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General Interest

Implementation of Visual-Only Swine Inspection in the European Union: Challenges, Opportunities, and Lessons Learned

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ABSTRACT

Consumption of contaminated meat and poultry products is a major source of foodborne illness in the United States and globally. Meat inspection procedures, established more than 100 years ago to detect prevailing food safety issues of the time and largely harmonized around the world, do not effectively detect modern hazards and may inadvertently increase food safety risks by spreading contamination across carcasses. Visual-only inspection (VOI) is a significantly different, modernized meat inspection system that is data driven and minimizes physical manipulation of the carcass during inspection. It was developed based on scientific evidence and risk assessment and aims to better control current food safety hazards. In 2014, the European Union (EU) became the first supranational government in the world to require VOI for all swine herds slaughtered in member states that met certain epidemiologic and animal rearing conditions. Here, we review the implementation of this new inspection system with the goal of informing similar modernization efforts in other countries and for other commodities beyond pork. This article reports the results of a literature review and interviews conducted with nine experts in 2018 on the implementation of the EU's 2014 VOI regulation. Challenges, opportunities, and lessons learned about the implementation of the regulation are described for audiences interested in adapting inspection procedures to prevent and detect modern food safety hazards. Overall, implementation of VOI varies within and across member states, and among slaughterhouses of different sizes. This variation is due to disease risk patterns, supply chain conditions, and trade barriers. Before transitioning to a similar risk-based meat inspection system, other countries should consider the following: science-based research agendas to identify what food chain information best predicts herd health and foodborne hazards, regulatory system design that accurately reflects local hazards, and development of targeted VOI educational materials.

HIGHLIGHTS

- Visual-only inspection is a viable option for meat inspection modernization.
- Implementation in the EU varies by member state and by operation size.
- Trade barriers, poor food chain data, and local hazards can impede implementation.
- Robust, integrated information systems are needed to support visual-only inspection.

Key words: Food chain information; Risk-based; *Salmonella*; Supply chain meat inspection; Swine; Visual-only inspection

Globally, foodborne hazards cause an estimated 600 million illnesses and 420,000 deaths each year, with a significant portion of the burden attributed to tainted meat and poultry either consumed directly or after contaminating other foods during preparation *(48, 87)*. Nontyphoidal *Salmonella* is the leading cause of foodborne deaths, and pork, poultry meat, and eggs are identified as important sources of foodborne *Salmonella* infections worldwide *(48, 87)*. In the United States, the incidence of foodborne *Salmonella* infections was 17.1 cases per 100,000 persons in 2019 and has not declined in 10 years *(73)*. *Salmonella*-contaminated pork ranked among the top five leading causes of outbreaks, outbreak-associated illnesses, and hospitalizations between 2009 and 2015 *(21)*. The national prevalence of *Salmonella* in raw U.S. pork products sampled from slaughter and processing-only establishments is estimated to be 28.9% for ground pork, 5.3% for intact cuts, and 3.9% for nonintact cuts *(71)*. In the European Union (EU), salmonellosis cases are the second most common foodborne infection, with an incidence of 20.1 cases per 100,000 persons in 2018 (behind campylobacteriosis at 64.1 per 100,000 persons), and according to the latest available data, no statistically significant change in the number of illnesses occurred between 2013 and 2018 *(35)*. Pork is considered one of the most relevant sources of human salmonellosis cases in the EU, and *Salmonella* is commonly detected at multiple points in the pork production chain (feed, herds, and fresh meat) *(14, 16, 30–33)*.

The lack of reduction in the number of salmonellosis cases has prompted critical examination of current meat safety systems. Meat inspection programs are designed to

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protect the public from exposure to meat-borne hazards and to ensure the safety and quality of meat products consumed domestically or when exported for international markets *(45, 60)*. Inspection systems in the United States and most industrialized nations were designed over 100 years ago to address the most prevalent food safety risks at the time. Early meat inspection techniques were designed to detect grossly visible lesions, abnormalities through manual palpation and incision, and contamination or disease that could be detected by a distinct odor *(60, 81)*. Infectious diseases like tuberculosis, brucellosis, and trichinosis posed a large threat to public health at the time, some changing the physical characteristics of the carcass, an attribute that made early meat inspection techniques effective *(23, 45, 60, 62, 81, 84)*. Modern infectious diseases of concern typically do not physically change the carcass and cannot be detected by the same inspection techniques.

Inspection procedures designed to detect previously common zoonotic diseases have minimal connection to current public health risks from foodborne pathogens and do not efficiently use inspection resources *(28, 45, 81)*. The incision and palpation of organs has long been identified as a risk factor for cross-contamination and the spread of modern food safety hazards, e.g., *Salmonella, Campylobacter,* or *Yersinia (7, 28, 43, 60, 70)*. Most *Salmonella* infections are harbored in lymph nodes, do not change their appearance, and do not produce observable symptoms in the infected animals. Because these infections are far more prevalent than tuberculosis or brucellosis *(9),* incision and palpation of the lymph node in infected animals increases the probability of carcass cross-contamination and creates a public health risk that is far greater than the risk of not palpating and incising the lymph node and missing a very rare disease like tuberculosis.

