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Pig-level risk factors for in-transit losses in swine: a review

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Abbreviations: ITL, in-transit losses, NA, non-ambulatory, NAI, non-ambulatory injured,

NANI, non-ambulatory, not injured, MH, malignant hyperthermia, PSS, porcine stress

syndrome, RAC, ractopamine, *RYR1*, ryanodine receptor gene

Abstract

In-transit losses (ITLs) of market weight pigs are defined as pigs that die and/or pigs that become non-ambulatory (NA) during the process of loading and shipping from the farm to the abattoir.

Annual rates of transport mortalities are low relative to the number of pigs transported to slaughter annually, but are highly variable between countries and even between abattoirs within countries.

In-transit losses are not fully explained by the most commonly cited risk factors, such as environmental temperature, stocking density and journey length and other risk factors must be considered. Low numbers of ITLs compared to the large number of pigs shipped each year imply individual pig factors should be given greater consideration. Pig health pertaining to ITLs is not well-studied and post-mortems are rarely completed on in-transit loss (ITL) pigs. In particular, compromised cardiac function combined with a limited ability for cardiac compensation may predispose pigs to ITLs as a result of the exertion experienced during sorting, loading, and transport. Varying stages of cardiac compromise could explain the variable nature of ITLs. Future research should focus on investigating the health conditions which could make a pig more susceptible to death or becoming non-ambulatory during transport.

Keywords: Swine, transportation, in-transit, losses, mortalities, non-ambulatory

In-transit losses of market weight pigs is defined as pigs that die and/or pigs that become non-ambulatory (NA) during the process of loading and shipping from the farm to the abattoir (Ritter et al. 2009). Non-ambulatory pigs are often further classified into two categories. Either, non-ambulatory, not visibly injured (NANI) or non-ambulatory, visibly injured (NAI). Annual rates of transport mortalities are variable between countries and even between abattoirs within countries. Rates of ITL from studies completed over the last 10 years range from 0.012% in Denmark (Barton-Gade et al. 2007), 0.19% in USA and Germany (Werner et al. 2007, Sutherland et al. 2009) to 0.34% in the Czech Republic (Voslářová et al. 2010). Canadian

national annual transport mortalities ranged from 0.07% to 0.08% of market weight pigs transported to slaughter between 2003 and 2012, which does not include pigs transported to provincially inspected abattoirs. (Doonan et al. 2014).

A large amount of this variability is likely due to regional differences in climate, transport vehicles and shipping policies, but may also be due to how ITLs are defined or what data were used to calculate the ITL rate. Some studies include only mortalities (e.g. no NA data) and may further categorize those numbers into mortalities that occur either on the truck or in lairage at the abattoir. Author definitions of NANI pigs may include pigs that are unable to move and those able to walk but “not keeping up with their contemporaries” (Ritter et al. 2009). The definition of NANI is somewhat subjective and may result in non-ambulatory rates being more variable than mortality rates. It is rarely stated what the authors’ interpretation of “injury” is when differentiating between NAI and NANI pigs.

The well-documented, easily recognizable pattern of increased transport mortalities during warmer temperatures has led to a strong belief that heat stress is the primary risk factor for ITLs. However, ITLs are a complex, multi-factorial problem (Mitchell and Kettlewell 2008, Ritter et al. 2009) and temperature is only one risk factor. As Mitchell and Kettlewell (2008) concluded, “there are many concurrent stressors that may be imposed during transportation and the effects of these challenges may be additive or multiplicative in the sense that the detrimental effects of a given stressor may be exacerbated or enhanced by simultaneous exposure to another”. Stressors affecting ITLs include factors experienced on the farm during sorting and loading, during travel, within the transport vehicle and aspects of individual pig genetics and pig health (Anderson et al. 2002, Ellis and Ritter 2005ab). Rarely are the risk factors for transport losses from all aspects of sorting and shipping considered in one study. In particular, pig health prior to transport is

