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Risk-based surveillance for meat-borne parasites

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ABSTRACT

There is a plethora of meat-borne hazards – including parasites - for which there may be a need for surveillance. However, veterinary services worldwide need to decide how to use their scarce resources and prioritise among the perceived hazards. Moreover, to remain competitive, food business operators – irrespective of whether they are farmers or abattoir operators - are preoccupied with maintaining a profit and minimizing costs. Still, customers and trade partners expect that meat products placed on the market are safe to consume and should not bear any risks of causing disease.

Risk-based surveillance systems may offer a solution to this challenge by applying risk analysis principles; first to set priorities, and secondly to allocate resources effectively and efficiently. The latter is done through a focus on the cost-effectiveness ratio in sampling and prioritisation. Risk-based surveillance was originally introduced into veterinary public health in 2006. Since then, experience has been gathered, and the methodology has been further developed. Guidelines and tools have been developed, which can be used to set up appropriate surveillance programmes. In this paper, the basic principles are described, and by use of a surveillance design tool called SURVTOOLS (https://survtools.org/), examples are given covering three meat-borne parasites for which risk-based surveillance is 1) either in place in the European Union (EU) (*Trichinella* spp.), 2) to be officially implemented in December 2019 (*Taenia saginata*) or 3) only carried out by one abattoir company in the EU as there is no official EU requirement (*Toxoplasma gondii*). Moreover, advantages, requirements and limitations of risk-based surveillance for meat-borne parasites are discussed.

1. Introduction

There is a plethora of meat-borne hazards, which represent a potental risk to humans. In the European Union (EU), bacteria such as *Campylobacter* spp. and *Salmonella* spp. are causing the highest number of human foodborne cases (EFSA/ECDC, 2018). However, not just the number of cases but also the severity of infection is relevant when judging the importance of a hazard. To include this, the WHO Foodborne Disease Burden Epidemiology Reference Group (FERG) estimated the disability-adjusted life-years (DALYs[1]) of various potential food-borne hazards including microbiological and chemical contaminants. The FERG report contains a list of prioritised food-borne parasites, and among these, some are meat-borne (FERG, 2015). Among the meat-borne parasites, *Taenia solium* was identified as associated with the highest burden of disease, resulting in a world total of 2.8 million DALYs, in particular on the African continent. *Toxoplasma gondii* came in third, with 1.7 million DALYs, and *Trichinella* spp. was identified as the hazard with the lowest burden of disease, 550 DALYs, among all the hazards included in the final FERG analysis (FERG, 2015).

In a world with unlimited resources, there would be surveillance in place for all potential hazards. But resources are scarce and both private and public decision-makers need to take decisions on what hazards and activities to prioritise and how to use existing resources efficiently. Such processes are complicated by a variety of (and sometimes competing) demands; food business operators being under pressure to operate in a profitable manner, customers and trade partners expecting safe and affordable products, and public services being asked to ensure that food systems function reliably to the benefit of many in society.

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[1] DALYs are calculated by adding the number of life years lost due to mortality (YLL) to the number of years lived with disability due to morbidity (YLD): DALY = YLL + YLD (FERG, 2015).

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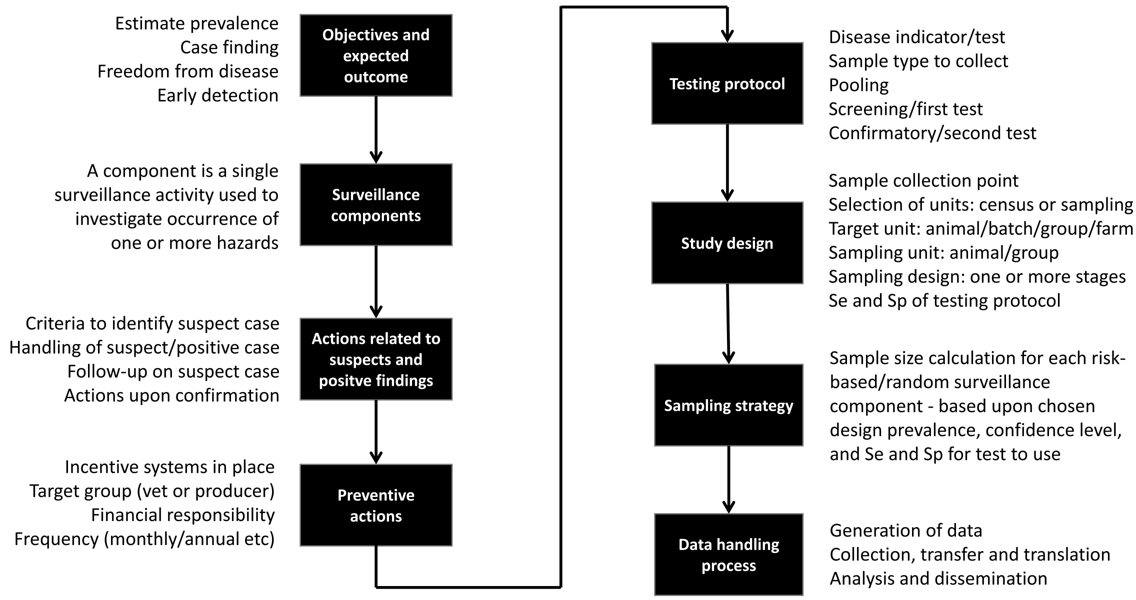

Fig. 1. Graphical description of the key areas to consider when setting up surveillance programmes. Se = sensitivity, Sp = Specificity. Modified after https://survtools.org/.