Modernization of meat inspection programs may help ensure that consumers are protected. A "modern" meat inspection system emphasizes the use of risk analysis principles to identify relevant hazards and revise meat inspection procedures to better protect human health *(4, 23, 39, 60)*. Visual-only inspection (VOI) is a risk-based postmortem meat inspection technique that does not use incision and palpation. The decision to perform VOI is determined on a herd-by-herd basis and is informed by herd health information from the producer, antemortem inspection results, and other information. Lesions or abnormalities identified during visual inspection would indicate that incision, palpation, or other inspection procedures are warranted to verify the animals are safe for human consumption. The European Food Safety Authority conducted risk assessments comparing the public health implications of adopting VOI for swine versus traditional inspection and concluded that incision and palpation reduces the overall microbial safety of meat and creates health risks that outweigh the potential protective effects of detecting lesions caused by rare diseases like tuberculosis *(28)*. The EU then revised meat inspection regulations to require VOI for swine if epidemiologic and other data indicated a low risk of infection for conditions requiring palpation and incision for detection *(24–26)*. Performance of incision and palpation or other procedures in addition to or instead of VOI would be beneficial for reducing human health risks when information indicates an increased probability of risk to human health. Presented here are the results of a literature review and interviews with EU experts on the implementation of the VOI regulation in the EU.

BACKGROUND

Progress in animal disease control and implications for meat inspection. Zoonotic diseases that were detectable by traditional meat inspection in the past have become rare today. National disease surveillance and eradication programs have drastically reduced the incidence of tuberculosis and brucellosis in developed countries in the last 50 years *(66, 77)*. In the United States, swine brucellosis has not recently been detected in commercial production swine herds, with the last detection dating back to 2017 *(75, 76)*. The National Tuberculosis Eradication program is credited with reducing the prevalence of tuberculosis infection in cattle from 5.0 to less than 0.01% *(61, 77)*. The same bacteria that cause bovine tuberculosis can infect pigs. Transmission may occur through contact with wildlife hosts like white-tailed deer or through shared grazing ground with infected animals, making bovine tuberculosis a concern in outdoor swine production *(17)*. However, traditional manual inspection of swine carcasses in the slaughterhouse is of limited importance in countries that have eradicated bovine tuberculosis and sufficiently controlled infection in wildlife populations *(38, 57, 86)*. Performance of inspection procedures to detect bovine tuberculosis is unnecessary in these countries, unless relevant abnormalities are observed. Furthermore, bovine tuberculosis is not a recognized animal health problem in domestic pig populations managed under controlled conditions in developed countries *(28)*. These improvements to animal disease control have been accompanied by reassessment of meat inspection procedures for their relevance to food safety outcomes *(66)*.

Steps toward updating the meat inspection system based on modern food safety risks began approximately 40 years ago with research on the reduction of carcass handling to control cross-contamination from *Salmonella* and other pathogens *(22, 46, 59, 81),* and efforts continue in industrialized countries around the world to modify and improve inspection practices, initially for swine *(18, 28, 66, 80)*. Early proposals for an updated risk-based inspection system recognized that shifting some food safety responsibility to the farm by requiring producers to take a more prominent role in preventing zoonotic infections in livestock created opportunities to reallocate inspection resources and reduce cross-contamination in the slaughterhouse *(58)*. VOI was recommended as part of an integrated quality control program that included a mandatory feedback information system from the slaughterhouse to the farm to enable pig producers to monitor and improve the quality of their stock *(58)*. Following quantitative and qualitative risk assessments, VOI was identified in the EU as a viable risk-based alternative to traditional inspection techniques for swine *(4, 28, 58)*. Multiple studies have further indicated VOI has the potential to reduce consumer exposure to

Salmonella and other bacterial hazards through reduction of cross-contamination *(18, 28, 67)*.

Evidence for need of alternate methods to control *Salmonella*. Current evidence indicates that meat inspection and slaughter interventions alone are not sufficiently reducing *Salmonella* levels and that controls along the entire swine production chain are necessary to reduce contamination *(2, 6, 12, 14, 65, 79)*. U.S. and European markets are following the same trend toward concentrating pig production among a few large integrators, which creates conditions that allow pathogens like *Salmonella* to infect large numbers of animals and have similar burdens of salmonellosis caused by contaminated pork. Findings from intervention studies from the United States and the EU could, therefore, be informative (while considering generalizability of the data to geographies that differ in animal health epidemiology, farm size, integrator structure, and slaughterhouse technology) *(48, 51, 52, 65)*. For instance, a risk model using Danish data demonstrated that only a combination of interventions in multiple stages of production would lead to significant reductions in *Salmonella* contamination because cross-contamination can occur at multiple points in the production chain; interventions included lowering the proportion of high-risk herds, increasing the efficacy of singeing (flaming the skin to remove hair and reduce bacterial contamination), and reducing contamination and cross-contamination at evisceration and during handling *(2)*. Preharvest interventions in combination with good slaughterhouse practices have been identified as essential to reduce microbial contamination in meat in both the United States and the EU *(2, 6, 12, 79, 85)*. Moreover, a systematic review using U.S. and international (EU, Australia, Brazil) data sources found that no single intervention after slaughter is superior in controlling *Salmonella* concentrations on pig carcasses *(74)*. Together, these studies indicate that multiple pre- and postharvest interventions aimed at production and processing steps that pose the greatest contamination risks would be most effective at reducing microbial contamination. They also suggest that an integrated risk-based meat safety system that includes VOI would be more effective at controlling hazardous bacteria like *Salmonella* than traditional postmortem meat inspection alone.