infrequently investigated. It is also rare that a post-mortem examination is completed on pigs that die during transport in order to identify a specific cause of death. While environmental temperature is the most commonly cited risk factor for ITLs of swine, other journey-level factors such as stocking density, length of journey, truck type and ventilation or trailer microclimate are frequently investigated. Much less time has been spent examining the relationships between ITLs and pig-level (e.g. existing health conditions) risk factors. To date, the study of environmental, truck, and handling related risk factors has provided some but not all of the explanation for why pigs die during transport (Haley et al. 2008). Consideration of pig health within these studies may have provided a more predictive model for ITLs.

The literature reviewed in this paper was gathered through a combination of topical internet searches and database searches of indexed journal citations (e.g. Medline). The articles included in this review were sourced from peer-reviewed journals, conference proceedings and industry reports. Numerous articles have been published examining the effects of potential risk factors for transport losses (e.g. stocking density) on meat quality or serological responses which represent the level of stress or physical exertion a pig experiences at shipping (Bradshaw et al. 1996, Barton-Gade and Christensen 1998, Guise et al. 1998, Aradom et al. 2012). Only papers which discuss the relationship between actual losses (mortalities and/or non-ambulatory pigs) and pig-level risk factors were included in this review. Relationships between risk factors and ITLs investigated by researchers and described within this literature review were statistically significant ($P \leq 0.05$), unless otherwise noted. Similarly, if it is stated in this review that an author found no association or relationship between a risk factor and ITLs, the association was tested but was not statistically significant ($P > 0.05$).

The purpose of this paper is to bring attention to less commonly considered pig-level risk factors for swine transport losses. Health conditions existing prior to transport could make a pig more susceptible to death or to becoming non-ambulatory during transport and may be a missing component in explaining the variability of ITLs.

Pig level factors and their relationship with in-transit losses

Fasting status prior to transport

Within the swine industry it is commonly thought that fasting prior to transport will reduce ITLs (Sains 1980). The physiological mechanism as to why fasting might reduce mortality has not been well-studied. Only one hypothesis could be found in the literature which suggested that the pressure from a full stomach may reduce the diameter of the vena cava which would impair venous return and result in circulatory insufficiency eventually resulting in death (Warris 1998). One of several possible alternative hypotheses may be related to the sympathetic and parasympathetic control of blood flow to the gastrointestinal (GI) system and pig health. After eating, the parasympathetic nervous system increases blood flow to the stomach and intestines to assist with the digestion and absorption of food (Guyton and Hall 2000). If the sympathetic nervous system is then stimulated, intense vasoconstriction of blood vessels to the GI system occurs in order to shunt blood to the heart and skeletal muscle (Guyton and Hall, 2000). However, after a few minutes the “autoregulatory escape” response returns GI blood flow to normal or near normal levels and continues the process of digestion (Guyton and Hall 2000). Pigs that are not fasted prior to shipping may have a full stomach when their fright/flight response is triggered by the sorting and loading process. Once the autoregulatory process has

returned blood flow to the GI system, pigs experiencing the exertion of loading may have increased risk of ITLs due to cardiac insufficiency.

There is disagreement on the appropriate length of time for fasting (Faucitano 1998). Guardia et al. (1996) states that fasting pigs between 12-18 h prior to shipping reduced in-transit mortalities compared to pigs that were fasted for less than 12 or greater than 18 h. Stewart et al. (2008) studied pigs fasted for 16 h prior to shipping and their controls (no fasting) but found no relationship with pigs that died or became non-ambulatory. However, the authors admit that the number of loads examined was low due to problems at the packing plant which resulted in data collection only occurring in less than half of the loads that were to be included in the study (Stewart et al. 2008). Averos et al. (2008) found that pigs on 71% of the 739 loads from five EU countries were fasted between 12-18 h prior to shipping and that the risk of in-transit deaths doubled in pigs that had not been fasted compared to those that had.

