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Meat inspection and hygiene in a Meat Factory Cell – An alternative concept

Ole Alvseike [a, *], Miguel Prieto [b], Kristin Torkveen [c], Cecilie Ruud [c], Truls Nesbakken [d]

[a] Animalia – Norwegian Meat and Poultry Research Center, P.O. Box 396 Økern, N-0513 Oslo, Norway
[b] Department of Food Hygiene and Food Technology, Faculty of Veterinary Medicine, University of León, Campus de Vegazana, E-24071 León, Spain
[c] Norwegian Food Safety Authority, Felles postmottak, Postboks 383, 2381 Brumunddal, Norway
[d] Dept. of Food Safety and Infection Biology, Norwegian University of Life Sciences, P.O. Box 8146 Dep, N-0033 Oslo, Norway

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ABSTRACT

The Meat Factory Cell (MFC) concept differs from conventional abattoirs by partly working in cell stations instead of production lines. It combines and merges elements of today's separate processes and disciplines, namely "slaughter" and "meat primal cutting", and "disassembles" the carcass from outside-in where limbs, neck, back and loin are removed before internal organs. The aim of this work is to qualitatively assess future meat inspection and hygiene of pork carcasses in the MFC. A holistic assessment of the carcass parts is needed to interpret the significance of findings on separate parts. The MFC offers some opportunities for targeted inspection with cutting edge diagnostic technology. Improved hygiene is expected from the MFC concept due to the fact that limbs, neck and loin are removed first and are not subject to faecal contamination from intestinal content. The MFC provides opportunities for customized chilling regime for different parts, targeted decontamination or pathogen killing processing, which should contribute to safer meat products and less energy consumption. We expect that the MFC approach will potentially fulfill the principles of *Codex alimentarius* and will improve public health compared to conventional slaughter and meat inspection.

1. Introduction

To some extent food legislation in the European Union (EU) and the European Economical Area (EEA) describes how industrial meat processing should be done. An example is that the "Carcasses of domestic ungulates may be cut into half-carcasses or quarters, and half carcasses into no more than three wholesale cuts, in slaughterhouses. Further cutting and boning must be carried out in a cutting plant." (EC, 2004a, p. 127) (Annex III Chapter V 1).

Such normative phrases do not encourage sound development in the industry, and might slow down highly needed innovation. Instead, functional demands would create space for new approaches that adopt and utilize new technologies. A good example is "They must have facilities for disinfecting tools with hot water supplied at not less than 82 °C, *or an alternative system having an equivalent effect*" (EC, 2004a, p. 127).

Increased productivity is crucial for competitiveness of industrial sectors. The trend has been to improve efficiency by scaling-up and speeding-up production lines in order to reduce unit costs. Automation solutions have so far addressed a traditional line set-up. Large capacities but huge investments, low flexibility and reliability are key traits of meat production facilities today. Consequently, a parallel trend has been an attempt to standardize animals to fit the factory in size and qualities (Barbut, 2014). This traditional line-solution approaches a point where it is not sufficient or sustainable, especially in markets with relative low volumes, long transport distances, non-specialized slaughterhouses and high workforce requirements (Lay, 1997). In a global perspective it is also a question of food security: Technology for efficient utilization of important food resources in marginal regions is needed.

We have searched for approaches that both better fulfill the intentions in the regulations than conventional slaughter and cutting practices, and carry potential for automation for even smaller plants. The Meat Factory Cell (MFC) concept has been suggested (Alvseike, Sverdvik, O'Farrell, & Berg, 2017). An animation of the

* Corresponding author.
E-mail addresses: ole.alvseike@animalia.no (O. Alvseike), miguel.prieto@unileon.es (M. Prieto), Kristin.Helgesen.Torkveen@mattilsynet.no (K. Torkveen), cecilie.ruud@mattilsynet.no (C. Ruud), truls.nesbakken@nmbu.no (T. Nesbakken).

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MFC is available in the electronic version. The MFC will apply three principal changes to meat production and processing:

1. Work partly organised in cell stations instead of lines
2. Combine and merge elements of the today's separate processes and disciplines, namely “slaughter” and “meat primal cutting”.
3. “Disassemble” the carcass from outside-in without removal of internal organs before removal of most primary cuts.

The cell layout enables better flexibility; in addition, the asynchrony between cells allows adaptation of tempo and equipment to accommodate carcass variation. Improvement and investment in automation could be stepwise as parallel cells might be operated differently. Capacity is obtained from a number of parallel cells. Hence, the MFC will provide a robust and dynamic layout for development of plants and processes.

The European Parliament and the European Council have adopted a new Regulation on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products. This regulation came into force in April 2017 (EC., 2017, p. 95). The work on reviewing the Regulation on meat control will start in the European Commission from 2017.