History of the EU's VOI regulation. Acknowledging increasing scrutiny of the public health relevance of traditional meat inspection in the modern meat industry, the European Commission asked a panel of experts in 2000 to provide an opinion concerning revisions to meat inspection procedures for swine *(4, 70)*. The panel concluded that mandated meat inspection procedures do little to improve food safety and protect consumers, and likely cause cross-contamination *(70)*. Based on this assessment the EU issued Regulation (EC) No 853/2004 and Regulation (EC) No 854/2004 in support of risk-based meat inspection *(4, 25)*. This regulation allowed (but did not require) VOI for swine raised in indoor controlled housing if a risk assessment could demonstrate the change would cause no harm to human or animal health. Only indoor-raised pigs were allowed because they were perceived as having a lower risk of infection with diseases that require incision and palpation for detection due to restricted contact with wildlife reservoirs. Core principles of the 2004 regulation—strengthening the responsibility of the food processor, prevention and continuous process improvement, and risk-oriented decision making—reflect the EU's shift in perspective on food safety concepts from end product–focused inspection to improving safety along the entire production chain *(10)*.

Denmark was one of the first countries to conduct and publish a series of risk assessments, and it was concluded that there is no increased risk associated with omitting incision for mandibular lymph nodes, intestinal lymph nodes, heart, liver, and lungs *(3, 4, 63)*. After release of the European Food Safety Authority (EFSA) 2011 Opinion on VOI in swine, the EU Commission made a revision to meat inspection regulation in 2014, specifying VOI should be used in all swine irrespective of age and way of rearing as the default postmortem inspection approach, unless information indicates incision and palpation are needed to detect a potential risk to public health *(28)*. Information for classification of herd-level risk includes using epidemiological data such as regional prevalence of *Salmonella* spp., *Yersinia enterocolitica, Toxoplasma gondii,* and *Trichinella* spp.; data on housing conditions and herd health from holdings; and antemortem or postmortem inspection findings *(26, 29)*. This evidence is collectively referred to as Food Chain Information (FCI) and covers general items, including relevant animal health status data from the farm or region; the herd's health status; veterinary medication or other treatments administered to the animals within a relevant period, dates of administration, and withdrawal periods; disease occurrence relevant to meat safety; the results of diagnostic tests relevant to the protection of public health; previous ante- and postmortem inspection reports from the same farm; production data indicating the presence of disease; and the name and address of the responsible veterinarian (reference *24*; see Annex II, Section III, Point 3 for FCI definition). Data indicating a herd coming to slaughter is high risk (interpretation of high risk may vary in different member states) signal the processor to revert to traditional inspection for that herd. Individual carcasses may also be rerouted for extended inspection if signs of infection are visually detected.

Swine inspection modernization in the United States and other countries. Australia recently approved VOI as an equivalent alternative to postmortem inspection procedures for all indoor- and outdoor-raised swine that are registered in a national tracking system called "PigPass" and are accompanied by the mandatory transportation documents identifying the property of origin *(42)*. New Canadian food safety regulations came into effect in early 2019 and included updated risk-based inspection procedures allowing slaughterhouse employees to identify hog carcass defects before presenting the carcass to Canadian Food Inspection Agency inspectors *(55)*. This system allows inspectors to focus on detection of food safety concerns during carcass-by-carcass inspection and on slaughter system oversight rather than expending those efforts on defect detection. The Canadian regulations still require incision of mandibular lymph nodes, although VOI has been recommended by Canadian researchers *(41, 68)*. Other lymph nodes and organs are to be visually inspected unless abnormalities are detected and indicate that further palpation and incision are needed.

