Osteochondrosis in Pigs

A Study of the Effects of Free-range Housing in a Herd of Fattening Pigs

Pernille Engelsen Etterlin
Faculty of Veterinary Medicine and Animal Science
Department of Biomedical Sciences and Veterinary Public Health
Uppsala

Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2016

Acta Universitatis Agriculturae Sueciae
2016:50

ISSN 1652-6880
ISBN (print version) 978-91-576-8602-2
ISBN (electronic version) 978-91-576-8603-9

Print: SLU Service/Repro, Uppsala 2016

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Abstract

Osteochondrosis (OC) is a growth cartilage disease initiated by ischemia which causes a focal delay in the endochondral ossification. It is a common joint disorder in fattening pigs causing lameness and joint condemnation at slaughter. Another cause of lameness and joint condemnation in fatteners is *Erysipelothrix rhusiopathiae* arthritis (ERA).

Pigs in organic production more often have joints condemned at slaughter than do pigs in conventional production. Outdoor access is mandatory in organic production, and the aim of this thesis was to examine whether a housing type that is common in organic production affects the prevalence of OC, ERA and joint condemnation at slaughter in fatteners. Fatteners were also scored for their gait to evaluate any association between lameness and OC, ERA and joint condemnation.

Post-mortem examination of joints showed that 95% of examined fatteners had OC. Pigs that could range freely indoors and had access to pasture and an outdoor paddock had more prevalent and more severe OC than did pigs confined to conventional small indoor pens. One explanation may be that free-range pigs are more active and receive more load on their joints, which may promote OC development. Pigs with many and severe OC lesions had their gait affected more than did pigs with less OC. Free-range pigs did, however, not show more lameness than confined housed pigs. Exercise strengthens muscles, tendons and bone tissue, which may render the free-range pigs less clinically affected by OC. A 100% seroprevalence of *Erysipelothrix rhusiopathiae* was detected in both free-range and confined pigs, but no joints with ERA were diagnosed. The association between lameness and joint condemnations was poor, and the joint condemnation rate appears to be a bad assessment of joint health.

Computed tomography scans of hock joints in wild boars indicate that OC is rare in wild boars. As wild boars roam and are hunted, selection pressure may have favoured those with healthy joints that are well adapted to an active life. More research on wild boars and hybrids between domestic pigs and wild boars may help understand which features in domestic pigs need alteration to secure enhancement of their joint health.

In summary, changes in housing systems and a pig breed with more robust joints may be needed for a sustainable organic pork production.

Keywords: fattening pigs, joints, osteochondrosis, lameness, free-range, housing, gait scoring, *erysipelothrix rhusiopathiae,* computed tomography, pathology, wild boars

Author's address: Pernille Engelsen Etterlin, SLU, Department of Biomedical Sciences and Veterinary Public Health, P.O. Box 7028, SE-75007 Uppsala, Sweden
E-mail: Pernille.Etterlin@slu.se

Dedication

To Cecilia, Naemi, Nathalie and Gabriel, my beloved kids, may you reach out and pursue your dreams :)

………..and to all the domestic pigs and the wild boars who contributed to this thesis :(

At vide hvad man ikke véd, er dog en slags alvidenhed ;)(; GRUK - *Piet Hein*

……………..ya ba da ba doo !

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Etterlin, P.E., Ytrehus, B., Lundeheim, N., Heldmer, E., Österberg, J. and Ekman, S. (2014). Effects of free-range and confined housing on joint health in a herd of fattening pigs. *BMC Veterinary Research* 10(1), 208.

II Etterlin, P.E., Morrison, DA., Österberg, J., Ytrehus, B., Heldmer, E., and Ekman, S. (2015). Osteochondrosis, but not lameness is more frequent in free-range pigs than in confined herd-mates. *Acta Veterinaria Scandinavica* 57(1), 63.

III Etterlin, P.E., Ekman, S., Strand, R., Olstad, K., Ley, C. (2016). Frequency pattern of osteochondrosis, synovial fossae and articular indentations in the talus and the distal tibia of domestic pigs and wild boars. (Manuscript).

Papers I-II are reproduced with the permission of the publishers.

The contribution of PEE to the papers included in this thesis was as follows:

I. Main author. Contributed to the study design, carried out most of the analyses, interpreted the data, and drafted/edited the manuscript in collaboration with the co-authors.

II. Main author. Contributed to the study design, carried out many of the analyses, interpreted the data, and drafted/edited the manuscript in collaboration with the co-authors.

III. Main author. Contributed to the study design, carried out many of the analyses, interpreted the data, and drafted/edited the manuscript in collaboration with the co-authors.