Too long a fasting duration may raise heart rates and exertion levels through increased aggression and fighting due to hunger (Guardia 2009, Warris 1998). Pigs with existing health conditions may be more susceptible to ITLs and this added exertion could potentially be the factor adding the variability to studies on appropriate fasting duration.

It is difficult to differentiate the effects of fasting from those of other risk factors such as how or where pigs to be shipped are sorted during the fasting period. For example, pigs fasted for 12-18 h may be: sorted early in the morning directly from their home pen after feeders were turned off the day before, mixed with unfamiliar pigs from other pens in a holding pen without a feeder or alternatively auto-sorted into a separate area with penmates. Fasting may be confounded by the

effects of pre-slaughter management and the changes in behaviors that arise because of it (Guardia et al. 2009).

Consumption of ractopamine

Ractopamine (RAC) is a β -adrenoreceptor agonist that is labelled for use as a feed additive for swine (American Veterinary Medical Association, {AVMA} 2014). Feeding RAC stimulates the β -adrenergic receptors to decrease fat deposition and increase protein synthesis which results in faster weight gains and increased lean deposition (Marchant-Forde and Poletto 2015). It may also stimulate tachycardia, hypotension, anxiety, weakness and hypokalemia (Rosendale 2004) and may result in an increased number of transportation losses as compared to pigs not fed RAC (AVMA 2014, FDA 2002, Marchant-Forde and Poletto 2015). It is plausible that RAC fed pigs are more susceptible to ITLs, as they are shown to experience increased aggressive interactions with other pigs (Poletto et al. 2010), increased physical contacts by handlers when moved (Marchant-Forde et al. 2003, Rocha et al. 2013) and increased heart rates (Marchant-Forde et al. 2003). Underlying pig health conditions would be exacerbated by these behaviours.

For these reasons and others (e.g. residues in the meat and environment) the use of RAC is permitted in only a few countries (Canada, USA, and Brazil) (Marchant-Forde and Poletto 2015). In 2002, Elanco added a warning to their label which stated, "Pigs fed Paylean are at an increased risk of exhibiting the downer pig syndrome." (FDA 2002).

Only one published study could be found which investigated the effects of RAC on the transportation losses of swine. Swan et al. (2007) examined 96 loads of pigs from two different regions (Midwest and Southeast) of the United States. In each region data were collected from four farm sites from four different production systems. At each site the treatments of 0, 5 and 10

ppm of RAC fed were randomly assigned to different barns. Two trailer loads of pigs from each barn were used to evaluate the affects. The researchers found that total transportation losses (deaths, NAI and NANI pigs) were higher in pigs fed RAC than those that were not in the Midwest region. However, there was not a significant difference in total losses between treatment groups from the Southeast region. The researchers suggested that differences in transport times and environmental conditions between the two regions were likely responsible for the differing results (Swan et al. 2007). Differences in barn and farm site effects would also impact the relationship between ITLs and the feeding of RAC. Further studies are needed to assess the relationship between these effects and pig health on ITLs in RAC-fed pigs.

Slaughter Weight

The average slaughter weight of market pigs in North America has been increasing over the last twenty years (National Agricultural Statistics Service 2015). With that trend has come speculation that heavier pigs may be associated with increased transportation losses of swine (Ellis and Ritter 2005a, Ellis and Ritter 2005b). However there is scant published literature which investigates this topic. Rademacher and Davies (2005) found a positive association with univariable analysis between pig weight and transportation mortalities through a retrospective examination of a dataset from a large swine operation in the USA but did not complete further analyses to determine if pig weight remained significant when considering multiple risk factors. Sains (1980) examined data from a four-month survey of pigs shipped to abattoirs in the United Kingdom and found no discernible trend between pig weight and in-transit mortalities but no details on the statistical analyses were included in the paper.