In general, alternative approaches and new concepts must at least obtain a risk reduction equal to conventional meat factories with traditional meat inspection verified according to the same functional requirements. Improved hygiene is expected from the suggested MFC concept as the meaty limbs, neck and loin are removed first, significantly reducing exposure to faecal contamination from intestinal content. Subsequently, the alimentary tract can possibly be removed intact.

Ideally, food producers should be encouraged to apply documented improved systems and technology, and maintain the access to markets. It should be up to the Food Business Operators (FBO) to choose their optimal technology and solutions that fulfill legal functional requirements.

The objective of this work is to qualitatively assess meat inspection and hygiene in a new “meat factory cell” concept of slaughter and cutting of pig carcasses, and to assess whether the principles of *Codex alimentarius* (CAC, 2005) and intentions and demands in the EU legislation can be fulfilled, and most importantly possibly improve public health.

2. Meat inspection

2.1. The history of the current meat inspection

Meat inspection as it is performed in the EU/EEA today is based on the procedures laid down by Robert Ostertag (Ostertag, 1899). New knowledge on e.g. transmission routes for *Trichinella spiralis* and *Taenia saginata* together with Robert Koch's work on tuberculosis in the 1890's, were the basis for a meat inspection by visual inspection, palpation and incision of relevant lymph nodes and organs. At that time the meat inspection was risk-based and focused on the contemporary disease panorama. Since then, this epidemiological picture has drastically changed as trichinellosis, brucellosis and tuberculosis and some other classical zoonoses are no longer a significant issue in most developed industrialized countries. In addition, other important zoonoses have emerged such as salmonellosis, campylobacteriosis and yersiniosis, which cannot be detected by current inspection techniques (EFSA, 2011). Furthermore, meat inspection with procedures such as palpation and incision of the carcass have actually contributed to the spread of zoonotic bacteria such as *Yersinia enterocolitica* and *Salmonella* (EFSA, 2011; Nesbakken, Eckner, Hoidal, & Rotterud, 2003; Pointon, Hamilton, Kolega, & Hathaway, 2000).

2.2. Codex alimentarius

The Code of hygienic practice has been published by *Codex Alimentarius Commission*, and outlines global principles and measures to obtain safe meat on the markets (CAC, 2005). Of particular importance for the MFC (Chapter 8.4): “All areas and facilities where bodies of animals are dressed or meat may be present should be designed and constructed so that they facilitate good hygienic practices (GHP), and contamination of meat is minimised to the greatest extent practicable”, and “*Post mortem* inspection procedures and tests should be established by the competent authority according to a science- and risk-based approach.”

The objectives of meat inspection are to protect the consumer and to ensure good animal health and welfare (Ninios, Lundén, Korkeala, & Fredriksson-Ahomaa, 2014). These objectives are met by a wide range of measures throughout the meat value chain. In abattoirs, *ante mortem* and *post mortem* inspection procedures and GHP are keystones for safe meat supply. In general, “A contemporary risk-based approach to meat hygiene requires that hygiene measures should be applied at those points in the food chain where they will be of greatest value in reducing food-borne risks to consumers. This should be reflected in application of specific measures based on science and risk assessment, with a greater emphasis on prevention and control of contamination during all aspects of production of meat and its further processing. Application of Hazard Analysis Critical Control Point (HACCP) principles is an essential element” (CAC, 2005). In addition “Meat hygiene requirements should control hazards to the greatest extent practicable throughout the entire food chain. Information available from primary production should be taken into account so as to tailor meat hygiene requirements to the spectrum and prevalence of hazards in the animal population from which the meat is sourced” (CAC, 2005).

2.3. Conventional slaughter and cutting process of pig carcasses

Swine slaughter is an open production process with many possibilities for contamination of the pig carcass with pathogenic bacteria. Also, it does not contain any point where hazards are completely eliminated. The major contamination during swine slaughter originates from the pigs themselves (faecal and pharyngeal contamination). Regulation 853/2004 claims that “measures must be taken to prevent the spillage of digestive tract content during and after evisceration and to ensure that evisceration is completed as soon as possible after stunning” (Annex III, Chapter IV,7 c). Contamination from environmental sources also occur (operators, equipment and facilities). HACCP and GHP in swine slaughter must be focused on limiting this spread. The following operations are critical: (i) lairage, (ii), killing, (iii) scalding, (iv) dehairing, (v) singeing/flaming, (vi) polishing, (vii) circumanal incision and removal of the intestines, (viii) excision of the tongue, pharynx, and in particular the tonsils, (ix) splitting, (x) *post mortem* inspection procedures and (xi) deboning of the head (Borch, Nesbakken, & Christensen, 1996). Normally, pig carcasses more than four weeks old are split lengthways. However, to take account of particular eating habits, technological developments or specific sanitary situations, the competent authority may authorise the submission for inspection of carcasses of domestic swine over four weeks old, not split in half (Reg 854/2004, Annex 1, Section 1, Chapter II, D 3).