Abbreviations

3D	Three-dimensional
AECC	Articular epiphyseal cartilage complex
DICOM	Digital imaging and communications in medicine
ECM	Extracellular matrix
ELISA	Enzyme-linked immunosorbent assay
EO	Endochondral ossification
ER	*Erysipelothrix rhusiopathiae*
ERA	*Erysipelothrix rhusiopathiae* arthritis
HE	Mayer´s haematoxylin and eosin
OC	Osteochondrosis
OCD	Osteochondrosis dissecans
OCM	Osteochondrosis manifesta
ROI	Region of interest
SLU	Swedish University of Agricultural Sciences (Sveriges lantbruksuniversitet)
SPF	Specific pathogen free
SVA	National Veterinary Institute (Statens veterinärmedicinska anstalt)
VR	Volume rendering

1 Introduction

Osteochondrosis (OC) is caused by necrosis of vessels in the cartilage canals followed by ischemic necrosis of the growth cartilage leading to a focal disruption in the endochondral ossification (EO). The disease is highly prevalent in domestic pigs, but occurs also in a wide range of species including humans.

Pigs in organic production more often have joints condemned at slaughter than do pigs in conventional production. Since outdoor access is mandatory in organic production, the aim of this thesis was to examine whether a housing type that is common in organic production affects the prevalence of OC and joint condemnation at slaughter in fattening pigs.

This introduction will cover important aspects of osteochondrosis (historical, suggested etiologic factors, pathogenesis and hosts), and includes a discussion of aspects of modern pig production.

1.1 Historical aspects and nomenclature

König (1888) defined osteochondritis dissecans (OCD) as a non-traumatic and non-inflammatory joint disease in humans with presence of loose bone fragments. Saunders Comprehensive Veterinary Dictionary (2012) and www.dictionary.com define the word as follows:

- Osteo-, a prefix with roots from the Greek word “osteon,” meaning bone.
- Chondritis,
    - derived from the Greek words *khondros* meaning cartilage
    - and the suffix “-ites” as in “belonging to”, nowadays being used as -itis meaning inflammation in a specific tissue.
- Dissecans was derived from the Latin word *dissec,* as in “to separate”.

Due to the lack of primary inflammation, Howald (1942) suggested that the suffix -itis should be exchanged for the Greek suffix -osis meaning disease.

In 1970, Ljunggren & Reiland (1970) coined the term osteochondrosis (OC) in pigs for a joint disease with similar pathology as that described in humans. Grøndalen (1974c) defined OC as a focal disturbance in the endochondral process of the epiphyseal and physeal growth cartilage. A decade later, lesions comprising accumulation of hypertrophic chondrocytes occurring in the physeal growth cartilage were differentiated from chondronecrotic lesions seen in the articular-epiphyseal growth cartilage (Hill *et al.*, 1984).

Osteochondrosis and osteochondritis are still often regarded as synonyms, and used interchangeably (McCoy *et al.*, 2013). The term OC in humans often includes a broader spectrum of bone-cartilage diseases, including both juvenile and adult forms (McCoy *et al.*, 2013). In animals, the word OC is mostly restricted to focal necrotic lesions of the growth cartilage, leading to a focal impaired endochondral ossification of the articular-epiphyseal cartilage complex (AECC); for a review see Olstad *et al.* (2015a). The focal accumulation of hypertrophic chondrocytes, with subsequent focal disturbance of the ossification of the physeal growth cartilage, can also be included in the term OC. This thesis concentrates on OC of the AECC.

1.2 Endochondral ossification

Endochondral ossification (EO) is the process in which specialized growth cartilage in humans and animals is replaced by bone tissue. The EO of long bones leads to growth in height, and takes place in the metaphyseal growth plate present between the epiphysis and metaphysis at both ends of the diaphysis, and in the AECC of the epiphyses (Mackie *et al.*, 2011; Mackie *et al.*, 2008; Ytrehus *et al.*, 2007) (figure 1).

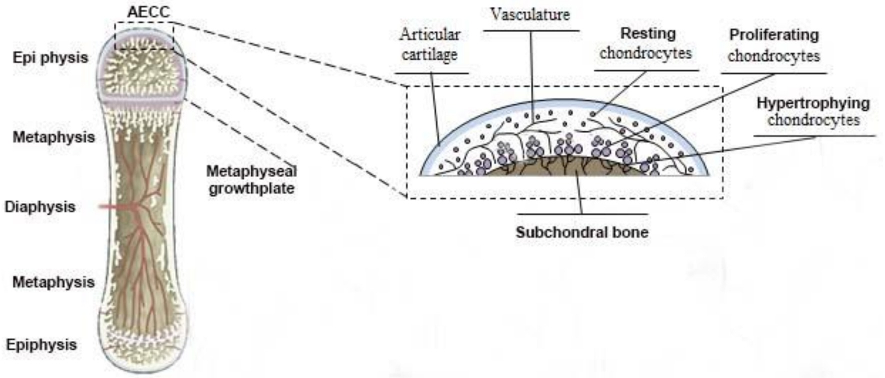

Figure 1. Endochondral ossification (EO) takes place in growing animals in the articular epiphyseal cartilage complex (AECC), and the metaphyseal growth plate of long bones. Resting chondrocytes will proliferate, hypertrophy, undergo apoptosis, and ossify. The distal growth plate of the long bone is portrayed here as closed, which happens once the EO ceases and the animals stops growing. The figure is modified from de Koning (2015) who in turn modified the image of the long bone from van Weeren (2006).