It is likely that pig weight is a confounder of other relationships associated with transport losses. For example, heavy pigs may be more likely to become wedged in narrow barn hallways, chutes or ramps during loading or unloading which has been associated with an increase in non-ambulatory pigs (Anderson et al. 2002). Alternatively, if the truck load size is determined simply by the number of animals that need to be shipped, then heavier pigs would be more crowded on the truck. While no study could be found which investigated the level of physical exertion or heart rates experienced by heavy hogs compared to lighter hogs during sorting and loading, it is plausible these responses may be greater at heavier body weights.

Genetic predisposition to stress susceptibility

Porcine stress syndrome (PSS) is a condition of swine where following physical or psychological stress, a pig develops muscle stiffness, open-mouth breathing, blotchy skin, and increased body temperature often followed by death within minutes of the stress being experienced (Topel 1968, Ball et al. 1978, Mabry et al. 1981). The syndrome was considered a major industry problem between the late 1960s and early 1990s as it was associated with on-farm and in-transit deaths of finishing pigs and sows, and associated with poor meat quality in those affected animals that survived transport (Eikelenboom et al. 1978, Mabry et al. 1981, Mitchell and Heffron 1982, Rundren et al. 1990, McPhee et al. 1992). Porcine stress syndrome was recognized to be a heritable syndrome similar to malignant hyperthermia (MH) in humans (Webb and Jordan 1978). Fujii et al. (1991) discovered a mutation in the ryanodine receptor gene (*RYR1*) which was responsible for the pathological response of the majority of MH/halothane reactors/PSS pig. A blood test based on this finding made it easier and less costly (as compared to the use of the halothane challenge) to find reactors which allowed for the dramatic reduction of homozygous stress-gene positive animals from breeding herds.

In 1993, a study of commercial pigs from two western Canadian abattoirs found the proportion of positive or carrier pigs to be 9.7% (Murray and Johnson 1998). A 2007 study determined the proportion of positive or carrier animals in commercial herds from four Midwest American abattoirs to be 2.7% (Ritter et al. 2007). It was speculated that ITLs would dramatically decrease with the decreased prevalence of stress-gene positive pigs (Murray and Johnson 1998). Data from the United States Food Safety and Inspection Service did not confirm this prediction (Ellis and Ritter 2005b).

Research by Ritter et al. (2007) regarding ITLs has concluded that PSS/*RYRI* positive pigs with the specific C to T single nucleotide polymorphism at nucleotide 1843 are no longer the main cause of pigs dying during transportation. Ball and Johnson (1993) suggested that the large size of the *RYRI* gene creates increased likelihood of other mutations in the gene giving rise to a MH phenotype. This has proved true in humans with MH, but no literature could be found which investigated or found other mutations of the *RYRI* gene in swine associated with MH. However, researchers have documented *RYRI* mutation-free pigs which experience muscle rigidity without death when challenged with halothane anesthesia (Allison et al. 2005). The proportion of these *RYRI* mutation-free halothane reactors ranged from 0-62% of the pigs tested in the studies (Rempel et al. 1993, Allison et al. 2005). No published rates of in-transit mortalities for these *RYRI* mutation-free, yet halothane sensitive pigs were found.

After experiencing transport (1100 km) and simulated handling of a processing plant, Allison et al. (2006) found that *RYRI* mutation-free pigs with a high scoring response (severe levels of muscle rigidity, blotchy red skin and tremors) to halothane anesthesia were more likely to become NA after transport and rigorous handling than *RYRI* mutation-free pigs that had a low score response to halothane anesthesia (18.7% vs. 9%). It has been postulated that genetic

mutations (in genes other than *RYR1*) may still be a risk factor for the susceptibility of some pigs to death or fatigue during transit (Ellis and Ritter 2005b). Supporting this hypothesis, investigators at an American research facility have found that mutations in the dystrophin gene are associated with a PSS-like stress response in nursery pigs during handling and anesthesia (Nonneman et al. 2012).