Risk-based surveillance and control may offer a solution to the challenge by applying risk analysis principles; first to set priorities and secondly to allocate resources effectively and efficiently. Risk-based surveillance makes use of information about the probability of occurrence and the magnitude of the biological and/or economic consequence of health hazards to plan, design and/or interpret the results obtained from surveillance systems.

Risk-based surveillance was originally introduced into veterinary public health by Stärk et al. (2006). Since then, the approach has been used in many countries for a range of hazards, validated and refined. Guidelines and tools have been developed that can assist, when setting up a risk-based surveillance programme adequate for the issue and including the context. The approach has already been used for *Trichinella* spp., but there is scope for enhanced use of risk-based surveillance with the potential to increase cost-effectiveness of surveillance for similar pathogens.

In this paper, the basic principles of risk-based surveillance are described. Next, the surveillance of three meat-borne parasites is described using the so-called SURVTOOLS (https://survtools.org/) approach (Fig. 1), which was developed as part of the RISKSUR project (https://www.fp7-risksur.eu/). The parasites are *Trichinella* spp., *Taenia saginata and Toxoplasma gondii*. The first two were chosen because they are covered in international legislation and risk-based surveillance is either in place (*Trichinella*) or soon to be implemented (*T. saginata*) in the EU. As the last example, *T. gondii* was chosen, because the FERG report identified this hazard as the third-most important parasite worldwide (FERG, 2015), although no official requirements for surveillance or interventions are in place in the EU. By use of these selected, illustrative examples, the progress made in risk-based surveillance for meat-borne parasites, the implications thereof, and the opportunities for the future are described and discussed.

2. Basic principles of risk-based surveillance and control

In the RISKSUR project it was suggested that risk-based surveillance could include one or more of the following four elements: Risk-based prioritisation, risk-based sampling, risk-based requirement, and risk-based analysis. Risk-based prioritisation involves determining which hazards to select for surveillance, based upon the probability of their occurrence and associated consequences. Risk-based sampling covers designing a sampling strategy to reduce the cost or enhance the accuracy of surveillance by preferentially sampling strata (e.g. age groups or geographical areas) within the target population that are more likely to be exposed, affected, detected, become affected, transmit infection or cause other consequences (e.g. large economic losses or trade restrictions). Risk-based requirement deals with use of prior or additional information about the probability of hazard occurrence to revise the surveillance intensity required to achieve the stated surveillance purpose. Risk-based analysis makes use of prior or additional information about the probability of hazard occurrence, including contextual information and prior likelihood of disease to revise conclusions about disease status. In this paper, the focus is on risk-based prioritisation and risk-based sampling.

2.1. Setting the priorities – Risk-based prioritisation

The higher purpose is mitigation, where surveillance and intervention are two elements of the mitigation aim. Surveillance provides the information, intervention the action. But an intervention is not always necessary. Therefore, first it should be assessed where there is a need for surveillance, why, and which kind of knowledge is expected to be provided by the surveillance. This constitutes the strategic part of the analysis. Often, it starts with a perceived or actual risk that needs to be dealt with or a requirement set by regulatory bodies. In the present context, risk is seen as the product of probability of the occurrence of the hazards and the extent of biologic and/or economic consequences of their occurrence. Regarding consequences, these may include production losses, animal welfare problems, human disease (specific to zoonotic infections), trade loss, reputation loss, loss of ecosystem services and food security.

Perturbations may be defined as a deviation of a system or process from its regular or normal state or path, caused by an outside influence. If a high capacity to cope with perturbations is judged as vital by decision-makers or society, indicators of consequences might be required as part of the surveillance. In international trade in meat, findings of unwanted hazards such as *Salmonella*, residues or *Trichinella* may be interpreted as incidents leading to perturbations – such as withdrawal of the meat from the market or a ban on export. In line, outbreaks due to foodborne hazards may result in consumer boycotts, leading to a switch to other products. Hence, one sector's loss may be another sector's gain. Moreover, in extreme cases as currently seen with the spreading of African swine fever, food security issues on a local market due to culling of many infected herds may evolve.

Governments and the livestock sector often have ambitions for improving public and/or animal health and/or expanding the access to the export market. If improvement of public and animal health is the objective, information about the burden of different diseases is the basis, for humans as well as animals. The FERG report may be useful for public health as it contains an assessment of the human burden of different foodborne diseases in the world, divided into regions (FERG, 2015). Next, a source account is needed, whereby the contribution to human exposure of each kind of food consumed is assessed. For example, if the highest burden of foodborne disease is ascribed to campylobacteriosis, and poultry meat is the main source, then the value of surveillance in pig meat would be limited. To assess animal health, production recordings may be a good indicator, e.g. in cases where disease surveillance data are not available.

If access to a foreign market is the objective, then first an identification of the requirements regarding food safety and the zoo-sanitary status for the foreign market is needed. Next, establishment of a specific surveillance may be required. Although the outcome of a burden of disease assessment and a source account may show that a specific risk is negligible in a given commodity, surveillance may still be needed - if required by the importing country. That could be the case for *Trichinella* in pig meat. After access to the foreign market, a continued documentation of a high zoo-sanitary status and food safety level may be essential, requiring continued surveillance. Alternatively, bilateral negotiations may lead to acceptance of equivalence on other terms such as a risk-based surveillance in the high-risk sub-population. A country may be in a position where it is considered too costly to implement certain food safety standards for the entire production. In response, the country may decide to limit the surveillance programme to animals due for export, or farms or abattoirs that export their produce, to be able to export to countries with a high level of animal health or food safety.

2.2. Designing the surveillance - risk-based sampling

Once the relevant hazards have been identified, technical and operational considerations should be made regarding surveillance design. Here, the surveillance objective should be further defined, and surveillance designers should discuss which kind of surveillance is needed to meet the objective.