The growth cartilage consists of four zones. Small chondrocytes surrounded by a large amount of extracellular matrix (ECM) are found in the resting zone of the AECC, situated closest to the articular cartilage and towards the epiphysis in the metaphyseal growth plate. In the next zones the chondrocytes multiply (the proliferation zone) and in the zone closest to the ossification they enlarge (the hypertrophic zone). The hypertrophic chondrocytes produce an ECM that calcifies, and thereafter the chondrocytes die. At the ossification front the mineralized cartilage is used as a scaffold for the ingrowth of vessels with osteoblasts that produce osteoid. The vessels grow in from the subchondral bone, and the osteoid laid down on the mineralized framework will calcify and become a primary spongiosa (bone trabeculae with a core of mineralized cartilage). The primary spongiosa is removed by active osteoclasts and replaced by secondary spongiosa, which is bone trabeculae without a cartilage corebone (Mackie *et al.*, 2011; Mackie *et al.*, 2008; Ytrehus *et al.*, 2007).

Vessels derived from the perichondrium and subchondral bone are present within cartilage canals in the growth cartilage of the AECC (Carlson *et al.*, 1995; Stockwell, 1971). The cartilage canals include an arteriole branching into capillaries and a venule circling back to the perichondrial vascular plexus (Ytrehus *et al.*, 2007; Stockwell, 1971). Cartilage canals may also include structures resembling unmyelinated nerve fibres and lymphatics (Ytrehus *et al.*, 2007; Ekman & Carlson, 1998; Hedberg *et al.*, 1995; Carlson *et al.*, 1989; Stockwell, 1971). With age, the vessels at the end of the canals closest to the nonvascular articular cartilage gradually regress through chondrification (Lutfi, 1970). During growth, the cartilage canal will form anastomoses with vessels originating in the subchondral bone. Ossification proceeds quicker than proliferation of cartilage, and finally the growth halts once the epiphyseal cartilage complex of the AECC is completely ossified (Ytrehus *et al.*, 2007).

1.3 Pathogenesis of OC

1.3.1 Ischemia

There is substantial evidence that OC in animals is initiated by ischemia of the growth cartilage, caused by necrosis of vessels in the cartilage canals causing a failure of the blood supply within the AECC (Olstad *et al.*, 2015a; Ytrehus *et al.*, 2007; Ytrehus *et al.*, 2004b; Carlson *et al.*, 1995; Carlson *et al.*, 1991; Carlson *et al.*, 1989).

The earliest OC lesions (OC latens) (Ytrehus *et al.*, 2007), are histologically visible as focal necrosis of the vessels within the cartilage canals of the resting zone of the AECC, causing ischemic necrosis of the surrounding cartilage cells and their matrix (Ytrehus *et al.*, 2004b). It has been proposed that many of these lesions can, if small, be resolved by the progressing ossification front and thus heal. In other cases the ossification front continues to grow around the necrotic growth cartilage, causing retention of the necrotic cartilage (OC manifest) into the subchondral bone (Ytrehus *et al.*, 2007). This may also cause focal hyperemia, hemorrhages and inflammation in the affected subchondral bone tissue. Macroscopically in bone slabs, OC manifesta are visible as focal cartilage cones within the ossification front. These cartilage cones appear as a focal radiolucent area in radiographs, and as focal hypoattenuating regions in CT images.

Manifest OC can proceed towards an OCD. Clefts develop in and between the articular surface and the manifest OC lesions, and pieces of the necrotic cartilage and affected bone tissue (osteochondral fragments) may loosen, and then sometimes undergo complete ossification (Carlson *et al.*, 1991). These osteochondral lesions are called OCD, and they cause an inflammation in the joint and may proceed to chronic osteoarthritis (OA)(Reiland, 1975).

Manifest OC lesions can heal by being enveloped in the subchondral bone tissue and removed through phagocytosis via osteoclast and chondroclast activity, and be replaced by bone via intramembranous ossification. If the manifest OC remains as focal necrotic and inflamed cartilage, or with prominent dilated vessels in the subchondral bone, it is classified radiographically as “subchondral cyst-like lesions”, i.e. pseudocysts or true cysts (Olstad *et al.*, 2015a; Olstad *et al.*, 2015b; Ytrehus *et al.*, 2007).

OC is a disease of growing pigs, but it can proceed as chronic OA in breeding sows and boars. The main focus of this thesis is on OC in growing-finishing pigs.

