummings, E.C., Kuteyi, O.E., Eke, R.E., Titus, J.B., Smith, E.A., Hicks, J.W., Foege, W.H., 1972. Human monkeypox. *Bull. World Health Organ.* 46 (5), 569–576.
- Gómez-López, V.M., Jubinville, E., Rodríguez-López, M.I., Trudel-Ferland, M., Bouchard, S., Jean, J., 2021. Inactivation of Foodborne Viruses by UV Light: A Review. *Foods* 10 (12), 3141. <https://doi.org/10.3390/foods10123141>.
- Grant, R., Nguyen, L.L., Breban, R., 2020. Modelling human-to-human transmission of monkeypox. *Bull. World Health Organ.* 98 (9), 638–640. <https://doi.org/10.2471/blt.19.242347>.
- Guagliardo, S.A.J., Doshi, R.H., Reynolds, M.G., Dzabatou-Babeaux, A., Ndakala, N., Moses, C., McCollum, A.M., Petersen, B.W., 2020. Do monkeypox exposures vary by ethnicity? Comparison of Aka and Bantu suspected monkeypox cases. *Am. J. Trop. Med. Hyg.* 102 (1), 202–205. <https://doi.org/10.4269/ajtmh.19-0457>.
- Guillier, L., Chaix, E. Data and model for describing Poxviridae thermal inactivation, v 1; 2022. [https://github.com/guillier/pox\\_inactivation](https://github.com/guillier/pox_inactivation).
- Guillier, L., Martin-Latil, S., Chaix, E., Thébault, A., Pavo, N., Poder, S.L., Batéjat, C., Biot, F., Koch, L., Schaffner, D.W., Sana, M., 2020. Modeling the inactivation of viruses from the Coronaviridae family in response to temperature and relative humidity in suspensions or on surfaces. *Appl. Environ. Microbiol.* 86 (18) <https://doi.org/10.1128/AEM.01244-20>.
- Haddad, N., 2022. Les animaux hors d'Afrique peuvent-ils être concernés par la flambée de Monkeypox en cours, voire en devenir des acteurs importants. *Bull. Acad. Vet. Fr.* 175 <https://doi.org/10.3406/bavf.2022.70989>.
- Hahon, N., Kozikowski, E., 1961. Thermal inactivation studies with variola virus. *J. Bacteriol.* 81 (4), 609–613. <https://doi.org/10.1128/jb.81.4.609-613.1961>.
- Haut Conseil de la Santé Publique, 2022. Conduite à tenir autour d'un cas suspect, probable ou confirmé d'infection à Monkeypox virus.
- Hobson, G., Adamson, J., Adler, H., Firth, R., Gould, S., Houlihan, C., Johnson, C., Porter, D., Rampling, T., Ratcliffe, L., Russell, K., Shankar, A.G., Wingfield, T., 2021. Family cluster of three cases of monkeypox imported from Nigeria to the United Kingdom, May 2021. *Eurosurveillance* 26 (32). <https://doi.org/10.2807/1560-7917.ES.2021.26.32.2100745>.
- Huhn, G.D., Bauer, A.M., Yorita, K., Graham, M.B., Sejvar, J., Likos, A., Damon, I.K., Reynolds, M.G., Kuehnert, M.J., 2005. Clinical characteristics of human monkeypox, and risk factors for severe disease. *Clinical infectious diseases: an official publication of the Infectious Diseases Society of America*. (NY). 41 (12), 1742–1751. <https://doi.org/10.1086/498115>.
- Hutson, C.L., Damon, I.K., 2010. Monkeypox Virus Infections in Small Animal Models for Evaluation of Anti-Poxvirus Agents. *Viruses* 2 (12), 2763–2776. <https://doi.org/10.3390/v2122763>.
- ILSI Europe Expert Group on Animal-Borne Viruses, 2009. Animal-Borne Viruses of relevance to the food industry, ILSI Europe Report Series. p. 64.
- Jansen, W., Müller, A., Grabowski, N.T., Kehrenberg, C., Muylkens, B., Al Dahouk, S., 2019. Foodborne diseases do not respect borders: Zoonotic pathogens and antimicrobial resistant bacteria in food products of animal origin illegally imported into the European Union. *Vet J* 244, 75–82. <https://doi.org/10.1016/j.tvjl.2018.12.009>.