Surveillance involves use of the obtained information for decision-making regarding whether to initiate action or not. For example, actions may be required when positive samples are found or when the prevalence gets above a certain accepted threshold. In contrast, monitoring differs from surveillance in the sense that no actions are planned (Hoinville et al., 2013). In the following, "design of surveillance" is used in a broad meaning, not differentiating between monitoring or surveillance. During the design of surveillance, design tools may be used. One example is the SURVTOOLS, which guide the user through key elements of surveillance (Fig. 1). Such a standardized approach ensures that all elements are carefully considered before decisions are taken.

Information about the biology of a hazard is commonly needed when designing surveillance. For parasites this includes the lifecycle, information about the prevalence of infection in different animal species, knowledge about risk factors, ways of spreading and the effects of infection or disease. All this information may be used to identify where the risk is high, enabling targeting of sampling to the sub-populations or commodities that harbor the highest risk (Stärk et al., 2006). As described above, in the context of risk-based surveillance, risk is seen as the product of probability and consequences. Therefore, the highest risk may be found either in the population strata with the highest expected prevalence of the hazard or the strata, where the impacts of having the hazard may be highest.

It is important to identify infected animals or their products in food systems to manage the risk and avoid human exposure. Unlike bacterial foodborne pathogens, where cross-contamination and bacterial growth along the food chain is a major concern, meat-borne parasites do not multiply in the food chain. Risk-based sampling may be focusing on meat originating from animals raised outdoors and not indoors – if outdoor-raising is perceived as a risk factor for the hazard of concern. Moreover, one should have a view on the intended use of the meat. If the hazard is eliminated during processing, then there will be no need for surveillance in that part of the production or afterwards. But there may be a need for surveillance in another part of production. This implies that a meat value chain perspective is useful as it might offer novel opportunities for risk-based sampling.

Feasibility of sampling and its cost-effectiveness are also important considerations. In 2011, EFSA introduced the concept of harmonized epidemiological indicators, consisting either of direct measurements of the hazard itself or an indirect measurement based upon the production system. Using the latter approach, a farm or a herd could be categorized into low- or high-risk (EFSA, 2011a). Regarding direct measurements, sampling at the abattoir is easier and cheaper than sampling on the farm, because for each abattoir there is a high number of farms delivering animals for slaughter. Choice of laboratory methods requires considerations regarding whether a high sensitivity or a high specificity is needed – and whether more methods should be used and interpreted, in parallel or in series. Regarding choice of sampling material (matrix) to use in the laboratory, meat may be easier to collect than blood. However, care should be taken before deciding, because the laboratory method may have been validated for one matrix and not for another. Finally, when estimating the prevalence of a given infection, the test characteristics need to be considered as well as the cut-off used when judging whether an individual sample is positive or not. Here, parasites may represent a challenge as many different tests are available and used, unfortunately sometimes without knowing the sensitivity and the specificity, hampering comparisons of prevalence estimates (Felin et al., 2017; Olsen et al., 2019).

3. Surveillance for *Trichinella*

Trichinella infection in humans may result in life-threatening disease. *Trichinella* was first detected in its larval form in a human cadaver in 1835 and in a human clinical case in 1859 (Campbell, 1983). Following this discovery, many European countries implemented inspection and control of *Trichinella* in meat using trichinoscopy (Boireau et al., 2015). In the USA, *Trichinella* testing was also put in place, but mainly with a focus on export of pork to Europe. Today, *Trichinella* is under control not just in Europe and the US, but in most parts of the world and is, therefore, associated with a low burden of disease worldwide (FERG, 2015).

Several animal species may get infected with *Trichinella*, although consumption of meat from pigs, horses and wildlife has been ascribed to most of the human cases observed. *Trichinella* infection can only occur if an animal or a human ingest muscle tissue containing infective larvae (Gamble et al., 2019). This implies that infection cannot spread from one pig to the next, unless cannibalism takes place. It also means that feeding of raw waste containing infected meat to pigs (which is not allowed in the EU due to the probability of spreading infectious disease such as African or Classical swine fever), as well as unsafe handling of dead animals are major risk factors. Moreover, presence of a high number of rodents and outdoor-raising of pigs have been identified as risk factors. The longer an animal lives, the higher is the probability that it may get exposed. Therefore, age may be interpreted as a risk factor.

The general surveillance for *Trichinella* in the EU is described in Table 1, based upon Alban and Petersen (2016) and the EU legislation (Anon., 2015). Until 2014, all pigs raised in the EU were supposed to be tested, unless the Member State had official recognition of having a negligible risk of *Trichinella* in its domestic pigs; only Denmark and Belgium had obtained this recognition (Alban and Petersen, 2016).

Table 1
Overview of selected surveillance design elements for *Trichinella* and *Taenia saginata* in the European Union, 2019.