A schematic overview of OC pathogenesis is presented in figure 2.

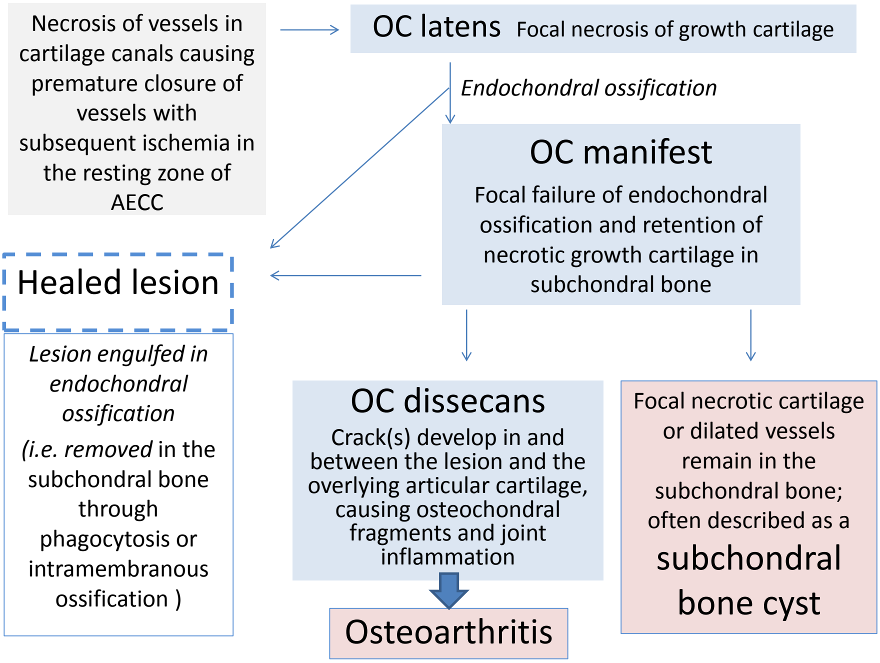

Figure 2. A simplified diagram of the development of osteochondrosis lesions and the possible fate of these lesions.

1.3.2 Collagen

Collagen type II is a major component of cartilage, and contributes to its tensile strength (Fox *et al.*, 2009; Nakano *et al.*, 1987). The cartilage canals in the AECC are supported by the surrounding ECM collagen, comprising types I and II collagens (Hellings *et al.*, 2016; Stockwell, 1971).

A modified collagen II that is less resilient to biomechanical stress may play a role in development of OC/OCD (Laverty & Girard, 2013). A major objection to this theory is that a defective collagen structure would likely cause a general collapse of cartilage canals and not a multifocal disease. A recent study of equine growth cartilage, however, found that the collagens surrounding the cartilage canals differ with the localization of the canals. Some canals were surrounded by collagen type I and others by type II (Hellings *et al.*, 2016) The authors suggest that the difference in collagen types could result in a less resilient matrix surrounding certain canals. This may render these canals more vulnerable to mechanical load and vessel collapse with subsequent focal ischemic necrosis.

1.4 Etiology of osteochondrosis

There is a consensus that vascular ischemia of the growth cartilage initiates OC, but the exact mechanisms behind the premature vascular closure have not been delineated; for review see Olstad *et al.* (2015a). Why some OC lesions heal and disappear and others develop into manifest and dissecans lesions is not fully understood, but OC is regarded as a joint disorder that has many etiological factors contributing to initiation and further development of the lesions.

The etiological factors most often discussed are:

- heredity (Aasmundstad, 2014; Kadarmideen *et al.*, 2004; Jørgensen & Andersen, 2000; Lundeheim, 1987; Reiland *et al.*, 1978);
- nutrition (Van Grevenhof *et al.*, 2011; Ytrehus *et al.*, 2007; Jørgensen, 1995; Nakano *et al.*, 1987; Nakano *et al.*, 1984);
- housing types and housing factors (de Koning *et al.*, 2014; Van Grevenhof *et al.*, 2011; Jørgensen, 2003; Brennan & Aherne, 1986; Perrin *et al.*, 1978);
- fast growth rate (Aasmundstad *et al.*, 2013; Van Grevenhof *et al.*, 2012; Kadarmideen *et al.*, 2004; Jørgensen & Andersen, 2000; Lundeheim, 1987; Nakano *et al.*, 1987; Nakano *et al.*, 1984);
- anatomical characteristics (Ytrehus *et al.*, 2007; Kadarmideen *et al.*, 2004; Grøndalen, 1974e); and
- biomechanical forces (Olstad *et al.*, 2015a; Edmonds & Polousky, 2013; McCoy *et al.*, 2013; Ytrehus *et al.*, 2007; Ytrehus *et al.*, 2004b; Olsson, 1987; Nakano *et al.*, 1984; Kincaid & Lidvall, 1983).