- Jezeq, Z., Arita, I., Mutombo, M., Dunn, C., Nakano, J.H., Szczeniowski, M., 1986. Four generations of probable person-to-person transmission of human monkeypox. *Am. J. Epidemiol.* 123 (6), 1004–1012. <https://doi.org/10.1093/oxfordjournals.aje.a114328>.
- Jordan, R., Goff, A., Frimm, A., Corrado, M.L., Hensley, L.E., Byrd, C.M., Mucker, E., Shamblin, J., Bolken, T.C., Wlazowski, C., Johnson, W., Chapman, J., Twenhafel, N., Tyavanagimatt, S., Amantana, A., et al., 2009. ST-246 antiviral efficacy in a nonhuman primate monkeypox model: determination of the minimal effective dose and human dose justification. *Antimicrob. Agents Chemother.* 53 (5), 1817–1822. <https://doi.org/10.1128/AAC.01596-08>.
- Kalthan, E., Tenguer, J., Ndjapou, S., Koyazengbe, T., Mbomba, J., Marada, R., Rombebe, P., Yangueme, P., Babamingui, M., Sambella, A., 2018. Investigation of an outbreak of monkeypox in an area occupied by armed groups, Central African Republic. *Med. Mal. Infect.* 48 (4), 263–268. <https://doi.org/10.1016/j.medmal.2018.02.010>.
- Kampf, G., 2022. Efficacy of biocidal agents and disinfectants against the monkeypox virus and other orthopoxviruses. *J. Hosp. Infect.* 127, 101–110. <https://doi.org/10.1016/j.jhin.2022.06.012>.
- Kaplan, C., 1958. The heat inactivation of vaccinia virus. *J. Gen. Microbiol.* 18 (1), 58–63. <https://doi.org/10.1099/00221287-18-1-58>.
- Khodakevich, L., Jezeq, Z., Messinger, D., 1988. Monkeypox virus: ecology and public health significance. *Bull. World Health Organ.* 66 (6), 747–752.
- Kong, J., Lu, Y., Ren, Y., Chen, Z., Chen, M., 2021. The virus removal in UV irradiation, ozonation and chlorination. *Water Cycle* 2, 23–31. <https://doi.org/10.1016/j.watcy.2021.05.001>.
- Langohr, I.M., Stevenson, G.W., Thacker, H.L., Regnery, R.L., 2004. Extensive lesions of monkeypox in a prairie dog (*Cynomys* sp.). *Vet. Pathol.* 41 (6), 702–707. <https://doi.org/10.1354/vp.41-6-702>.
- Lapa, D., Carletti, F., Mazzotta, V., Matusali, G., Pinnetti, C., Meschi, S., Gagliardini, R., Colavita, F., Mondì, A., Minosse, C., Scorzolini, L., Cicalini, S., Maffionelli, G., Specchiarello, E., Camici, M., et al., 2022. Monkeypox virus isolation from a semen sample collected in the early phase of infection in a patient with prolonged seminal viral shedding. *Lancet Infect. Dis.* [https://doi.org/10.1016/S1473-3099\(22\)00513-8](https://doi.org/10.1016/S1473-3099(22)00513-8).
- Larway, L.Z., Amo-Addae, M., Bulage, L., Adewuyi, P., Shannon, F., Wilson, W., Ilesanmi, O.S., Nagbe, T., Gebeh, S., 2021. An outbreak of Monkeypox in Doedain District, Rivercess County, Liberia, June, 2017. *J. Interv. Epidemiol. Public Health* 4. <https://doi.org/10.37432/jieph.2021.4.2.35>.



- Laudisoit, A., Komba, M., Akonda, I., 2016. Scientific report research bushmeat and monkeypox Yahuma health zone-Aketi health zone-Bombongolo health area. DRC. Lelie, P., Reesink, H., Lucas, C., 1987. Inactivation of 12 viruses by heating steps applied during manufacture of a hepatitis B vaccine. *J. Med. Virol.* 23 (3), 297–301. <https://doi.org/10.1002/jmv.1890230313>.
- Luong, N.-D.M., Guillier, L., Martin-Latit, S., Batejat, C., Leclercq, I., Druenes, C., Sanaa, M., Chaix, E., 2022. Database of SARS-CoV-2 and coronaviruses kinetics relevant for assessing persistence in food processing plants. *Scientific Data* Accepted for publication.
- Marennikova, S.S., Seluhina, E.M., 1976. Susceptibility of some rodent species to monkeypox virus, and course of the infection. *Bull. World Health Organ.* 53 (1), 13–20.