Hazard	Objectives[a] and expected outcome	Sub-populations to consider for surveillance components	Actions related to suspects and positive findings	Preventive actions	Testing protocol	Study design	Sampling strategy	Data handling
Trichinella	Populations not free from infection: to ensure food safety by identifying infected animals and take them out of the supply chain (case finding) Populations free from infection: to document freedom from disease continuously to enable trade and avoid perturbations of export	Two individual risk factors: age and production system 1. 1. Indoor finishers 2. 2. Indoor sows/boars 3. 3. Outdoor finishers 4. 4. Outdoor sows/boars	Condemnation of carcass Trace back to the farm of origin and an investigation of the source of infection	Actions to ensure a high level of biosecurity following the EU requirement for controlled housing as specified in Annex to the EU *Trichinella* Regulation 1275/2015	At abattoir: artificial digestion of single meat pieces or a pooled sample of meat pieces from different pigs. Confirmation testing for positive samples. Serology may also be used for monitoring purpose On farm: auditing of biosecurity in accordance with EU *Trichinella* Regulation[b]	One-stage sampling with the individual pig as the target	Census implying that all animals are tested OR Risk-based involving pork for export out of the EU or high-risk sub-populations such as pigs from non-controlled housing If Member State has not yet documented that prevalence is < 1 per million, then 10% of pigs from controlled housing should be tested	Continuous evaluation of samples and reporting to the national authorities
Taenia saginata	To ensure food safety by identifying infected animals and take them out of the supply chain (case finding)	Three confounded risk factors: sex, age, and way of raising 1. 1. Young bovines 2. 2. Adult bovines 3. 1. Females 4. 2. Males 5. 1. Indoor raising 6. 2. Outdoor raising OR Combination of above	Few cysticerci found in carcass: the parts not infected may be declared fit for human consumption after having undergone a cold treatment Many cysticerci found in carcass: condemnation	Application of Good Agricultural Practices regarding application of human sewage on fields and grazing of cattle Ensuring toilets for farm workers and people walking in area with bovines (hikers, scouts, tourists)	At abattoir: meat inspection of individual bovines through examination of the masseter muscles in which incision must be made as well as opening if the heart OR Serology	One-stage sampling with the individual bovine as the target	Currently: all bovines > 6 weeks of age unless holding has been officially certified to be free of cysticercosis[c] EU Commission's new legislation[d]: Only testing of All bovines > 20 months AND Bovines > 8 months raised outdoors	Findings will be reported from the abattoir to the cattle producer, who will be paid less or nothing for positive cattle depending on the judgment of the carcasses

[a] For both hazards, surveillance is a prerequisite for trade and export. b: EU Regulation 2015/1375 (Anon., 2015). c: although allowed for in the EU Meat Inspection Regulation 854/2004, such systems are not in place in the EU according to the knowledge of the authors. d: New EU Regulation 2019/627 on meat inspection of bovines coming into force in December 2019 (Anon., 2019).

Then, the EU legislation adopted a risk-based approach for surveillance of *Trichinella* in pigs and officially required testing only of pigs raised in the low-biosecurity compartment, such as outdoors or backyard production (called the non-controlled compartment in the EU). As an intermediate stage, a Member State was obliged to test 10% of the pigs (finishers, sows or boars) from the controlled housing compartment. This was to continue until the Member State was able to document, using historical data on continuous testing carried out on slaughtered swine population, that the prevalence of *Trichinella* was below 1 per million in the controlled housing compartment. Denmark and Belgium were excepted from this requirement because of their negligible risk status (Anon., 2015). The move towards a risk-based sampling was due to an overwhelming amount of data showing that *Trichinella spp.* is absent in the controlled housing compartment (Alban et al., 2008, 2011).

This moved focus from testing pigs individually to auditing of biosecurity on-farm. Such indirect measurements are much cheaper than testing all pigs for the presence of the parasite, in particular if an auditing system is in place already for other reasons (Alban and Petersen, 2016). To ensure acceptance of the risk-based sampling, compliance with the requirements for controlled housing should be checked at regular intervals and ideally, the frequency of the auditing should be risk-based. These requirements are described in detail in Annex IV to the EU *Trichinella* Regulation (Anon., 2015). For many years, the International Commission of Trichinellosis (ICT[2]) has published guidelines for pre-harvest control of *Trichinella* in food animals. The ICT guidelines have recently been updated (Gamble et al., 2019); they are almost identical to the requirements listed in the EU *Trichinella* Regulation. Either the veterinary authorities or a third-party independent auditor may do the auditing. The latter is undertaken as part of a private standard, building on top of national and international legislation. Such private standards are common in many parts of the world, and it may be expected that they will increase further in use and importance (Alban and Petersen, 2016).

According to the EU legislation, carcasses of horses, wild boar and other farmed and wild animal species susceptible to *Trichinella* infection shall be systematically sampled in slaughterhouses or game-handling establishments as part of the post-mortem examination (Anon., 2015). Hence, testing will only take place if the meat is intended to be consumed by humans. For foxes or other indicator animals, monitoring is encouraged but not required in the EU *Trichinella* Regulation, despite wildlife potentially having a higher prevalence of *Trichinella* spp. than livestock, reflecting that food safety is the overall objective of the surveillance. Moreover, surveillance in outdoor pigs can be interpreted as an early warning for indoor pigs, raised in the same geographical area.

Despite the FERG report pointing to a marginal negative impact on human health and the EU legislation allowing no testing for *Trichinella* spp. of pigs raised under controlled housing conditions, extensive testing is still taking place in the EU, because of trade requirements from countries outside the EU (Alban and Petersen, 2016). This shows the importance of international harmonization regarding surveillance and control of the most common animal health and food safety issues - as it could lead to a more effective distribution of resources spent on assuring food safety and animal health and welfare.

4. Surveillance for *Taenia saginata*

Humans are the definitive host of the cestode *T. saginata.* If humans are exposed to live cysticerci, by eating undercooked beef, infection in the form of a tapeworm may develop, where after the tapeworm will begin excreting infective eggs. The presence of the tapeworm will usually result in very mild infection or no symptoms at all (Laranjo-Gonzalez et al., 2016). Contrary to *T. solium* (the swine tapeworm) the eggs of *T. saginata* are not infective to humans (Gerts, 2015). Neurocysticercosis is therefore not related to *T. saginata*. Hence, the human burden of disease related to *T. saginata* is assessed as low, although no precise studies have been undertaken. In line, the FERG report excluded *T. saginata* from their priority list due to the presumed low burden of disease (FERG, 2015).