The EU regulation demands that “carcasses and accompanying offal are to be subjected without delay after slaughter to *post mortem* inspection” (Reg 853/2004 Annex I, Section I, Chapter II, D

1). "Parts of a slaughtered animal subject to *post mortem* meat inspection must remain identifiable as belonging to a given carcass until *post mortem* inspection is completed" (Reg 853/2004, Chap IV, 13). *Post mortem* inspection is taking place after evisceration of the carcasses, the pluck and bowl and intestines are presented in parallel. In many abattoirs, one inspector controls the carcass presented on a conveyor and another inspector controls the internal organs on a different conveyor. All external surfaces are to be viewed (Reg 853/2004 Annex I, Section I, Chapter II, D 1).

Finished carcasses are then subject to cold storage regimes. These compromise between hygiene and sensory qualities, because the whole carcass receives the same treatment. Thin parts (e.g. belly) get too intensive temperature reduction, and temperature reduction could possibly be faster or longer for thick parts (e.g. ham). Pork cutting and deboning should according to EU legislation be performed in specialized plants separated from the operations in the abattoir. Cutting of chilled carcasses are most common but hot deboning is also an option. Typically, tenderloins are removed first and then the carcass halves are split in three primary cuts; forepart, midpart and backpart. These primary cuts are further processed in separate lines. Different cutting patterns are applied to serve the request for different products from the markets.

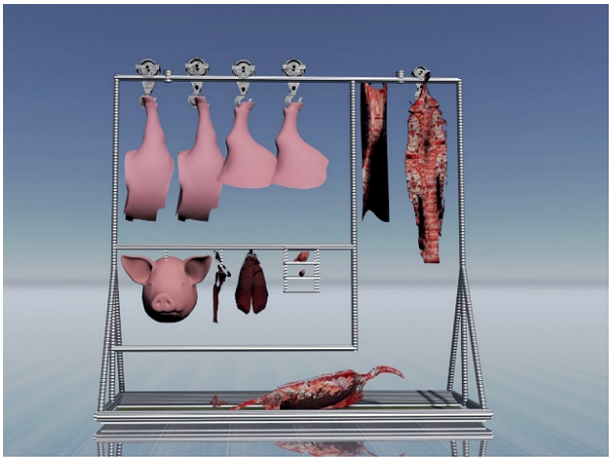

Fig. 1. Imagined frame presenting the carcass parts from a Meat Factory Cell for meat inspection. From upper left: Forelimbs, hams, belly (one piece), and neck loin and tail (one piece). 2nd row from left: Head, tongue, pluck (trachea, lungs and diaphragm), heart and kidneys. Below: The esophagus, gastro-intestinal tract, spleen, mesentry, bladder and reproductive organs.

2.4. Slaughter and primary cuts from the Meat Factory Cell

The MFC concept is inspired from traditional home slaughter procedures in Eastern Europe (Cosmin Muntean, personal communication).

Operations like stunning, killing, bleeding, scalding, dehairing, singeing and polishing are supposed to be like in a conventional abattoir. The carcasses enter the MFC after polishing and include primary cutting conventionally performed in cutting plants. The head with tongue is removed. The forelimb is attached to the body with connective tissues only, and can easily be removed. To remove the hind limb, the anatomically more complicated pelvic joint (articulatio coxae) has to be *trans*-sected and the hip muscles' attachments must be dissected from the pelvic bone. Puncture of the approximate and easily severed belly and underlying intestines constitute a risk. It is also important not to sever the belly's junctions to the pelvic bones that keep the intestines in place in the abdominal cavity. We have experienced that if one leaves the pelvic bone to the trunk the procedure is practicable and rather straight forward. Then the trunk is turned 180° around so the back points upwards. The neck, and spine with loins and rind can be loosened by a saw cutting longitudinally the thoracic ribs and abdominal side just lateral to the *M. longissimus dorsi*. This means that the vast majority of muscles are removed hygienically with significantly reduced exposure to gastro intestinal content and faecal material.

Next, the internal organs are exposed. The pluck can be removed similarly to conventional procedures. Kidneys are picked and decapsulated. Esophagus, stomach, intestines, spleen, reproductive and urinary organs are loosened in one piece and slides off. In this way the operator can avoid accidental puncture and fecal contamination from the gastro intestinal tract. Alternatively, the tongue and pharynx could possibly be left intact with esophagus, but the operations need to be developed and tested. Left on the table is the ribs and belly that can be removed in one piece.

All cuts mentioned above are transferred to a standardized frame (Fig. 1) and the parted carcass can be presented together for meat inspection.