- Marennikova, S.S., Shelukhina, E.M., Zhukova, O.A., 1989. Experimental infection of squirrels *Sciurus vulgaris* by monkey pox virus. *Acta Virol.* 33 (4), 399.
- Mbala, P.K., Huggins, J.W., Riu-Rovira, T., Ahuka, S.M., Mulembakani, P., Rimoin, A.W., Martin, J.W., Muyembe, J.J.T., 2017. Maternal and fetal outcomes among pregnant women with human Monkeypox infection in the Democratic Republic of Congo. *J. Infect. Dis.* 216 (7), 824–828. <https://doi.org/10.1093/infdis/jix260>.
- McCollum, A., Nakazawa, Y., Ndongala, G.M., Pukuta, E., Karhemere, S., Lushima, R.S., Ilunga, B.K., Kabamba, J., Li, Y., Damon, I., 2014. Human monkeypox in the Kivus, a conflict region of The Democratic Republic of the Congo. *Int. J. Infect. Dis.* 21, 192. <https://doi.org/10.4269/ajtmh.15-0095>.
- Meyer, H., Perrichot, M., Stemmler, M., Emmerich, P., Schmitz, H., Varaine, F., Shungu, R., Tshioko, F., Formenty, P., 2002. Outbreaks of disease suspected of being due to human monkeypox virus infection in the Democratic Republic of Congo in 2001. *J. Clin. Microbiol.* 40 (8), 2919–2921. <https://doi.org/10.1128/JCM.40.8.2919-2921.2002>.
- Miura, F., van Ewijk, C.E., Backer, J.A., Xiridou, M., Franz, E., Op de Coul, E., Brandwagt, D., van Cleef, B., van Rijckevorsel, G., Swaan, C., van den Hof, S., Wallinga, J., 2022. Estimated incubation period for monkeypox cases confirmed in the Netherlands, May 2022. *Eurosurveillance* 27 (24), 2200448. <https://doi.org/10.2807/1560-7917.ES.2022.27.24.2200448>.
- Müller, G., Meyer, A., Gras, F., Emmerich, P., Kolakowski, T., Esposito, J.J., 1988. Monkeypox virus in liver and spleen of child in Gabon. *Lancet N. Am. Ed.* 331 (8588), 769–770. [https://doi.org/10.1016/S0140-6736\(88\)91580-2](https://doi.org/10.1016/S0140-6736(88)91580-2).
- Nakouné, E., Kazanji, M., 2012. Monkeypox detection in maculopapular lesions in two young Pygmies in the Central African Republic. *Int. J. Infect. Dis.* 16, e266–e267. <https://doi.org/10.1016/j.ijid.2012.05.916>.
- Nakoune, E., Lampaert, E., Ndjapou, S.G., Janssens, C., Zuniga, I., Van Herp, M., Fongbia, J.P., Koyazegbe, T.D., Selekon, B., Komoyo, G.F., Garba-Ouangole, S.M., Manengu, C., Manuguerra, J.C., Kazanji, M., Gessain, A., et al., 2017. A Nosocomial Outbreak of Human Monkeypox in the Central African Republic. *Open Forum Infect Dis* 4 (4), ofx168. <https://doi.org/10.1093/ofid/ofx168>.
- Okareh, O., Morakinyo, O., 2018. Monkeypox in Nigeria: a case report of re-emerged disease outbreak. *J. Microbiol. Exp.* 6 (2) <https://doi.org/10.15406/jmen.2018.06.00193>.
- Parker, S., Buller, R.M., 2013. A review of experimental and natural infections of animals with monkeypox virus between 1958 and 2012. *Futur. Virol.* 8 (2), 129–157. <https://doi.org/10.2217/fvl.12.130>.
- Patrono, L.V., Pléh, K., Samuni, L., Ulrich, M., Röhemeier, C., Sachse, A.D., Muschter, S., Nitsche, A., Couacy-Hymann, E., Boesch, C., Wittig, R.M., Calvignac-Spencer, S., Leendertz, F.H., 2020. Monkeypox virus emergence in wild chimpanzees reveals distinct clinical outcomes and viral diversity. *Nat. Microbiol.* 5 (7), 955–965. <https://doi.org/10.1038/s41564-020-0706-0>.