Infection of cattle with the eggs of *T. saginata,* resulting from exposure to human feces, results in development of cysticerci, located in the muscle, enabling infection of humans as described above. Natural infections in cattle are normally asymptomatic (Laranjo-Gonzalez et al., 2016). Like cattle, reindeer and buffalo can also act as an intermediate host. Exposure of cattle to human fecal material is the main risk factor for infection of cattle. *Taenia* infection cannot be spread from one bovine animal to the next. Age is a risk factor, as it has been documented that animals slaughtered before the age of 2 years have a very low probability of being infected. Moreover, sex is a risk factor, with male cattle having a lower risk than females (Calvo-Artavia et al., 2012). However, sex and age at slaughter are confounded, as male cattle are usually slaughtered before the age of 2 years, while females are kept longer.

The general surveillance for *T. saginata* in the cattle in the EU is described in Table 1, based on a systematic review undertaken by Laranjo-Gonzalez et al. (2016), the EU legislation (Anon., 2004) and other selected publications.

As stated above, the human burden of disease related to *T. saginata* is assessed as low (FERG, 2015). Moreover, the prevalence of infected cattle found at meat inspection is very low (Laranjo-Gonzalez et al., 2016) and the sensitivity of meat inspection of lightly-infected animals is very low, implying that most infected carcasses are overlooked. Kyvsgaard et al. suggested that the sensitivity for lightly infected animals was around 15%, (Kyvsgaard et al., 1990). The value of the routine inspection has therefore been questioned (Calvo-Artavia et al., 2012). Alternative suggestions are risk-based surveillance and/or use of serology (Laranjo-Gonzalez et al., 2016). A risk-based approach could involve inspection limited to the high-risk sub-population consisting of adult cows (Calvo-Artavia et al., 2012). Adult cows were also found as the sub-population with the highest prevalence in the United Kingdom (Marshall et al., 2016) and in France (Dupuy et al., 2014). A new EU Regulation 2019/627 about meat inspection of bovines, making use of age and production system as risk factors, will come into force in December 2019. This will imply that bovines, either raised indoors and slaughtered before 20 months of age, or slaughtered below 8 months of age will be excepted from incisions into the masseters (Table 1 and Fig. 2) (Anon., 2019).

Serological tests for detection of antigens or antibodies again *T. saginata* are available, and the EU Meat Inspection Regulation 854/2004 allows use of serology as a replacement for meat inspection for *T. saginata* (Anon., 2004). However, such tests are associated with additional costs. Therefore, before being recommended for routine use, the economic efficiency should be carefully considered. A recent study using a mathematical model estimated a prevalence of 43% of *T. saginata* (in the form of viable, degenerated or calcified cysticerci) in Belgian cattle (Jansen et al., 2018). Somewhat similar, Eichenberger et al. (2013) estimated the prevalence to be 16% in Swiss cattle. This high prevalence warrants further investigations into the ways that Belgian, Swiss and maybe cattle in other countries get exposed: grazing practices, availability of toilets for farm workers and others, and handling of the sewage system. In this way, it may be possible to identify and rectify systematic risky practices in place. This may be more cost-effective than subjecting all Belgian cattle to a serological test for *T. saginata.* Alternatively, individual farmers may be interested in documenting freedom from infection, using serology at meat inspection on a subset of their animals. Such meat would be safe to use for ready-to-eat beef products, but a higher price would most likely be required before a larger number of farmers would embark on this strategy.

[2] http://www.trichinellosis.org/.

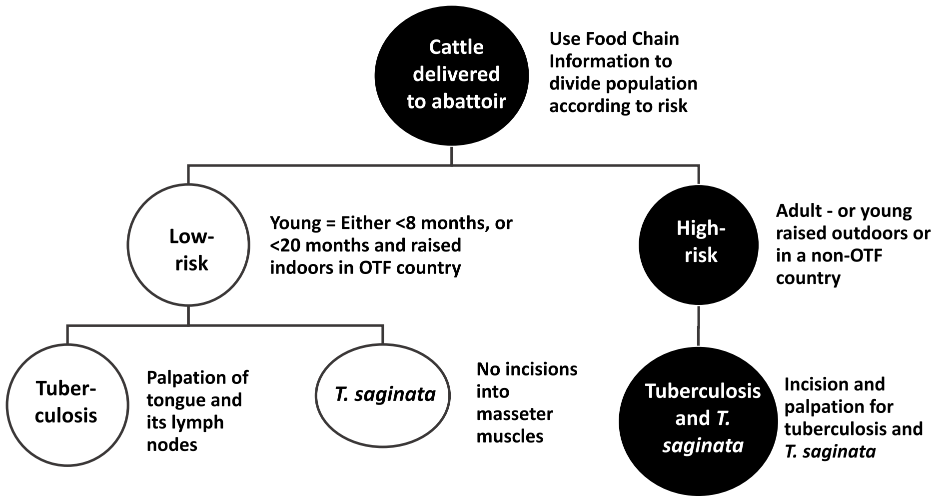

Fig. 2. Graphical description of a risk-based approach to meat inspection for tuberculosis and *T. saginata* cysticercosis in bovines making use of knowledge about the risk factors age, sex and production system. This approach is part of the new EU Meat Inspection Regulation 2019/627 on bovines coming into force in December 2019. OTF = Official Tuberculosis free country.