VOI is not currently in place in the United States *(80)*. The U.S. Department of Agriculture, Food Safety and Inspection Service (USDA FSIS) recently finalized a rule to modernize swine inspection that creates an opt-in program called the New Swine Inspection System. In operations that choose to adopt this program, slaughterhouse employees are required to incise mandibular lymph nodes and palpate viscera before postmortem inspection by an FSIS inspector. USDA determined that more information is needed to understand the public health impact of VOI in the United States before developing additional rulemaking that would allow establishments to make the decision to visually inspect carcasses on their own. To obtain this information, establishments interested in adopting VOI can apply for a waiver, provided they can supply data showing diseases caused by bacteria like *Mycobacterium avium* are "not reasonably likely to occur" in herds. Establishments are further required to submit data to FSIS after the waiver is granted (criteria for these waivers will be announced by FSIS at another time) *(80)*.

Approach for literature review and interviews. With other countries considering or in the process of integrating VOI, meat inspection modernization efforts in the EU can serve as a case study for understanding the challenges and opportunities in implementing updated meat safety policies. The strengths and weaknesses of the traditional meat inspection system as well as of the VOI system as designed are described elsewhere *(28, 82)*; however, the implementation of a modern risk-based inspection regulation has not been well characterized in the literature. The objective of this article is to describe some of the opportunities and challenges of implementing VOI, to characterize the current state of its implementation in the EU (Regulation [EC] No 853/2004, Regulation [EC] No 854/2004, which was repealed and replaced with Regulation [EC] No 2019/627 in December 2019, and amendment Regulation [EC] No 218/2014), and to gather lessons learned for audiences interested in implementing similar changes to meat inspection systems in other countries or for other animal species.

The analysis presented here was informed in part by nine informal semistructured interviews with EU food safety experts representing industry, academia, nongovernmental organizations, and government (results are summarized in Table 1). Interviews were conducted because implementation of VOI is ongoing and analyzing the literature may not provide a complete picture of the issue due to factors such as lack of publication, publication in the gray literature inaccessible to the food safety community, or studies that are yet to be published. Interviews also offered an opportunity to capture perspectives from multiple EU countries and stakeholder groups and identify topics important to implementation efforts to target for literature review. Interviewees were identified through a review of the literature, conference proceedings, government agency reports, membership listings of food safety and veterinary experts, and peer nominations (details on the interviews available from the corresponding author on request). All interviewees were given an opportunity to review a draft of the manuscript before publication. Approval processes, FCI, training, communication, trade, cost, and enforcement were primary factors influencing the rate and success of VOI implementation identified from the literature review and interviews. Table 1 presents a summary of key points from interviews.

LOGISTICS OF VOI IMPLEMENTATION AT THE SLAUGHTERHOUSE LEVEL

EU regulations (EC) No 853/2004 and No 2019/627 require that VOI systems be scientifically sound and not result in any increased food safety risks or risk to animal health and welfare *(24, 25, 27, 28)*. Risk assessments should assess the unique regional disease risks or other risks associated with production conditions prior to VOI implementation *(50)*. Important risk factors are rearing environment (i.e., indoor controlled housing, outdoors foraging) and animal health and disease epidemiology for specific regions *(36, 53, 54)*. FCI, which may include epidemiologic data and serological testing results, is used to classify herd risk level and can inform the order in which herds are slaughtered *(13)*. In this approach, known as logistic slaughter, high-risk herds are transported and slaughtered after low-risk herds to reduce the risk of cross-contamination in transport and lairage and from slaughterhouse equipment and environment *(49)*. Specific conditions for a slaughter company's VOI system may vary by member state's competent authority; however, an electronic or paper-based FCI system is required by regulation before VOI can be performed *(15, 24)*. FCI must arrive at the slaughterhouse 24 h in advance of the animals to be slaughtered, with an exception for small operations that allows FCI arrival at the same time as the herd *(5, 24)*. Figure 1 illustrates a generic information system supporting risk-based swine inspection and herd risk ranking. The figure demonstrates how the flow of meaningful information from the processor to the farm can form a feedback loop to help improve herd health.

Some studies recommend operational guidelines to standardize inspection decisions, and an accompanying serological monitoring program to minimize errors in disease detection before implementation *(1, 12, 40, 53)*. Flexibility is also an important factor in preparing slaughterhouse operations for VOI; because supply chain conditions (e.g., the number and size of herds, ease of information exchange, and differential risk patterns geographically and by slaughter operation) all influence the availability of FCI, flexible use of these data is necessary to make risk-based inspection decisions about incoming herds