The effect of sex (Jørgensen, 2003; Lundeheim, 1987; Grøndalen, 1974a) and breed (Jørgensen, 2003; Jørgensen & Andersen, 2000; Lundeheim, 1987; Goedegebuure *et al.*, 1980; Reiland *et al.*, 1980; Perrin *et al.*, 1978) on OC prevalence are also often examined. Some of these reports show that the listed factor(s) have an effect on OC prevalence and/or severity, whereas others report contradictory results.

1.4.1 Biomechanical forces

Both normal body movements and incidental traumatic events influence the type, amount and frequency of mechanical load upon the joints. Mechanical load may influence the development of OC lesions in both animals and humans

(Olstad *et al.*, 2015a; Edmonds & Polousky, 2013; McCoy *et al.*, 2013; Ytrehus *et al.*, 2007; Ytrehus *et al.*, 2004b; Nakano & Aherne, 1988; Olsson, 1987; Nakano *et al.*, 1984; Douglas & Rang, 1981).

Pool (1993) and Ytrehus *et al.* (2004b) proposed that the vessels crossing between growth cartilage and bone at the osteochondral junction are vulnerable, and that shear forces (Pool, 1993) or microtrauma (Ytrehus *et al.*, 2004b) may harm these vessels. This causes premature cessation of blood supply to the AECC and subsequent development of OC lesions.

Repetitive trauma may be one cause of microtrauma (Ytrehus *et al.*, 2004b), and this has been suggested to contribute to formation of OC latens (Ytrehus *et al.*, 2007; Ytrehus *et al.*, 2004b) and progression to OCD lesions in pigs (Ytrehus *et al.*, 2007), dogs (Harari, 1998; Olsson, 1987) and horses (Laverty & Girard, 2013). Repetitive trauma is also considered to be a possible explanation for the higher prevalence of OCD recorded in those humans who participate in sport activities compared to the general public (Edmonds & Polousky, 2013; McCoy *et al.*, 2013).

König stated in 1888 that acute trauma is not a characteristic etiologic cause of OC. However, Nakano & Aherne (1988) reported that pigs that were dropped into a crate at an average body weight of 29 kg, had developed more OCD lesions at 90 kg than pigs that were lifted into the crate. Hence, it cannot be excluded that a single case of acute major trauma also may contribute to development of an OCD.

It has been reported that the prevalence of OC latens in the medial and the lateral femoral condyle of piglets do not differ, whereas progression to OCD is observed only in the medial condyle (Carlson *et al.*, 1991). Other reports simply state that OC has a predilection for medial condyles or sites (Hill *et al.*, 1984). Several authors propose that a reason the major predilections sites of OC are located medial and not lateral, is that the medial joint surfaces receive higher mechanical loads during weight bearing (Van Grevenhof *et al.*, 2011; Olsson, 1987; Grøndalen, 1974b).

Variations in biomechanical stress and load, as well as accidental traumatic events upon joint surfaces, may hence explain why OC is more prevalent and severe in some anatomical locations, and that the locations differ between species (Ekman & Carlson, 1998).

Biomechanical forces and anatomical characteristics

Anatomical characteristics of joints and other tissues involved in locomotion may influence the biomechanical forces exerted on the joints. In 1974, Grøndalen suggested that certain joint shapes and exterior features of pigs may influence OC development (Grøndalen, 1974e). He further demonstrated that the shape of the lateral and medial tubercles of the intercondyloid eminence of tibia vary, and that this may cause variation in the amount of pressure that the medial tubercle exerts on a location of the medial femoral condyle known as a predilection site for OCD (figure 3 A-C). Grøndalen (1974e) proposed that local overload due to unfortunate joint geometry may be one explanation for the development of an OCD. As a result of some of Grøndalen´s findings, the Norwegian breeding program for domestic pigs started selecting against animals with a specific joint and exterior conformation. Seven years later, Grøndalen reported a sharp decline, (>4 times lower), in the prevalence of OCD in the stifle joint of Norwegian slaughter pigs (Grøndalen, 1981).