In traditional East European home slaughter procedures, the different parts may be further processed. In an industrial cell, it is crucial to obtain at least similar capacity and tempo as in conventional lines. Therefore, as few operations as possible should take place in the cell. This is in line with a rational meat inspection. All parts should be presented for inspection simultaneously and a limited number of parts are preferable. Our suggestion is that the carcasses are presented for inspection in ten parts in a standardized frame:

- head,
- four extremities with bones,
- loin and neck with intact backbone covered on top by rind.
- belly, rib and leaf fat.
- pluck (tongue, trachea, lungs, heart, diaphragm, liver with gall bladder).
- gastro-intestinal tract including esophagus, spleen, reproductive and urinary organs.
- kidneys.

The frame should be hygienically designed to ease cleaning and disinfection, as well as to avoid cross-contamination and blood stains.

Approval stamps might be exchanged with for example Quick Response codes (QR-codes), printed or tattooed, providing individual identity to carcasses. ID marks should be printed on all parts to fulfill legislation, but additionally be printed to as many cuts as the FBOs pleases. Combined with the FBO's business intelligence system such an approach would offer a significant improvement to internal traceability, safety and value creation from optimization.

Parts and trimmings destined for production of heat treated products can preferably be produced directly after hot deboning. Parts for secondary cuts, like cutlets and fillets, can be brought to cold storage with optimal chilling regimes for the particular cuts. Malformation and toughness from rigor mortis contractions can be counteracted if the loins are kept attached to the backbone during cold storage and maturation, still protected from the rind.

2.5. EFSA's risk assessment on meat inspection

The European Food Safety Agency (EFSA) has identified and ranked biological hazards in pig meat based on source attribution and main risks for public health that should be addressed by meat inspection in the European Union. Based on a qualitative risk assessment, *Salmonella* spp. are considered of high relevance and *Yersinia enterocolitica*, *Toxoplasma gondii* and T*richinella* spp. as of

medium relevance. Other hazards were considered of low relevance (EFSA, 2011).

EFSA addressed some key features for an up-to-date meat inspection:

- Relevant food chain information should be collected and analyzed to conduct risk evaluation and subsequent risk management.
- Measures might be improved slaughter hygiene, decontamination, freezing or heat treatment at a later stage.
- Cross contamination should be prevented, i.e. *Y. enterocolitica* and *Salmonella* from lymph nodes.
- An integrated risk-based meat inspection and the safety of the products depends on a systemised participation from all involved parties along the production line.

In particular, the three last bullet points are addressed with the MFC concept.

2.6. Future legislation in the EU/EEA

The new Regulation (EU) 2017/625 on official controls (EC., 2017, p. 95) lays down rules for the performance of official controls and other official activities by the competent authorities of the EU Member States. Detailed delegated acts from Regulation 2017/625 will be adopted in the years to come. Related preambles and articles give several important signals: High standards of human and animal health, the rational development of the value chains, and increased productivity (preamble 5), in addition to the general obligation for effectiveness and appropriateness of official controls (Article 5); both are examples welcoming improvement and innovation. Official controls being adjusted to the risk and level of compliance (Preamble 32) also targets a rational development based on state-of-the-art scientific standards that will offer sound, reliable and comparable documentation (Preamble 7 and 71). Importantly, when adopting delegated acts, the Commission shall take into account experience gained and scientific and technological developments (Article 16). Article 15 contain an important obligation for operators to give the competent authorities access to their computerised information management systems. Carcasses carrying individual ID labelling will probably become a key feature.

In our view, future delegated regulations should be based on the following main principles:

- appropriate flexibility that opens for innovations and new approaches;
- risk-based approach, taking into account the epidemiological situations and risk analyses;
- lack of documented status should imply more preventive and controlling actions;
- objective targets from functional demands, not detailed descriptions on how the targets shall be addressed and obtained.

3. Meat inspection: hazards and abnormalities

In the EU, the Regulations No. 853/2004 (EC, 2004a, p. 127) and No. 854/2004 (EC, 2004b, p. 320) lay down specific rules for food of animal origin and control measures in detail. Official controls on products of animal origin should cover all aspects that are important for protecting public health and, where appropriate, animal health and animal welfare. They should be based on the most recent relevant information available and it should therefore be possible to adapt them as relevant new information becomes available (EC, 2004b, p. 320).

3.1. General hazards and abnormalities

Carcasses that derive from animals which are dead before slaughter, stillborn, unborn or slaughtered under the age of 7 days are unfit for human consumption. These carcasses carry risk for being infected by serious zoonotic hazards. *Bacillus anthracis* (anthrax) has caused disease from meat consumption (Meselson, Guillemin, Hugh-Jones, & Langmuir, 1994). Peracute antrax may not leave obvious symptoms. Consumption of animals dead before slaughter have been identified as a risk factor (Mwenye, Siziya, & Peterson, 1996). The likelihood that diseased animals from anthrax, and other diseases such as piroplasmosis (*Babesia divergens*) arrive at the abattoirs are extremely low in industrialized countries and the likelihood for detection at slaughter will not be negatively affected by the MFC concept.