- Peiró-Mestres, A., Fuertes, I., Camprubí-Ferrer, D., Marcos, M.Á., Vilella, A., Navarro, M., Rodríguez-Elena, L., Riera, J., Català, A., Martínez, M.J., Blanco, J.L., Group, o.b.o.t. H.C.d.B.M.S., 2022. Frequent detection of monkeypox virus DNA in saliva, semen, and other clinical samples from 12 patients, Barcelona, Spain, May to June 2022. *Eurosurveillance* 27 (28), 2200503. <https://doi.org/10.2807/1560-7917.ES.2022.27.28.2200503>.
- Personal communication from the French National Reference Center-Expert Laboratory for Orthopoxvirus, 2022. French National Reference Center data on levels of viral shedding found in vesicles and dry scabs of French first cases.
- Rehfeld, I.S., Fraiha, A.L.S., Matos, A.C.D., Guedes, M.I.M., Costa, E.A., de Souza, M.R., Cavalcante, L.F., Lobato, Z.I., 2017. Survival of Vaccinia virus in inoculated cheeses during 60-day ripening. *J. Dairy Sci.* 100 (9), 7051–7054. <https://doi.org/10.3168/jds.2017-12560>.
- Reynolds, M.G., Carroll, D.S., Olson, V.A., Hughes, C., Galley, J., Likos, A., Montgomery, J.M., Suu-Ire, R., Kwasi, M.O., Jeffrey Root, J., Braden, Z., Abel, J., Clemmons, C., Regnery, R., Karem, K., et al., 2010. A silent enzootic of an orthopoxvirus in Ghana, West Africa: evidence for multi-species involvement in the absence of widespread human disease. *Am. J. Trop. Med. Hyg.* 82 (4), 746–754. <https://doi.org/10.4269/ajtmh.2010.09-0716>.
- Reynolds, M.G., Wauquier, N., Li, Y., Satheshkumar, P.S., Kanneh, L.D., Monroe, B., Maikere, J., Saffa, G., Gonzalez, J.P., Fair, J., 2019. Human monkeypox in Sierra Leone after 44-year absence of reported cases. *Emerg. Infect. Dis.* 25 (5), 1023. <https://doi.org/10.3201/eid2505.180832>.
- Rouhandeh, H., Engler, R., Taher, M., Fouad, A., Sells, L., 1967. Properties of monkey pox virus. *Arch Gesamte Virusforsch* 20 (3), 363–373. <https://doi.org/10.1007/BF01241954>.
- Santé publique France, 2022a. Cas de Monkeypox en Europe, définitions et conduite à tenir - 08. SpF. Juillet 2022.
- Santé publique France, 2022b. Cas de variole du singe: point de situation au 16 août 2022. <https://www.santepubliquefrance.fr/les-actualites/2022/cas-de-variole-du-singe-point-de-situation-au-16-aout-2022>. (Accessed 18 August 2022).
- Sauerbrei, A., Wutzler, P., 2009. Testing thermal resistance of viruses. *Arch. Virol* 154 (1), 115–119. <https://doi.org/10.1007/s00705-008-0264-x>.
- Silva, N.I.O., de Oliveira, J.S., Kroon, E.G., Trindade, G.d.S., Drumond, B.P., 2021. Here, There, and Everywhere: The Wide Host Range and Geographic Distribution of Zoonotic Orthopoxviruses. *Viruses* 13 (1), 43. <https://doi.org/10.3390/v13010043>.
- Simpson, K., Heymann, D., Brown, C.S., Edmunds, W.J., Elsgaard, J., Fine, P., Hochrein, H., Hoff, N.A., Green, A., Ihekweazu, C., Jones, T.C., Lule, S., MacLennan, J., McCollum, A., Muhlemann, B., et al., 2020. Human monkeypox - After 40 years, an unintended consequence of smallpox eradication. *Vaccine* 38 (33), 5077–5081. <https://doi.org/10.1016/j.vaccine.2020.04.062>.
- Smith, K.M., Anthony, S.J., Switzer, W.M., Epstein, J.H., Seimon, T., Jia, H., Sanchez, M. D., Huynh, T.T., Galland, G.G., Shapiro, S.E., 2012. Zoonotic viruses associated with illegally imported wildlife products. *PLoS One* 7 (1), e29505. <https://doi.org/10.1371/journal.pone.0029505>.