TABLE 1. *Summary of results from semistructured interviews*

Topic	Summary of main points
Implementation	Implementation varies by member state, within member states, and by operation size.
	Food chain information (FCI) plan must be developed before implementation.
	System must be at least as safe as traditional meat inspection.
Advantages	Shift in responsibilities allows time for ensuring facility hygiene and thorough inspection of smaller number of animals.
	Information feedback to farms on herd health issues creates improvement in biosecurity measures and reduced production risk for farmers, e.g., financial loss due to carcass condemnation.
	Faster slaughter line, enabled by investment in redesign of conveyor system.
	Basic equipment required, e.g., mirrors and additional lighting sources.
	Fewer mistakes through informed risk classification of herds.
Challenges	No official procedure or method to guarantee a proposed slaughterhouse VOI system is safe.
	Equivalence not established for all trade partners, limits use of VOI to domestic product.
	Serological testing, electronic data systems, slaughterhouse redesign may be expensive initial investment.
	Strategies are needed to communicate food safety advantages to official veterinarians, slaughterhouse employees, and other stakeholders, accounting for language barriers and potentially frequent meat inspection staff changeover.
	Inspectors' unions, veterinarians worry abattoirs will use VOI regulation to justify reducing the workforce.
	Difficult to ensure accurate FCI, analyze, and combine with meat inspection results for full herd health profile.
	Cost savings may only be realized in large slaughterhouses.
	Lack of technology (e.g., integrated computer systems) may hinder performance of risk-based inspection no matter the size of the slaughterhouse or quality of paper-based recordkeeping.
Lessons learned	Provide detail on requirements for FCI in regulation or designate central authority to ensure system is scientifically sound.
	Emphasize importance of animal disease epidemiology, risk assessment, development of integrated FCI system with serological monitoring, and good slaughterhouse technique.
	Improve training programs to highlight food safety benefits, decision making using diagnostic tests, techniques for risk identification, and regional animal health epidemiologic factors that influence food safety risk.
	Need incentives and legislative pressures for slaughterhouses and farms.
	Focus on food safety advantages and improvements to animal health and welfare in communication plans.

(12). The use of VOI may be decided on a herd-by-herd basis, dependent on the official veterinarian's evaluation of FCI, serological test results, and previous meat inspection results from the same producer. These factors help determine the likelihood of safety risks that are only detectable through incision or palpation or other inspection procedures, based on the history of public health–relevant infections in the herd and from other herds from the same farm. Abnormalities observed during VOI may also indicate that additional inspection tasks are needed to verify that the animals are safe for human consumption. A planned workflow and a designated rework area are also recommended to be in place to perform traditional meat inspections when the official veterinarian decides a herd is high risk or if lesions are detected in individual carcasses.

Implementation of VOI requires a shift in skill sets of slaughterhouse employees. Training is necessary for inspectors or official veterinarians to evaluate data sets and visually recognize disease instead of palpating or incising to inspect organs *(1, 40)*. Official veterinarians may expect to adapt to new tasks, including working on computers to analyze FCI. Guidance for farmers may be required to increase accuracy in reporting FCI *(36)*.

Effective communication is a necessity in conveying the conceptual basis for VOI and the steps for process implementation. In pilot studies, slaughterhouse operators initially believed that the only steps necessary for implementation were changes to the slaughter line, and veterinarians expressed concern that the system would leave gaps in food safety *(5, 54)*. Therefore, slaughterhouse employees, official veterinarians, and inspectors first need to understand the food safety advantages of not incising or palpating organs to fully support the transition to VOI.

STATUS OF VOI IMPLEMENTATION IN THE EU

Regulation (EC) No 218/2014 requires VOI in all member states, but actual implementation varies among slaughterhouses of different sizes, within member states and provinces, and among member states *(1, 5, 15)*. This is due to large variability in supply chain conditions (level of operation integration, quality of food chain data exchanged among feed manufacturer, farm, and slaughterhouse), disease risk patterns among slaughterhouses, regions, and member states (depending on operation capacity, rearing environment, and housing conditions), and trade barriers with countries outside the EU that have not accepted VOI in swine *(1, 5, 54)*. EU member states with existing trade agreements based on traditional inspection need to renegotiate new inspection conditions with trade partners before VOI can be implemented in exporting slaughterhouses. Additionally, EU member states that had obtained acceptance of equivalence of VOI for indoor-raised swine herds