Meat is to be declared unfit for human consumption if it derives from animals that have not undergone *ante mortem* inspection. At *ante mortem* it is possible to detect some generalized conditions like septicaemia, toxaemia or viraemia. *Ante mortem* inspection is carried out before the carcasses enter the MFC. Therefore, any symptoms, conditions or infringements formerly detected in lairage will be equally detected, e.g. reduced general condition, lameness or violation of animal welfare during transport and lairaging.

Likewise, meat is to be declared unfit for human consumption if it derives from animals that has not undergone *post mortem* inspection. In general, the official veterinarian is to check that the operators' procedures guarantee, to the extent possible, that meat: (a) does not contain patho-physiological abnormalities or changes; (b) does not bear faecal or other contamination; and (c) does not contain specified risk material (854/2004 Annex I, Section I, Chapter I, 2). In particular, the instructions for inspection of pig carcasses and offal are given in 854/2004 Annex I, Section IV, Chapter IV. The MFC concept will not impair these examinations, but may contribute to job enhancement as all the parts from each animal will be presented for the inspector simultaneously.

The general cardinal symptoms, general pathological changes and pathognomonic symptoms should be equally detected in the MFC concept, e.g. pneumonia, pleuritis, endocarditis (kidney infarcts), pericarditis, arthritis, impetigo, erysipelas, ascariasis and tuberculosis. Most often, these conditions represent animal diseases and unwanted aesthetical changes and are not important zoonoses. However, feedback to farmers on herd incidence rates is valuable for optimizing animal husbandry to reduce disease, economical losses, and improve animal welfare. Usually these pathological changes do not affect the meat directly, but may cause partial condemnations. In our opinion, individual ID on pigs on farm and pork carcasses combined with effective systems for vertical information exchange carry the biggest potential for improvement on these conditions.

The MFC approach provides smaller carcass parts and targeted risk based investigation at meat inspection that make opportunities for future objective sensing and diagnosis. We think the meat inspection can be significantly improved and made more relevant by adoption, adaptation and development of present and future in-line technologies on objective sensing and diagnostic tools (Bjarnadottir, Lunde, Alvseike, Mason, & Al-Shamma'a, 2015; Canali et al., 2015; Gangsei & Kongsro, 2016; Klauke, Gronewold, Perpeet, Plattes, & Petersen, 2013; Lee et al., 2010; Mason et al., 2016; Mohrmann et al., 2006; M.; O'Farrell et al., 2014; Marion; O'Farrell, Wold, Hoy, Tschudi, & Schulerud, 2010; Sheridan et al., 2006; Wold, Veiseth-Kent, Høst, & Løvland, 2017). These tools can preferably be semi-automatic. The aim being that FBOs by operators, machines, robots and business intelligence systems do the cuts, present, keep track of ID and sort carcasses.

The meat inspection should keep on prioritizing assessment of food chain information, *ante mortem* inspection, diagnosing, verification and removal of pathological changes, monitoring and control of zoonoses and zoonotic agents, sampling for the National Residue Plans, and detection of notifiable animal diseases on the OIE list (http://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2018/).

Furthermore, Regulation 2004/854, Annex I, Section II Chapter V g) to u) formulate important general conditions that have to be fulfilled to make the pork fit for consumption. These conditions are equally addressed by meat inspectors in the MFC concept.

3.2. Specific bacterial hazards

EFSA concluded based on a qualitative risk assessment, that *Salmonella*, *Y. enterocolitica*, *T. gondii* and *Trichinella* were the most relevant biological hazards that should be covered by meat inspection of pork carcasses. This conclusion was mainly based on the occurrence of these pathogens among pigs, confirmed human cases of disease caused by these agents in EU member states together with epidemiological studies (mainly molecular and case-control studies). In this context also a ranking of the disease burden of pathogens in food sources in the United States using attribution data from outbreak investigations and expert elicitation (Batz, Hoffmann, & Morris, 2012) is interesting. The following ranking of agents connected to pork was presented in a list of "estimated annual disease burden for top 50 pathogen – food combinations by combined QALY (Quality-Adjusted Life-Year) and cost of illness ranking (rank in parenthesis): *T. gondii* (2), *S. enterica* (13), *Y. enterocolitica* (16), *L. monocytogenes* (23), *Campylobacter* (31).