Pig health

The health status of a finishing pig prior to transportation may affect the pig's physiological response to stress (Ellis and Ritter 2005b) which may increase the risk of a pig becoming NA or to die during transport to the abattoir (Bergmann et al. 1988, Carr et al. 2005, Johnson et al. 2013). Allison et al. (2006) recognized that there is "variability in the threshold of stress required to induce fatigued pigs". Individual pig health could explain the variation in the rate of swine transportation losses when pigs shipped to market are exposed to the same risk factors of extreme temperatures and intense handling.

Sutherland et al. (2008) investigated the hoof and organ pathology of NANI and non-downer commercial pigs at abattoirs in the mid-west USA. They found no differences in rate of stomach ulcers, liver damage (scored as unaffected, minor or severe, N=249) or foot health (cracked hooves, swollen joints and abscesses, N=389) between the two groups.

Respiratory health has been hypothesized to be associated with increased mortality and fatigued pigs during transit (Carr et al. 2005, Wenzlawowicz 2004). Animals with poor lung health may not be able to effectively remove CO₂ or heat from their system when undergoing the stress of transport or handling (Carr et al. 2005). Sutherland et al. (2008) found no difference overall between NANI and control pigs when evaluating the percent of the lungs that were consolidated

if abattoir was not considered. The authors did not discuss if there was clustering with the NANI pigs (i.e. if down pigs were from the same farm site or production system) or indicate that temperature or season were included within the analyses. Carr et al. (2005) evaluated the lungs of 246 downer pigs from 4 abattoirs in the Midwest USA and concluded that respiratory health was likely not a risk factor for downer pigs, as a relationship with lung score was not found. However, the paper does not discuss non-downer pigs as a comparison and there were few details on statistical analyses. MacGregor and Dewey (2003) palpated the lungs from all pigs that died during transit on a one-day visit to a Canadian abattoir and found that only 20% had evidence of chronic pneumonia (gross examination only). No comparison to non-ITL pigs was completed and neither the number of pigs examined nor if they were from the same farm was listed. Based on the above studies, it seems unlikely that respiratory health is the primary cause of ITLs.

Clark (1979) examined 366 randomly selected ITL pigs from 3500 ITL pigs in, Canada and found chronic or pre-existing lesions (in all body systems) in 60/366 (16.4%) of the pigs examined. Clark (1979) concluded that pre-existing health conditions were responsible for a low number of transportation losses in these finishing pigs due to the low number of ITL pigs affected and the mild status of the lesions. However, 256/366 (70%) of pigs were found to have severe diffuse pulmonary congestion and pale contracted hearts, suggestive of acute left sided heart failure as the cause death.

In agreement with Clark (1979) and other later studies (Yang and Lin 1997, Niewold et al. 2000) cardiac pathology has been suggested as a cause of mortality or severe distress in pigs during transport. The ratio of organ size and weight to the total body weight of an animal is relatively constant within most species and is a product of natural selection to maximize physiological

efficiencies (Niewold et al. 2000). Deviations from these standard ratios are often indicative of pathology as they can create functional problems for the animal as the adaptive capability of body systems is limited (Niewold et al. 2000). The average heart-weight to body-weight ratio of modern finishing pigs is reported at 0.3% which is low compared to other mammalian species (Niewold et al. 2000). It has been suggested that the selective pressure for breeding fast-growing, lean and heavily-muscled pigs has led to this low heart-weight to body-weight ratio (Yang and Lin 1997). Hearts that exceed their innate physiological limits compensate to maintain normal cardiac function which over time lead to adaptive changes in the heart walls such as dilation and hypertrophy (Yang and Lin 1997, von Fleet and Ferrans 2000). These adaptive changes limit a pig's ability to respond during periods of increased exertion (strenuous activity, fighting, fear, etc.) that may be experienced on the farm or during transport which could manifest as non-ambulatory or dead pigs during or after transport. Allison et al. (2006) measured elevated pre-test blood metabolites in pigs that became NANI after completing a course which represented handling at a processing plant. The researchers stated that these pigs had a pre-existing hypermetabolic state which made them prone to becoming non-ambulatory. Tissue hypo-perfusion due to circulatory dysfunction and the presence of a hypermetabolic state can be responsible for lactic acidosis (Anderson et al. 2013), which is reported to occur in NANI pigs (Anderson et al. 2002, Ellis and Ritter 2005b).