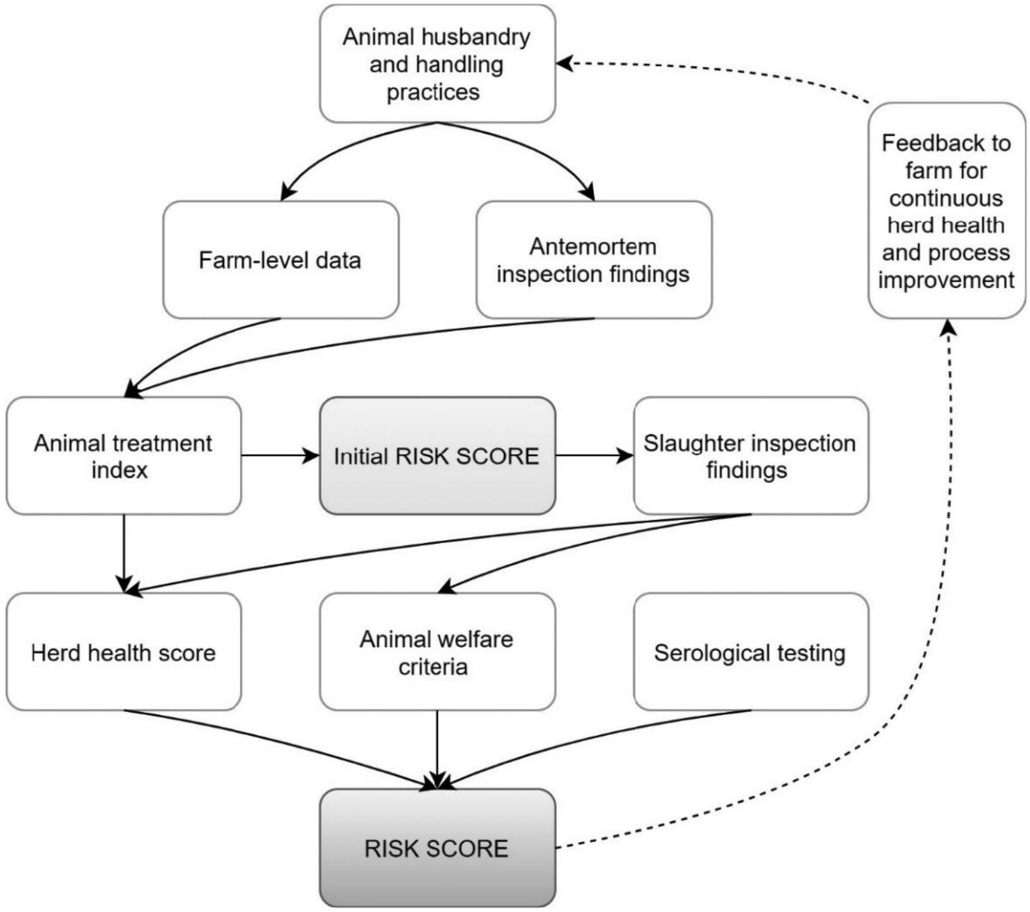

FIGURE 1. *An example of the components of a food chain information system for risk-based meat inspection and how they may be organized. Inputs are information from the farm and antemortem inspection that signal deficiency or success in animal husbandry, genetics, or animal handling (54). Indices, for example, the Animal Treatment Index (ATI), can serve as a semiquantitative assessment tool for herd morbidity, where ATI = [(no. of treated animals) (no. of treatment days)/total no. of animals in herd] and contributes to an overall herd health score that includes slaughter inspection findings (11). The ATI, other relevant FCI, and antemortem inspection results may be combined to calculate an initial risk score (e.g., low, medium, high) that determines the inspection level. Low-risk herds would be subjected to VOI, medium-risk herds would go through traditional inspection, and high-risk herds would be subject to extended inspection (11). Meat inspection results (e.g., number of lesions, reasons for carcass condemnation) could then be combined with other measurement tools, for example, a herd health score or animal welfare criteria, and serological monitoring results to calculate a final risk score for the herd, which would be transferred back to farmers to improve herd health and food safety (13, 53, 54). Serological monitoring includes testing for zoonotic, production, and notifiable diseases. Cumulative inspections results and FCI over months may be used to assess risk level of farms and predict the risk scores of incoming herds.*

would need to renegotiate for outdoor-reared pigs, sows, and boars.

The VOI regulation requires establishment of an FCI system, which is easier to implement in fully integrated swine operations where farm of origin information is more readily obtained and may partly explain differences in implementation across slaughterhouses *(15, 40)*. Differences in VOI implementation are also due to variation in the usage of FCI among member states, some persons regarding FCI as highly valuable whereas others consider the data useless *(5)*. In EU operations, investments in equipment such as redesigned pluck conveyor systems (allowing one inspector to see lungs, heart, liver, tongue, above the intestines placed on the conveyor belt) may be needed for slaughterhouses to increase line speeds. In most cases, this results in cost reductions only for large high-throughput slaughterhouses and may also create differences in implementation among small, medium, and large slaughterhouses *(5)*.

OPPORTUNITIES ASSOCIATED WITH THE IMPLEMENTATION OF VOI

Although the majority of EU member states have not fully implemented VOI due to the need for acceptance of equivalence in importing countries *(1, 5),* opportunities associated with implementing VOI have, nonetheless, been identified. They include improved food safety, a feedback system to farmers to continuously improve herd health and welfare, associated cost savings, and a data-sharing system that enables standardization, benchmarking, and animal traceability *(1, 19, 20, 54)*. Through collection of FCI, large amounts of meaningful information and data can be collected to improve farm practices and slaughterhouse processes.

VOI may reduce cross-contamination from *Salmonella* spp. in pigs with subclinical infections and does not significantly increase the probability that diseases relevant to animal health will not be detected, for instance, foot and mouth disease *(40, 47, 58, 72)*. Early studies predicted, and a more recent implementation study in Germany observed, that less time spent incising and palpating organs allows inspectors to perform other duties that ensure hygienic conditions in the facility; it allows them to spend more time inspecting incoming herds, on high-risk carcasses or on a smaller percentage of animals for more thorough inspections *(12, 58)*. Meat inspectors may be amenable to the reduction of monotonous repetitive tasks and reassignment to more stimulating work, and they also benefit from reduced exposure to occupational hazards *(39)*. Furthermore, pigs raised under controlled housing with limited access to outdoors are at low risk of being carriers of two other relevant pork-borne hazards not detectable by incision or palpation, *T. gondii* and *Trichinella* spp. *(28)*.