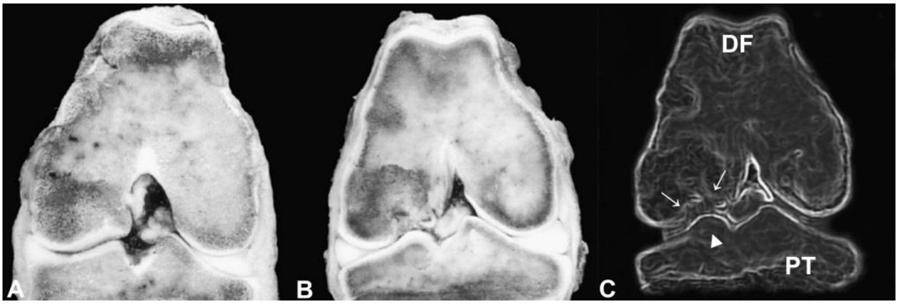

Figure 3. shows sagital sections in two different pigs (A and B) and a sketch of B (C) of the distal femur (DF) and proximal tibia (PT), and how the anatomic configuration and site of impact of the medial tubercle of the intercondyloid eminence (white arrowhead figure C) on the medial condyle of femur is exatly where most OCD lesions (white arrows figure C) appear. In figure A, no OCD lesions occur on the medial condyle, and the joint surfaces of DF and PT are intact. In figure B, the intercodyloid eminence appears (as sketched in figure C) to protrude into the fragmented joint surface of the OCD lesion present on the medial condyle. Photos A and B are modified reprints of Dr.T. Grøndalen´s presented in (Ytrehus *et al.*, 2004a), and are reproduced with permission from the publisher.

These findings support the idea that variation in anatomical characteristics, such as joint shape and exterior, may increase exposure of some joint surfaces to traumatic forces, and may hence also contribute to development of OC. The effect of joint geometry on the development of OC lesions has also been discussed in dogs (Olsson, 1987) and horses (Laverty & Girard, 2013), but more research is needed to understand the role that anatomical characteristics play in the pathogenesis of OC.

1.5 Osteochondrosis in animals

Apart from single reports of OC in other species such as cats (Palierne *et al.*, 2010), OC is a joint disease of pigs (Reiland, 1978c; Grøndalen, 1974b), horses

(Jeffcott, 1991), dogs (Olsson, 1987), cattle (Trostle *et al.*, 1997) and poultry (Julian, 1998). Only pigs will be discussed here.

1.5.1 Domestic pigs

Sites and prevalence

The reported prevalence of OC in different populations and joints of domestic pigs varies between 41.4–100% (de Koning *et al.*, 2014; Olstad *et al.*, 2014; Aasmundstad *et al.*, 2013; Van Grevenhof *et al.*, 2011; Ytrehus *et al.*, 2004a; Jørgensen & Andersen, 2000; Jørgensen *et al.*, 1995; Hill *et al.*, 1984). The reported prevalence of OCD in different populations of conventional fattening pigs varies between 1–21.2% (de Koning *et al.*, 2014; Van Grevenhof *et al.*, 2011; Ytrehus *et al.*, 2004c; Jørgensen *et al.*, 1995; Nakano *et al.*, 1984; Grøndalen, 1981; Grøndalen & Vangen, 1974).

The joints most commonly and most severely affected are the elbow, stifle and hock joints (Van Grevenhof *et al.*, 2011; Hill *et al.*, 1984; Reiland, 1978c; Grøndalen, 1974d), but OC has also been reported in the shoulder, hip, and vertebral joints (Reiland, 1978c; Grøndalen, 1974d).

OC is a focal disease, but it often develops bilaterally in specific predilection sites and in many different joints at the same time. The major predilection sites of OC manifesta and OCD are the medial humeral condyles and the medial aspect of the femoral condyles (Ytrehus *et al.*, 2007; Hill *et al.*, 1984; Reiland, 1978c; Grøndalen, 1974c). High prevalence of OC has also been reported on the medial trochlea (Van Grevenhof *et al.*, 2011; Hill *et al.*, 1984) and the medial distal aspect (Reiland, 1975; Grøndalen, 1974b) of the talus.

The impact OC has on pigs and the pig industry

Joint health is considered to be an important welfare parameter in pigs. Visual methods of scoring the gait are used to evaluate locomotion health, and are included in welfare inspections of pigs (RSPCA/AssureWel, 2013; Welfare Quality© Assesment Protocol for Pigs, 2009). These types of gait scoring methods are also commonly used to evaluate the impact that OC has on gait problems in pigs.

OC affects joint health, and may affect gait and cause lameness in slaughter pigs (Stavrakakis *et al.*, 2014; de Koning *et al.*, 2012; Jensen & Toft, 2009; Jørgensen & Andersen, 2000; Jørgensen & Vestergaard, 1990). OC is subsequently considered to be a risk to the welfare of pigs (Jensen *et al.*, 2012). However, the reported impact of OC on locomotion, and the prevalence and magnitude of lameness, are non-consistent.

Nevertheless, OC associated lameness has been considered to have considerable direct and indirect costs (Jensen *et al.*, 2012; Yazdi *et al.*, 2000; Hill, 1990), such as; lower growth rates, reduced daily weight gain, premature slaughter, premature replacement of breeding animals, or euthanasia. Other costs associated with OC are condemnation of joints at slaughter (Heldmer & Ekman, 2009).