5. Surveillance for *Toxoplasma gondii*

Felids, such as cats, are the definitive hosts of the protozoan parasite *Toxoplasma gondii*. Infected felids can shed millions of oocysts through their feces for a limited time period. Cats contaminate the environment with such oocysts, and water, soil, feed and food can be the transmission pathways, whereby a wide range of hosts gets infected. If *Toxoplasma* infection takes place in a naïve pregnant woman, infection may result in abortion of the unborn child, or in life-long impairment of normal functionality of the child. In adults, infection usually has a mild course with few symptoms, however there are indications that infection with *T. gondii* might be associated with schizophrenia (Burgdorf et al., 2019). According to the FERG report, *Toxoplasma gondii* is the third-most important parasite worldwide, associated with 1.7 million DALYs (FERG, 2015). Consumption of meat has been ascribed to a large, but unknown proportion of the human cases observed (Cook et al., 2000; FERG, 2015). Freezing and heat treatment render infected meat safe to consume, whereas curing requires that the meat product is subjected to high saline concentrations over a longer time to be effective (Dubey, 1997). This implies that there are only few meat products which will contain viable parasites at the time of consumption. Therefore, ready-to-eat (RTE) products such as mildly cured products may be considered as high-risk.

Toxoplasma gondii cannot easily be detected directly, but serological testing can be used as an indirect measurement. According to a recently published systematic review, the seroprevalence is highest in wild boar followed by sheep, moose, and cattle, and lowest in indoor finishing pigs (Olsen et al., 2019). For pigs, Limon et al. identified three confounded risk factors: 1) small herds, 2) outdoor-rearing and 3) farm cats with access to sow feed and concluded that in the United Kingdom most batches of pigs delivered to slaughter consists of negative animals (Limon et al., 2017). Moreover, sows and boars have a higher probability of being infected than finishing pigs (Olsen et al., 2019).

The non-negligible importance of *T. gondii* for human health has been recognized both by WHO (FERG, 2015) and EFSA. The latter identified *T. gondii* as a relevant hazard in their opinion on hazards to be covered by meat inspection of pigs (EFSA, 2011b). Still, in the EU and elsewhere, there is currently no official requirement for surveillance or intervention for *T. gondii* in any livestock. Overall, the higher purpose is mitigation, where surveillance and intervention are two elements of mitigation. As stated above, intervention is not always necessary. The current stage of mitigation may be called investigation, and it is about understanding the situation and getting ready for intervention strategies, if needed (Häsler et al., 2011). Depending upon the outcome of this exercise, the risk manager may decide upon moving to implementation of a mitigation phase or accept the situation as it is.

In the following, considerations regarding how to set up a future surveillance programme for *T. gondii* in swine is described, following the key areas defined in SURVTOOLS. The overall objective should be to protect consumers against being exposed to infective meat. This can be done through identification of herds with an unacceptable high prevalence of *T. gondii* (estimate within-herd prevalence). The kind of surveillance to put in place could be monitoring or surveillance. As age and way of raising are risk factors, there are four potential sub-populations for which a surveillance component could be set up for swine: finishing pigs/sows combined with controlled housing/non-controlled housing. A discussion should be taken to set the threshold between acceptable and unacceptable, while knowing that such a threshold can later be changed. Experience from the Danish *Salmonella* surveillance programme may come in useful; after some years into the programme, the within-herd seroprevalence of *Salmonella* was lowered from 70% to 65% for allocating pig herds into the highest risk category, for which there is requirement for risk mitigation, as described by Alban et al. (2012).

Actions related to detection of an unacceptable high seroprevalence may involve visit at the farm of origin, including evaluation of current biosecurity practices and correction of potential weak points. Farmers could be notified and payed less for their pigs or asked to pay for the follow-up visit on the farm. Outdoor raising is known as a risk factor, making it a priority to develop recommendations to ensure safe ways of housing and feeding of outdoor pigs. For herds with an unacceptable high prevalence of *T. gondii*, a recommendation could be to freeze meat intended for production of risky RTE products.

Serological testing may constitute a feasible way of detecting herds with a high prevalence. One important question is whether to initiate surveillance in all four potential sub-populations or not, and if so, how. Here, a farm categorization may be used in line with what is seen for *Trichinella.* This could imply that all meat from the sub-population with the highest prevalence may be considered as high-risk requiring freezing, if the meat is intended for risky RTE products. Following upon this view, surveillance may target the low-risk sub-population such as indoor finishing pigs. One drawback about this approach is that a substantial number of samples would have to be tested before infection can be detected, due to the low prevalence. This issue was raised by EFSA, who recommended to use auditing of biosecurity for controlled housing instead of testing for *T. gondii* for low-risk farms (EFSA, 2011a). To make a testing programme economically feasible, only few samples may be taken at each delivery. This would imply that longer time might pass, before infection would be detected.

Hence, the point of sample collection is the abattoir, and the testing protocol could involve serology (blood) or meatjuice. Although EFSA recommends use of blood (EFSA, 2011a), collection of meatjuice samples is much more convenient. The approach used in the Danish *Salmonella* surveillance in finishing pigs may be used, implying automatic identification of carcasses to be sampled in the cooling room as described by Alban et al. (2012). The sampling strategy could be risk-based sampling restricted to either high-risk or low-risk, as explained further up. The study design could consist of a two-stage sampling, where farms with no test-positives are placed in the low-intensity part of the programme involving e.g. one sample per delivery, and farms that have tested positive are re-tested in relation to the next delivery of pigs with a higher number of samples to estimate the within-herd prevalence.

The choice of cut-off to be used when judging the individual sample constitutes a challenge for *T. gondii*, as pointed out by Felin et al. (2017). For the low-risk sub-populations such as the indoor finishing pigs, the major part of the apparently seropositive pigs may be false-positives. An example of this could be seen in a study by Kofoed et al. (2017). That challenge could be solved by re-testing more animals from the herd and allowing a certain number of reactors within a given sampling period. The data handling process would be a continuous evaluation of samples to confirm the seroprevalence level of each farm.