Implementation of VOI strengthens the producer-processor relationship, and there can be a positive impact on farm practices when feedback is consistently and transparently provided to producers on diseases identified in herds *(20)*. Serological monitoring is not widely used in the EU; however, The Netherlands and Denmark have had success using it to detect low prevalence, asymptomatic diseases in swine (*M. avium* and *T. gondii* in The Netherlands, and *Salmonella* in Denmark) that are sometimes unfamiliar to farmers. Providing feedback to farmers on unfamiliar diseases found during slaughter from serological testing can open lines of communication and lead to improvement in biosecurity measures *(5)*. For example, a large swine processor in The Netherlands visits farms in their VOI regime if serology indicates a high prevalence of *M. avium* or *Toxoplasma (5)*. The Dutch processor helps design biosecurity measures or changes to husbandry practices to reduce herd infection rates and associated production risks for the producers. Continuous FCI feedback provides opportunities for improvement to herd health and reduces financial losses to farmers through carcass condemnation *(20)*.

CHALLENGES OF VOI IMPLEMENTATION

Major challenges associated with implementation of the VOI system are a lack of central approval systems, exportation limits, costs, and building efficient and accurate FCI systems *(15, 36, 44)*. There is no official procedure available for approving plans to implement VOI in slaughterhouses across the EU; however, some member states (e.g., The Netherlands) do have an official procedure in place.

Establishing acceptability of meat inspected under VOI with trading partners in export countries has been considered a major challenge and has slowed the adoption of VOI *(15)*. Some countries previously established equivalence using the 2004 regulations (VOI allowed only for indoor-raised finishers), whereas because the 2014 amendment requires VOI for all pigs regardless of age or type of housing system, trade agreements need renegotiation based on this change *(1)*. Equivalence is a process to determine whether an exporter's inspection system achieves the same level of public health protection as the importer's inspection system *(78)*. Challenges in controlling zoonotic diseases are another barrier to implementation. Epidemiologic data must indicate there is no increased risk to human health under VOI, and in some countries, high-risk diseases like bovine tuberculosis have not been completely eradicated *(56)*.

Costs associated with adopting VOI systems may be prohibitive for some slaughterhouses. Monitoring and surveillance programs, FCI systems, handheld electronics for recording lesions observed during inspection, large-scale trials to verify the process is comparable to or more efficient than traditional meat inspection for detecting lesions, or facility renovations may pose a large expense for slaughterhouses and may be limiting for smaller slaughterhouses *(1, 5)*. However, costly electronics and major renovations are not always necessary. Paper-based data recording and modification of existing software programs to make risk-based inspection decisions are a reasonable alternative for smaller operations *(12)*.

Obtaining sufficient and accurate FCI is a key implementation challenge. The current EU regulation gives a flexible framework for member states to make modifications for specific microbiological problems and food safety issues in cooperation with their producers and processors. Interviewees suggested that implementation of VOI in the EU would have been aided by providing more detail in the regulation about what FCI is most valuable for making risk-based inspection decisions, for instance, antibiotic usage, herd mortality rate and number, and indicator organisms for monitoring *(53)*. However, there are varying degrees of success using the prescribed FCI and other relevant information across the EU. Several studies have reported complicating factors beyond identifying appropriate FCI. Farmers may provide irrelevant, incomplete, or inaccurate information or may not provide specific data needed for risk-based meat inspection *(36, 83)*. These studies suggest the need to modify the structure and design of the forms to make them easier to fill out by farmers.

Fostering positive relationships and trust across the food chain may facilitate improvements to FCI accuracy and information exchange *(20, 64, 69)*. For example, EU farmers recognize the potential benefit of using meat inspection data to inform planning for herd health and welfare, but they report that processor feedback is inconsistent. Processors may condemn carcasses without providing reasons for condemnation, and producers also find that feedback on health or quality issues varies depending on the processor. One processor may consistently condemn herds for one reason, whereas another processor may condemn herds from the same farm for other reasons *(20)*. This inconsistency and lack of transparency in feedback from processors may create distrust among producers *(19)*. To minimize error in inspection results and improve the consistency and perceived objectivity of information conveyed back to farmers, slaughterhouse operational guidelines are recommended to increase reliability and standardization of inspection data, to include a standardized definition of lesions and reasons for condemnation *(1, 5, 20, 40)*. Accuracy in all pre- and postharvest FCI is essential for making risk-based decisions about herd health and the type of inspection to use, as illustrated in Figure 1 (i.e., visual or traditional depending on the herd risk levels) *(36, 53)*.