Among these most prevalent hazards with zoonotic potential are specific bacterial infections. However, the infections are usually subclinical, e.g. carriers of *Salmonella*, *Yersinia* and *Campylobacter*. These bacterial infections are not detected at *post mortem* neither in conventional nor the MFC approach, and in-line meat inspection is not sufficient to address these challenges directly. Detection is based on cultivation and results from analyses are not available within appropriate time and costs, or sensitive to relevant low concentrations. Available tests are also hampered with false positives or high technological demand (Easter & Gibson, 1985; Ko & Grant, 2006; Villamizar, Maroto, Rius, Inza, & Figueras, 2008; Zhou & Pollard, 2010). Indirect assays like scanning of carcasses for fecal contamination due to fluorescence from porphyrins has been published and patented (Casey, Rasmussen, & Petrich, 1999; Lee et al., 2010), but to our knowledge these techniques are not yet commonly operative in industry. The only available in-line strategy to control these hazards is effective decontamination obtained from e.g. steaming or singeing (Hugas & Tsigarida, 2008; Taormina & Dorsa, 2007). Again, the MFC may offer an advantage as different parts can undergo customized, optimized and targeted procedures. Relevant control strategies are briefly discussed below.

3.2.1. Salmonella

Salmonella is usually carried by pigs without symptoms, and traditional meat inspection is not able to detect the bacteria in asymptomatic pigs. Along the slaughter line the chances of contamination are multiple (Borch et al., 1996). Cross contamination of the carcass, and possibly between carcasses is possible following incision of lymph nodes (Pointon et al., 2000). In any case the prevalence and degree of contamination of *Salmonella* spp. on pork carcasses is highly variable and dependent on the effectiveness of on-farm control strategies and resulting prevalence in pigs before slaughter. It is possible to categorize herds using serological testing of herds for the main pork-borne hazards such as *Salmonella*. "Both the sample matrix and the method of the test can be chosen according to the target and the purpose of the testing. Blood or meat juice samples analyzed serologically can provide evidence of the pig exposure to the hazard but not of its current presence, the latter can be determined by sampling of intestinal content or lymph nodes analyzed with microbiological methods" (EFSA, 2011).

Prevalence of *Salmonella* positive carcasses also depends on the extent of fecal cross-contamination in the abattoir, and eventually the effectiveness of interventions to inactivate the pathogen on carcasses. With the MFC approach, reducing the possibility of gastrointestinal spillage and fecal contamination on carcasses in the factory, would have a positive impact on *Salmonella* contamination.

3.2.2. Yersinia enterocolitica

Case-control studies of yersiniosis conducted in Belgium (Tauxe et al., 1987) and in Norway (Ostroff et al., 1994) have identified consumption of pork as an important risk factor for infection in humans. Combining a range of preventative measures and controls applied both on-farm and at-abattoir in a vertically integrated way is the only way to ensure effective control of *Y. enterocolitica* through the value chain. The improved slaughter hygiene with respect to *Y. enterocolitica* is one example of successful intervention of hazards in the meat chain initiated by the industry, and has not been part of the current meat inspection system. In Norway, the decline in human cases of yersiniosis from about 200 cases in the beginning of the nineties to about 50 human cases annually from 2008 is probably a result of implementing improved slaughtering methods during 1994 and 1995, including enclosure of the anus into a plastic bag after rectum-loosening (Nesbakken, Nerbrink, Røtterud, & Borch, 1994). However, it is important to keep in mind that, in pigs at the age of 150–180 days (when most fattening pigs are slaughtered), the tonsils may be a more important source of human pathogenic *Y. enterocolitica* than the intestinal contents as its occurrence in the latter is reduced over time (Nesbakken, Iversen, Eckner, & Lium, 2006). Accordingly, hygienic handling of the head and the pluck during slaughter, dressing, and *post mortem* inspection, is important to avoid or reduce contamination of the carcass. In the MFC, bagging of rectum is simpler, but may be unnecessary because the intestines are meant to slide away and off the belly without apparent risk for contamination. The pharyngeal and tonsillar source *Y. enterocolitica* must be paid attention to avoid cross-contamination. It is also possible to categorize herds using serological testing of herds for *Y. enterocolitica,* but we are not aware that anyone has put separate slaughter into practice based on farms' *Y. enterocolitica* status.

3.2.3. Campylobacter

It should be noted that most pigs are carriers of *Campylobacter coli* in the gastro-intestinal tract, and the surface of pig carcasses is frequently contaminated with this agent (Nesbakken et al., 2003). Still, *Campylobacter* was ranked as low risk in the Scientific Opinion of EFSA (2011), because most slaughterhouses in Europe have implemented blast chilling. A significant decimation is seen after blast chilling due to the sensitivity of the bacterium to both freezing and drying (Bracewell, Reagan, Carpenter, & Blankenship, 1985; Nesbakken, Eckner, & Røtterud, 2008; Oosterom, Dekker, De Wilde, van Kempende Troye, & Engels, 1985). Even after traditional slow chilling there is a significant decline of this agent (Chang, Mills, & Cutter, 2003). Accordingly, pig carcasses and pork are not regarded as an important source of *Campylobacter* in a public health context as confirmed by epidemiological studies (Domingues, Pires, Halasa, & Hald, 2012; Kapperud, Skjerve, Bean, Ostroff, & Lassen, 1992; Kapperud et al., 2003). However, in the MFC concept, *Campylobacter* might possibly represent a challenge because the parts of carcasses might be de-boned directly after

slaughter. The decimating effect of drying on carcass surfaces might be lost, but all parts or products will eventually be chilled or undergo other preservation processes that eliminate *Campylobacter*.