1.5.2 Wild boars

The domestic pig´s (*Sus scrofa domestica*) closest ancestor is the wild boar (*Sus scrofa ferus*) (Giuffra *et al.*, 2000). OC is moderately inheritable, and is a common disease in domestic pigs (Jørgensen & Andersen, 2000; Lundeheim, 1987; Reiland *et al.*, 1978), and hence it may also exist in wild boars. Wild boars range freely, sometimes over large distances, and are hunted by predators (Powell, 2004). Biomechanical forces on the joints might also contribute to the development of OC in wild boars. Examinations of OC in wild boars are few, however, and the prevalence of articular OC is reported to be low (Ehlorsson *et al.*, 2006; Klaessen, 1987).

1.6 Modern pig production

The production systems in which fattening pigs are raised vary both within and between countries. These differences may affect development of OC in pigs.

1.6.1 Conventional and organic production of fatteners in Sweden

Pork production is dominated by conventional indoor systems for “intensive” production of fattening pigs. Only approximately 1.5% of all pork is organic, but as the demand from consumers for organic meat is growing in Sweden and other European countries, this is likely to change (Sonesson, 2014; Lauritsen, 2009). There are many differences between the two production forms (conventional intensive versus organic) including housing, feeding, veterinary treatments, welfare standards, and slaughter routines (KRAV, 2013; Wallenbeck *et al.*, 2009).

Organic production of fattening pigs in Sweden is performed according to the regulations of the European Union (Council Reulation No 834/2007) or the Swedish organization for organic products (KRAV, 2013). KRAV production fulfills all of the demands of the EU legislation, but it also has some additional requirements.

1.6.2 Free-range and confined housing

There are many differences between conventional and organic housing, but two main differences are the floor space available per pig and whether or not the pigs have outdoor access (Wallenbeck *et al.*, 2009).

Pigs in conventional production are housed indoors, and are commonly confined to small pens with little straw (Jordbruksverket, 2014; EFSA, 2007). Minimum space requirements depend on national criteria and age, and are between are 0.7–0.94 m^2/pig (Jordbruksverket, 2014; Wallenbeck *et al.*, 2009; EFSA, 2007).

Pigs in organic production are often housed in larger groups, with varying housing types. However, one factor these housing types have in common is that the pigs can move freely between indoor and outdoor areas for at least part of the day, and this is commonly defined as “free-range”. Pigs in EU organic farms have access to an outdoor concrete paddock, whereas KRAV pigs also must have access to pasture during the grazing season. The minimum space requirements in the organic systems depend on age and are between 0.8–1.3 m^2/pig indoors and 0.6–1.0 m^2/pig on the outdoor paddock (Wallenbeck *et al.*, 2009; EFSA, 2007), allowing the organic fatteners to have more freedom of movement than pigs in conventional indoor pens. Free access to straw and deep straw beddings enriches their environment; and together all these housing factors are meant to provide pigs in organic production with a more “natural” habitat.

The pig breeds used in many of the organic production systems in Sweden are the same as those used in conventional indoor production (Wallenbeck *et al.*, 2009). These breeds are primarily bred for conventional indoor production. Since the environment of organic free-range and conventional confinement differs vastly it is important that the effect of free-range housing on the prevalence of OC and OCD is examined.

1.7 Arthritis in pigs caused by *Erysipelothrix rhusiopathiae*

Different housing systems could also affect the prevalence of joint lesions other than OC. One of the most important differential joint diagnoses to OC in fatteners is an arthritis caused by *Erysipelothrix rhusiopathiae* (ER) (Jensen & Toft, 2009). Indeed, ER arthritis (ERA) is considered to be the most frequent and economically important infectious joint disease in Swedish fatteners (Wallgren *et al.*, 2011).

ER is a ubiquitous Gram-positive rod bacterium. The virulence of the bacteria varies, and many different serotypes exist. The serotypes 1a, 1b and 2 are considered to be the main causes of the disease Erysipelas in pigs

(Opriessnig & Wood, 2012; Wang *et al.*, 2010). The disease exists in acute, subacute and chronic forms, among which the symptoms and the clinical outcome vary. Acute ER infection is a septicaemic disease that may cause death. Pathognomonic diamond shaped lesions often develop in the skin in the subacute form, and all three forms may cause arthritis. However, it is the chronic form, primarily characterized by valvular endocarditis and/or chronic arthritis, that is regarded as a common cause of lameness in pigs (Opriessnig & Wood, 2012; Wang *et al.*, 2010).

A concern in Swedish pig production is that pigs in organic free-range production environments may be more exposed to ER than are pigs in conventional indoor production. Studies on the seroprevalence of ER in herds of Swedish organic fattening pigs confirm that they are widely exposed to *Erysipelothrix rhusiopathiae* (Engström, 2008; Svendsen *et al.*, 2008; Kugelberg *et al.*, 2001; Wallgren *et al.*, 2000), but it is not clear whether this exposure has led to a higher prevalence of ERA and subsequent lameness in pigs in the organic compared to conventional production systems.