- Stittelaar, K.J., Amerongen, G.v., Kondova, I., Kuiken, T., Lavieren, R.F.v., Pistoro, F.H. M., Niesters, H.G.M., Doornum, G.v., Zeijst, B.A.M.V.D., Mateo, L., Chaplin, P.J., Osterhaus, A.D.M.E., 2005. Modified vaccinia virus Ankara protects Macaques against respiratory challenge with Monkeypox Virus. *J. Virol.* 79 (12), 7845–7851. <https://doi.org/10.1128/JVI.79.12.7845-7851.2005>.
- Thornhill, J.P., Barkati, S., Walmsley, S., Rockstroh, J., Antinori, A., Harrison, L.B., Palich, R., Nori, A., Reeves, I., Habibi, M.S., 2022. Monkeypox virus infection in humans across 16 countries—April–June 2022. *N. Engl. J. Med.* <https://doi.org/10.1056/NEJMoa2207323>.
- Vaughan, A., Aarons, E., Astbury, J., Balasegaram, S., Beadsworth, M., Beck, C.R., Chand, M., O'Connor, C., Dunning, J., Ghebrehewet, S., Harper, N., Howlett-Shipley, R., Ihekweazu, C., Jacobs, M., Kaindama, L., et al., 2018. Two cases of monkeypox imported to the United Kingdom, September 2018. *Euro surveillance: bulletin European sur les maladies transmissibles = Eur. Commun. Dis. Bull.* 23 (38) <https://doi.org/10.2807/1560-7917.ES.2018.23.38.1800509>.
- Vaughan, A., Aarons, E., Astbury, J., Brooks, T., Chand, M., Flegg, P., Hardman, A., Harper, N., Jarvis, R., Mawdsley, S., 2020. Human-to-human transmission of monkeypox virus, United Kingdom, October 2018. *Emerg. Infect. Dis.* 26 (4), 782. <https://doi.org/10.3201/eid2604.191164>.
- Weiner, Z.P., Salzer, J.S., LeMasters, E., Ellison, J.A., Kondas, A.V., Morgan, C.N., Doty, J.B., Martin, B.E., Satheshkumar, P.S., Olson, V.A., Hutson, C.L., 2019. Characterization of Monkeypox virus dissemination in the black-tailed prairie dog (*Cynomys ludovicianus*) through *in vivo* bioluminescent imaging. *PLoS One* 14 (9), e0222612. <https://doi.org/10.1371/journal.pone.0222612>.
- Wolff, J., Beer, M., Hoffmann, B., 2020. Thermal Inactivation of Different Capripox Virus Isolates. *Microorganisms* 8(12), 2053, doi: 10.3390/microorganisms8122053.
- World Health Organization, 2022. 2022 Monkeypox Outbreak: Global Trends. [https://worldhealthorg.shinyapps.io/mpx\\_global/](https://worldhealthorg.shinyapps.io/mpx_global/). (Accessed 18 August 2022).
- Ye, F., Song, J., Zhao, L., Zhang, Y., Xia, L., Zhu, L., Kamara, I.L., Ren, J., Wang, W., Tian, H., Wu, G., Tan, W., 2019. Molecular evidence of human Monkeypox virus infection. *Emerg. Infect. Dis.* 25 (6), 1220–1222. <https://doi.org/10.3201/eid2506.180296>.
- Yinka-Ogunleye, A., Aruna, O., Dalhat, M., Ogoina, D., McCollum, A., Disu, Y., Mamadu, I., Akinpelu, A., Ahmad, A., Burja, J., 2019. Outbreak of human monkeypox in Nigeria in 2017–18: a clinical and epidemiological report. *Lancet Infect. Dis.* 19 (8), 872–879. [https://doi.org/10.1016/S1473-3099\(19\)30294-4](https://doi.org/10.1016/S1473-3099(19)30294-4).
- Yohn, D.S., Haendiges, V.A., Grace Jr, J.T., 1966. Yaba Tumor Poxvirus Synthesis *In Vitro* I. Cytopathological, Histochemical, and Immunofluorescent Studies. *J. Bacteriol.* 91 (5), 1977–1985. <https://doi.org/10.1128/jb.91.5.1977-1985.1966>.
- Yong, S.E.F., Ng, O.T., Ho, Z.J.M., Mak, T.M., Marimuthu, K., Vasoo, S., Yeo, T.W., Ng, Y. K., Cui, L., Ferdous, Z., 2020. Imported Monkeypox, Singapore. *Emerg. Infect. Dis.* 26 (8), 1826. <https://doi.org/10.3201/eid2608.191387>.