So far, only one EU abattoir company has a surveillance programme for *T. gondii* in place, like described above, implying one sample tested per delivery of pigs from low-risk herds, and six samples from herds with a higher risk. Farms are re-tested when positives are found to determine the within-herd prevalence more precisely. A within-herd prevalence below 5% is considered as low-risk, and above 15% as high-risk, and in-between as moderate risk (Heres et al., 2015).

More work is needed before a surveillance programme for *T. gondii* can be recommended widely. Such work would include a burden of disease assessment for *T. gondii* for the country of interest, followed by a source account or an exposure assessment for the most important sources of human exposure. That information could be included in a cost-benefit analysis, addressing different kinds of surveillance systems. In Denmark, a source account has been made for congenital toxoplasmosis, showing a lower annual disease burden than expected. A total of 123 DALYs was found, of which 78 were due to fetal loss and 2 were due to neonatal death, and hence 43 DALYs for the persons who will have to live with congenital toxoplasmosis. This is substantially lower than the burden caused by campylobacteriosis (1586 DALYs) and salmonellosis (379 DALYs) (Nissen et al., 2014). However, this figure does not include the potential burden represented by schizophrenia, where *T. gondii* infection might be a contributing causal factor for some cases of schizophrenia - as suggested by Burgdorf et al. (2019). In Denmark, the next step involves a source account or an exposure assessment for selected food sources such as pig meat.

6. Advantages, requirements and limitations related to risk-based surveillance and control

The three examples of surveillance in foodborne parasites presented above show that there are several advantages of using risk-based surveillance systems: targeted efforts resulting in a better cost-effectiveness ratio, if planned well. One example is the Danish *Trichinella* programme in pigs, where only the pigs from non-controlled housing are subjected to individual testing whereas the controlled housing herds are subjected to auditing of biosecurity practices every 3 years (Alban and Petersen, 2016) Hence, risk-based surveillance and control harbors the opportunity to achieve the same surveillance performance at lower cost or to increase performance using the same resources. The approach is based on knowledge of the food system, the epidemiology of the hazard, contextual factors and risk factors, where sampling can be targeted to the population strata with the highest risk.

To ensure confidence in risk-based surveillance, documentation of all elements of the risk-based approach is crucial. Here, reporting guidelines may be useful, and example of this can be found in https://github.com/SVA-SE/AHSURED. However, in many cases it can be difficult or even impossible to get enough data to estimate e.g. the size of a risk factor precisely. One example is the area of surveillance for residues of antimicrobial origin in meat, where a risk-based approach is encouraged (Anon., 1996). Detailed studies of the cases seen in Denmark indicate that use of injectable antimicrobials is the primary cause and that a high within-herd prevalence of chronic pleurisy (where treatment is often done using injectable antimicrobials) may be a risk factor or an indicator. However, the number of cases in Denmark is so low that it disables a precise estimate of this risk factor. Here, a comparison with Dutch data helped to estimate the relative risk (Alban et al., 2014; Veldhuis et al., 2019). Still, prudence should be used to avoid over-confidence, and the impact of uncertainty on the risk to be estimated should be studied – e.g. in the form of scenario analysis - to ensure robustness of the system.

Livestock farming is not static; and major shifts in production have been observed in Europe in the last decades. This implies fewer and larger farms and a specialization, resulting in a change in the trade flows. For pigs, a specialization into breeding, growing or finishing farms is taking place (Marquer et al., 2014). Moreover, the preferences of the consumers are not stationary. Therefore, changes in risk distribution should be foreseen and incorporated into surveillance e.g. as an early warning system. A solution to this could be to expand surveillance efforts to food systems to characterize and monitor their changes over time and trigger alerts of major changes that may require further investigation and adaptation of surveillance programmes. An example is when livestock is raised in new ways or regions, where there might be an increased exposure to certain hazards, compared to the traditional production. Outdoor-raising of pigs may be an example of this – and the combination with an increase in the preference for pink pork may imply a higher exposure to *T. gondii* than seen before. Similar considerations should be made regarding climatic changes, which may lead to presence of infections or vectors of infection not previously seen in the area. For both examples, focus should be on the capacity of the livestock system to cope with perturbations.

In this paper, risk-based surveillance to ensure safe meat has been the focus. Still "safe meat" may have different meanings to the consumers, and some may be willing to take a risk for the taste, e.g. for tartare (raw beef). This implies that resilience as well as risk and risk evaluations may vary at different levels of the consumer and production cycle. In line, one group of consumers may perceive outdoor raising as associated with high animal welfare and a more resilient form of production compared to indoor production. For others, outdoor production may be perceived as a risk for animal welfare because of exposure to harsh climatic conditions and as a risk of introduction of various infections. In response, the authorities in collaboration with the food business operators may need to look more carefully into how we may frame risk, production and consumption in a way where the various aspects can be encompassed in a transdisciplinary process, with many perspectives considered simultaneously. Knowledge integration and multi-criteria decision-making is crucial here, but with current procedures slow, complicated, and difficult to obtain. Digitalisation may represent an opportunity to generate a more participatory approach to risk management from farm to fork.

Risk-based surveillance require that many kinds of information are gathered and carefully evaluated. This implies an opportunity to (re-) assess and evaluate traditional surveillance approaches and identify areas for enhancement, change or innovation. However, it also encompasses a weakness, because such systems may not necessarily be known *a priori* to the trade partner and the veterinary authorities in the importing country (Stärk et al., 2006). Hence, any risk-based surveillance programme can only realise its full economic efficiency potential, if trade partners and veterinary authorities are informed in detail about the specific approach, which implies that it should be transparent and evidence-based. Here, it should be borne in mind that trust is built up gradually but can be destroyed fast. Furthermore, it may be confusing, if each country defines their own risk-based surveillance for a given hazard, and some level of harmonization would be useful. To obtain this, open access to information about surveillance systems would be helpful for the process of identifying the systems that work best, depending on the settings. In case of sensitive issues, a controlled disclosure could be used.