Werner et al. (2007) examined one year's worth of records corresponding to 319,005 pigs, received at a German abattoir which included findings from the ante-mortem veterinary inspections. "Circulatory problems" was stated as the most common pathological finding (0.134% of animals examined), but no description of the clinical signs associated with this term was given. MacGregor and Dewey (2003) found petechial hemorrhage of the cardiac muscle on

all of the hearts examined from pigs that died in-transit on a one-day visit to an abattoir in central Canada. The authors stated that the cardiac hemorrhage was characteristic of cardiac exhaustion.

Bergmann et al. (1988) completed a post-mortem examination on 150 pigs that died during transport and found right ventricle dilation, lung congestion and edema which may indicate the impact of transport stress on the cardiac function of those pigs with existing heart lesions.

Bergmann et al. (1988) then compared 50 hearts (histologically) from the pigs that died in-transit to 150 hearts from pigs that did not die during transport to an abattoir. The researchers found greater pathological changes in ITL pigs and evidence that these cardiac lesions existed prior to transport.

Liu et al. (1994) have also described a heart condition in pigs at a research facility which resulted in sudden death of the pigs during transport or handling without any previous clinical signs of cardiac disease. These researchers compared the hearts of 55 pigs identified with the condition to 64 healthy crossbred pigs. The identified pigs had heavier heart weights ($473.5 \text{ g} \pm 31.8$ versus $344.3 \text{ g} \pm 28.9$, $P < 0.001$) and thicker left ventricle ($26.4 \text{ mm} \pm 3.1$ versus $14.1 \text{ mm} \pm 0.5$, $P < 0.001$) and septum measurements ($20 \text{ mm} \pm 2.7$ versus $15.6 \text{ mm} \pm 0.3$, $P < 0.001$) consistent with a pathological hypertrophy (Liu et al. 1994). Histologic findings included myocardial fibrosis, disorganization of cardiac muscle cells and abnormal coronary arteries (Liu et al. 1994). Based on these gross and histological findings, the researchers likened the condition to a heritable heart disease of humans, cats and dogs, called hypertrophic cardiomyopathy which has been associated with sudden death in apparently healthy individuals (Liu et al. 1994, Huang et al. 2001). Further work by this research group confirmed the heritable nature of the heart condition (Huang et al. 2001).

Conclusions

The well-documented, easily recognizable pattern of increased transport mortalities during warmer temperatures has led to a strong, industry-wide assumption that the cause of death in ITL pigs is due to heat-stress or hyperthermia. While temperature is strongly associated with transport losses, ITLs still occur when temperatures are low and many producers have no ITLs even when temperatures are greatly increased. In-transit losses are a complex, multi-factorial problem and temperature is just one risk factor. Similarly, other commonly published truck-level associations (e.g. stocking density, livestock trailer ventilation, length of journey) play a role, but are not the sole reason for swine transport deaths. Several studies examining ITLs in swine have concluded that farm-level risk factors may be the most significant when explaining transport losses. One of these farm-level risk factors is pig health and it is reasonable to assume that this plays a key role in transportation losses. The individual response of a pig to the stresses surrounding transport depends on their ability to compensate for the physiological stresses imposed. Compromised cardiac function combined with a limited ability for cardiac compensation may predispose pigs to ITLs as a result of the exertion experienced during sorting, loading, and transport. Varying stages of cardiac compromise could explain the seemingly unpredictable nature of ITLs. Further study of the cardiac health of market pigs that die or become NANI during transport is warranted.

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