KEY LESSONS LEARNED

Research is needed to identify what FCI best predicts public health hazards. Coordinated and comprehensive proof of concept studies for specific FCI were not carried out across the EU before VOI was required by the 2014 regulation. These studies are needed to evaluate the utility of FCI components for their accuracy in informing herd risk ranking in the farm and slaughter conditions under which the FCI is intended to be used. Prior to implementation, science-based evaluation is needed to identify what factors best predict risk, whether specific predictors vary geographically, or whether there are a standard set of factors that can be used broadly by all swine operations to consistently and accurately assess herd health risk *(29)*. If FCI cannot be identified that is applicable for all swine operations across a country, an open framework for FCI may be more appropriate.

Regulatory systems should accurately reflect local hazards. A robust VOI system approval process should emphasize use of an integrated FCI system for epidemiologic evaluation of animals and herd health at regional levels and sensitive diagnostic monitoring systems that are specific and targeted to detect hazards (e.g., *M. avium*). Awareness of geographical variation in the prevalence of foodborne pathogens to ensure that implementation appropriately addresses foodborne risks in the United States is important to veterinarians and food safety experts. For example, swine lymph node samples from U.S. slaughterhouses show that *Salmonella* prevalence varies by region and by production class *(8)*. In regions or production classes where *Salmonella* infection is more prevalent, emphasis should be placed on supporting performance of VOI because the risk of cross-contamination from lymph node incision may be higher. Approval procedures should also highlight development of VOI systems that outline use of standardized slaughterhouse guidelines for detecting and reporting lesions to reduce variation in detection among slaughterhouses or by inspectors within slaughterhouses *(5, 40)*.

Targeted VOI educational materials are needed. A strong educational campaign is recommended to communicate the opportunities associated with VOI to producers, processors, meat inspectors, and veterinarians, with discussions emphasizing benefits to food safety, slaughterhouse safety, and occupational health of workers *(15)* (Table 1). Communications should also emphasize how VOI systems may reduce foodborne illness risks to consumers compared with traditional inspection.

Training programs and improved guidelines were recommended for operators, veterinarians, and inspectors *(1, 5, 40)*. Veterinary inspectors or risk managers need proper training on decision-making, with an emphasis on choosing diagnostic tests and techniques for risk identification *(15)*. Training and standardized procedures for reporting are also needed to increase the accuracy of FCI from producers *(36)*.

DISCREPANCIES IN PERSPECTIVES AND OPPORTUNITIES FOR FURTHER RESEARCH AND ANALYSIS

Cost is an important consideration, but uncertainties remain on exact costs for implementation and return on investments. Reduced inspection costs allow for reallocation of resources to hygiene and surveillance tasks *(44, 58)*. Initial investments may be needed for slaughterhouse equipment and electronic data systems to ease data integration and risk ranking. Establishment of a surveillance program so that FCI can be readily transferred from the farm to the slaughterhouse may be expensive and appears to have impeded its use, slowing implementation of VOI in some member states in the EU *(15)*. However, it was demonstrated that VOI systems could be implemented in slaughterhouses of all sizes, from large multinational integrators to midsized family-owned operations *(12)*. In terms of serology, the cost-effectiveness of a serological testing program needs evaluation along with further research for improving the sensitivity and specificity of test results *(15, 37)*. Research is also needed to reduce the amount of uncertainty in evaluating the relationship between the presence of food safety hazards and serological test results, given that some findings may indicate past infections that are no longer a threat to humans *(15)*.

EU's summary report on outbreaks in 2017 indicates that there is no specific surveillance program for slaughterhouses that have implemented the regulation; therefore, the overall efficacy of the regulation in reducing contamination on pork carcasses by comparing EU processors that have implemented VOI to those that are not using VOI cannot be assessed *(34)*. Although no link has been proven between implementation of the VOI regulation in slaughterhouses and the burden of human illness due to *Salmonella* contamination in pork, *Salmonella* outbreaks connected to pig meat appear to have dropped from 9.0% (of all causes) in 2013 to 4.5% in 2017 *(30, 34)*. More work is needed to evaluate the contamination-reducing capacity of VOI systems and any correlated reductions in human salmonellosis cases.

CONCLUSIONS

VOI is a viable method for modernizing inspection of low-risk swine herds in developed countries when integrated with FCI systems, preharvest controls, epidemiologic indicators of herd health, and training programs for swine producers and processors. Risk assessments should be performed before VOI and any other changes to the slaughter inspection system are implemented. Key implementation challenges are establishing equivalence with trade partners and determining what implementation parameters should be predefined and what should be left to the discretion of the processor. Potential opportunities associated with implementing a VOI regulation are reduced operational costs and better use of resources by shifting attention to herd health and plant hygiene, improvements to farm biosecurity, and reduced production risks to farmers. To protect public health, implementation should, however, be integrated with other changes to meat inspection, including robust FCI systems, serological monitoring programs, accurate risk classification of herds, and further critical analysis of systemic issues in meat production that can impact food safety and public health.

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