In the EU legislation, unclear terminology is sometimes used, such as targeted surveillance, and with no distinction between monitoring and surveillance. For example, in the EU Residue Directive 96/23, it says: “The samples must be targeted taking account of the following minimum criteria: sex, age, species, fattening system, all available background information, and all evidence of misuse or abuse of substances of this group” (Anon., 1996). However, for finishing pigs, which exist in large numbers, not much help is provided to identify how to do risk-based surveillance. Although sows have a documented higher probability of harboring residues than finishing pigs, an extensive surveillance in sows does not help, if the objective is to demonstrate absence in finishing pigs to a trade partner, as explained by Alban et al. (2018).

In line with the recommendations by Ruegg et al. (2017), a collaboration between authorities, academia and food business operators should be encouraged. Such a collaboration might make it possible to develop an effective surveillance for a given hazard or indicator, based upon experience, feasibility and economics. Hereby, compliance with the surveillance system may be improved. Moreover, surveillance programmes need to be set up in a way which facilitates control, implying timely actions which can be made in an easy way. Again, a collaboration with the stakeholders may be beneficial, because it will also be in the interest of the stakeholders to ensure fast detection and effective handling of unwanted cases, including trace-back. This is already recognized by many Food Business Operators who have routine data collection and Hazard Analysis of Critical Control points (HACCP) in place for their production. This will minimize the perturbation to the system and, hereby, maintain consumer confidence and access to export markets. Given their business nature, the industry may have more interest and resources to set up surveillance in the form of own control than the national authorities. An example of this can be seen in Denmark (Alban et al., 2018) and the Netherlands (Veldhuis et al., 2019), where their own control for residues of antimicrobial origin in pig meat is involving many times more samples than the official sampling undertaken in line with the EU Residue Directive (Anon., 1996). However, such private surveillance data are only of use to public decision-makers (who have a mandate to promote and protect public health), if the information is shareable and can be trusted. Moreover, in some cultures, there is a lack of confidence in industry data.

Development of meat safety assurance systems (MSAS) as suggested by EFSA (2011b) may help to categorize farms and slaughterhouses according to the risk they represent. This involves setting appropriate targets for the final chilled carcasses. Such MSAS would involve a careful selection of harmonized epidemiological indicators, depending on the purpose and the epidemiological situation in a country. Private standards covering food are on the increase including meat, see for example the Global Red Meat Standard (https://grms.org). For more details about the status and the challenges related to the development of MSAS, please see Buncic et al. (2019).

Regular evaluation of surveillance is recommendable. This will, among other things, ensure that the latest technical achievements are incorporated, the objectives are met, and the cost-effectiveness is maintained. Tools developed for evaluation should preferably be used, e.g. the SURVTOOLS described above. Such tools are meant for inspiration to ensure that all relevant issues are dealt with.

A broader evaluation framework to consider has been developed by the Network for Evaluation of One Health (NEOH), http://neoh.onehealthglobal.net. NEOH is intended for the evaluation of any initiative addressing the health of people, animals and the environment. The framework is based upon a system's approach and provides a basis for assessing the integration of knowledge from diverse disciplines, sectors, and stakeholders through a systematic description of the system at stake and standardised sets of indicators. It illustrates how cross-sectoral, participatory and interdisciplinary approaches evoke characteristic One Health operations, i.e., thinking, planning, and working, and require supporting infrastructures to allow learning, sharing, and systemic organisation. It also describes systemic One Health outcomes, which are not necessarily possible to obtain through sectoral approaches alone (e.g. trust, equity, biodiversity etc.), and their alignment with aspects of sustainable development based on society, environment, and economy (Ruegg et al., 2017; http://neoh.onehealthglobal.net/).

Several other tools are currently available for evaluation of surveillance. A comparison of such tools is currently undertaken in an international project called “Convergence in evaluation frameworks for integrated surveillance of antimicrobial resistance approach” (Co-Eval-AMR[3]), where the focus is on characterizing evaluation tools for evaluation of surveillance systems for antimicrobial resistance. The intent is to identify which protocols or tools are suitable for evaluating what and – if possible – to move towards more harmonized evaluations. The output from this project may provide insights for surveillance in other fields including meat-borne parasites.

7. Conclusion

Surveillance and intervention can be considered a continuous, iteratively adaptive process, which can respond to changing food systems, risk patterns, consumer behaviors and trade dynamics. It is therefore important that surveillance is set up to produce fit-for-purpose information that allows making decisions for intervention where needed and react to changing circumstances. Risk-based surveillance systems may imply a higher effect of surveillance at a lower level of costs, through a targeted focus on the hazard that matter the most to a society or an industry. Similar considerations should be made for risk management. For meat-borne parasites, risk-based surveillance is well-established for *Trichinella,* and coming into force in December 2019 for *T. saginata.* For *T. gondii,* the current official mitigation approach is to evaluate how large the risk is, and whether intervention is needed. There are opportunities to expand similar principles to other hazards as well. Collaboration with the food business operator, consumers, NGOs and other organisations in the food system should be considered by identification of values, common interests, sharing of data and joint action. Finally, the surveillance system should be evaluated in a systematic way on a regular basis to ensure that the resources spent are providing value for money.

Declaration of competing interest

LA works for an organisation that gives advice to farmers and abattoirs.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.exppara.2019.107808.

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[3] Website under construction.

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