3.3. Specific parasitic hazards

In general, parasitic diseases are also equally or not detected in MFC as in conventional meat inspection. Cross-contamination is of little relevance for these parasitic agents in the abattoirs or cutting plants.

3.3.1. Trichinella

Among *Nematoda*, *Trichinella* is the most relevant zoonotic agent. *Trichinella spiralis* is an intramuscular parasite. *Trichinella* spp. does not cause usually visible pathological conditions so it can only be detected during *post mortem* inspection by laboratory examination. This hazard is the only where regular laboratory test of each individual carcass or pooled samples have been commonly undertaken before approval. However, it should be underlined that in the EU, e.g. domestic swine carcasses from a region presenting a negligible *Trichinella* risk can conditionally be exempt from *Trichinella* examination (EC, 2005), but to our knowledge implementation of these derogations has been limited.

In the MFC system a challenge arises from earlier disassembling and distribution of carcasses within the factories. The EU regulation would strictly speaking be violated due to more primary cuts than "if carcases are cut into half carcases or quarters, or half carcasses are cut into three pieces" (854/2004 Annex I, Section 1, Chapter III (Health marking)). Carcasses may be cut up into a maximum of six parts in a slaughterhouse or in a cutting plant on the same premises as the slaughterhouse, pending the results of the *Trichinella* examination and provided full traceability is guaranteed by the food business operator (EC, 2005). However, the normative limitation of number of primary cuts probably does not have impact on safety. Instead, improved traceability based on individual carcass ID marks allows an efficient retrieval of parts from positive carcasses. The primal cuts are traceable as long as the parts carry an ID. Hence, this approach would improve safety from what is obtained from "each piece bears a health mark" (854/2004 Annex I, Section 1, Chapter III (Health marking)). Another challenge arises from analysis of pooled samples. This can be solved by keeping a piece of the diaphragm left for repeated individual analysis. Where parts from positive carcasses have entered into non-individually labeled batches, the whole batch must be condemned. The extreme low frequency should still make this risk economically acceptable for the industry.

Complementary control strategies are preharvest, on-farm control measures and corrective actions of carcasses or batches (freezing, thermal treatment, irradiation). Data on *Trichinella* spp. prevalence in pig carcasses are systematically collected in Europe. Based on frequencies and expert opinions the risk associated to *Trichinella* was judged as "Medium" by EFSA (2011). Nonetheless its prevalence in some areas (e.g. outdoor husbandry systems) should be taken into account. Trimmings and meats that undergo industrial sufficient heat treatment as part of their processing do not represent any risk and will not cause trichinellosis in consumers (Chin & Ascher, 2000). This is slightly more liberal than 854/004 Annex I, Section I, Chapter IX C that unconditionally prescribe that "Meat from animals infected with trichinae is to be declared unfit for human consumption."

3.3.2. Toxoplasma

Toxoplasma gondii infections are assessed to be one of the most important hazards from meat (EFSA, 2011), while other protozoan infections like porcine babesiosis and sarcosporidiosis are considered of little significance. Toxoplasmosis is not detected with *post mortem* inspection, and no in-line diagnostic system exists.

"Because there is no issue of between-animal cross-contamination with *T. gondii* at slaughter, it is not necessary to handle pigs from negative and positive herds separately during the transport-lairage-slaughter line period. However, incoming batches of pigs can be categorized into those from *T. gondii* free herds and infected herds (sows are particularly at-risk). The categorization can be based on historical testing results e.g. by serological testing of meat juice. Both categories can undergo usual slaughter, dressing and chilling operations, but after chilling carcasses from pigs originating from *T.gondii*-infected herds would have to be treated by a reliable and validated cyst-inactivating method (e.g. freezing) before de-boning/cutting or distribution as whole carcasses. Alternatively, meat from positive animals can be heat-treated after de-boning" (EFSA, 2011).

To protect the general population, freezing of meat destined for raw or undercooked consumption is the most readily applicable option, especially when limited to meat from animals originating from non-biosecure husbandry systems. In the long term, more health benefits are expected from cat vaccination; therefore, development of a cat vaccine and evaluation of its implementation is a research priority (Opsteegh, Kortbeek, Havelaar, & van der Giessen, 2015). The MFC offers opportunities for logistic freezing of batches destined for products not undergoing other oocyst killing procedures.

3.3.3. Taenium solium

Taenium solium causes cysticercus cellulosae infestation and belongs to the class *Cestoda*. The vesicles are easily seen when present on organs' or cut surfaces. However, low infestations are not easily detected in *post mortem* meat inspection (Boa et al., 2002; Sciutto et al., 1998). Meat inspection therefore plays an important role in surveillance, while control is mainly dependent on competence, infra structure, and hygienic sewage systems (Chin & Ascher, 2000). The MFC approach should not make any difference to detection of cysticercosis in abattoirs.

3.3.4. Trematoda

Diseases caused by *Trematoda* is not common in pigs in Europe, and are not further discussed here.

3.4. Pyemia

Pyaemia, is a common finding in meat inspection of pig carcasses (Huey, 1996; Martínez et al., 2007; Nannoni, Valsami, Sardi, & Martelli, 2014). A wide variety of bacterial genera may cause initial infections, which are usually not of zoonotic relevance (Mousing et al., 1997), *Arcanobacterium pyogenes* being the most prevalent. However, the resulting abscesses are of great aesthetic and economic relevance for the industry. Infections could often originate from wounds on tail, extremities, umbilicus or teeth. Following a limited bacteremia the infections tend to encapsulate in loci minors resistentiae, typically along the lumbar column or spinal cord, in rib bone joints, and palate. Local lymph nodes normally get enlarged and are noticed even if the abscesses are localized deep in the tissue. Multiple abscesses may also occur in lungs that filter infective material being emitted to the bloodstream. Old processes may not affect the general condition of the carcass, but more chronic and active infections may result in carcasses of inferior general condition.

In the EU regulation, splitting of porcine carcasses older than 4 weeks is compulsory, but if particular eating habits, technological developments or specific sanitary situations, the competent authority may authorize the submission for inspection of carcasses domestic swine over four weeks old, not split in half (Reg 854/2004,

Table 1
Summary of expected differences in sensitivity and efficacy for detection of pathological findings and hazards in conventional and MFC approaches.

Hazards or pathological findings	Conventional abattoir	MFC	Comments
Pyemia and abscess	+	++	Many predilection sites will be easily available and not cut through in the MFC. Smaller parts can facilitate future targeted and automatic use of diagnostic tools like CT.
Petechial haemorrhage and haematoma	+	++	The whole carcass presented for one inspector and better exposure of surfaces in the MFC.
Bruises	+	++	Better exposure of surfaces in the MFC.
Changes in conformation, shape or contour	+	−	May need to turn and orient primary parts to expose contour changes in the MFC.
Visual fecal contamination	+	++	Easier exposure in the MFC.
Trichinella	+++	+++	Same methodology in both approaches. Solvable logistic challenges will occur with immediate hot deboning.
Toxoplasma	−	(+)	MFC allows logistic freezing of parts.
Salmonella	+	+(+)	MFC allows logistic decontamination of parts posing higher risks.
Yersinia	+	+	MFC allows logistic decontamination of parts posing higher risks.
Campylobacter	+	?	Decimating effect of shock-chilling and drying needs to be documented for the MFC.
Brucella	(+)	(+)	Preharvest serological testing possible in both systems.

(+++ = high impact, ++ = impact, + = limited impact, - = probably no or negative impact, ? = not determined effect).

Annex 1, Section 1, Chapter II D, 3.). In the MFC concept, the main predilection sites for abscesses is not cut through but they are very well exposed for visual inspection. Consequently, a reduced frequency of cross-contamination from such infected abscesses should be obtained with similar sensitivity of detection. Furthermore, the reduced sizes of carcass parts may in the future make automated routine scanning of critical parts to avoid presence in meat cuts and products.

In summary, only small differences should be expected in sensitivity and efficacy for detection of hazards and pathological findings in conventional and MFC approaches. Most differences are in favour of the MFC concept (Table 1).

EFSA has assessed toxicological aspects from pork (EFSA, 2011). Regarding chemical but also physical hazards the conventional or the MFC approaches should not make any difference.

4. Conclusion: conventional slaughter and cutting vs meat factory cell

We expect that the meat inspection in the MFC approach can be significantly improved compared to procedures in conventional slaughterhouses. The suggested MFC meat inspection procedures fulfil *Codex alimentarius'* "Code of hygienic practice for meat" and public health targets. In addition, improved hygiene and risk reduction from important undetectable foodborne pathogens are expected from the MFC, as limbs, neck and loin are removed first and are not subject to faecal contamination from intestinal content. However, the rind might still carry some faecal contamination as the singeing and polishing do not possibly eliminate contamination fully. The MFC provides opportunities for customized chilling regime for different parts, targeted decontamination or pathogen killing processing that should contribute to safer meat products and less energy consumption. Today's meat inspection is the basic level for access to the market. However, alternative documented approaches should be allowed and appreciated. Inventions are highly needed and several core technologies are available but not exploited. Legislative demands should be worded in functional terms. If legislation is lagging behind technological advances, it will impede improvemnet of hygiene and food safety.

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