1.8 Condemnation of joints at slaughter

Routine meat inspection of pigs at slaughter includes inspection of joints. Slaughter statistics gathered in Sweden by Farm and Animal Health (previously known as Swedish Animal Health Service), show that the joint condemnation rate at slaughter during the past 18 years has been between 2–5 times higher in free-range organic than in conventional confined fattening pigs. The joint condemnation rate in 2015 was 0.7 % in conventional fatteners and 4.9 % in organic fatteners with access to pasture.

These routine inspections of joints after slaughter involve a visual examination of unopened joints. Only exceptionally are joints opened and sampled for microscopy or infectious agents, and hence the exact etiology of the joint condemnations is seldom known.

Friede & Segall (1996) sampled condemned joints from conventional Swedish pigs, and reported that 14% of the condemned joints had lesions "indicating" OC; 64% were condemned due to infections, and most of these (13%) were due to ERA. Heldmer & Ekman (2009) reported that 70% of the condemned joints in organic fatteners had OCD, and 4% were diagnosed as ERA. Both of these reports indicated that OC and infection with ER are the most common causes of joint condemnation in Swedish fatteners. The difference in OC prevalence between these studies has not been explained, but the housing systems could be one factor behind the difference.

Whether the higher joint condemnation rate in organic compared to conventional fatteners reflects a higher level of lameness due to joint lesions during rearing is not known.

2 Aims of the thesis

The general aim of this thesis was to learn more about the effects of free-range housing on joint health in domestic fattening pigs.
More specifically the aims in papers I and II were to compare how free-range (organic) compared to confined (conventional) housing affected:

- Joint pathology
  - The prevalence and severity of osteochondrosis (OC) (papers I, II)
  - The prevalence of other joint lesions (papers I,II).

- Joint condemnations
  - The association between OC and joint condemnations after slaughter (paper I)
  - Whether *Erysipelothrix rhusiopathiae* arthritis (ERA) contributes to joint condemnations, and to learn more about the association between these two parameters and ER seroprevalence (paper II).

- Lameness (paper II)
  - The effect that OC has on the prevalence and severity of lameness
  - Whether ERA contributes to lameness
  - The association between lameness during rearing and joint condemnations after slaughter.

In order to learn more about the OC prevalence in a conserved porcine species adapted to outdoor environment, paper III aimed to examine:

- The location and prevalence of OC, synovial fossae and other articular indentations in the talus and the distal tibia of free-range domestic fatteners and wild boars that range freely.

3 Hypotheses

- Paper I
  - Biomechanical forces imposed on the joint surfaces in pigs that range freely promote OC development.
    - This leads to a higher prevalence of joints condemned at slaughter.
    - Free-range fatteners have a higher prevalence and more severe lesions of OC than do confined housed pigs.

- Paper II
  - Free-range fatteners have a higher prevalence of lameness than do confined housed pigs.
  - Pigs with more and severe OC lesions or ERA have a higher prevalence of lameness.
  - There is an association between lameness during rearing and condemnations of joints at slaughter.

- Paper III

  The frequency patterns of OC, synovial fossae, and other articular indentations in the hock joint of the domestic pigs differ from those of wild boars.

4 Materials and methods

4.1 Study population and housing

4.1.1 Domestic pigs (papers I,II,III)

One hundred and fifty domestic crossbred (Hampshire boars, Landrace x Yorkshire sows) pigs were obtained for the studies. The use of the pigs was approved by the Gothenburg Ethical Committee on Animal Research (C56/12). All 150 pigs were born within the same week in one herd at a commercial organic breeding farm. At 12 weeks of age the pigs were transferred to a fattening farm, where 50 pigs were placed in conventional indoor pens and 100 pigs were placed in free-range organic housing (figure 4).

The conventional indoor pens were 12 m^2. They had a resting and feeding area, with solid concrete floors and sparse amounts of straw. This area was connected to a defecation area with a slatted concrete floor and no straw. Five to seven pigs were confined to each pen.

The free-range housing consisted of two neighbouring and identical 90 m^2 indoor pens, connected to an outdoor 26 m^2 run with concrete floors. The indoor pens each had a resting area with deep straw bedding, and a feeding area connected to a smaller defecation area with concrete floors and no bedding. The original plan was that 50 pigs should be placed in each pen, and that only the pigs in one of these pens should have access to an adjoining 2500 m^2 pasture. However the barrier between the two free-range pens was inadequate, and the pigs mixed from the first day. Consequently, they were considered as one free-range group.

All pigs received the same organic feeding, following the EU regulations on organic farming (Council Regulation No. 834/2007) and SLU norms for fattening pigs (Feedstuffs and Nutrition Recommendations for Pigs, Version 2010-2). Henceforth in this thesis, the pigs are referred to as free-range and confined instead of organic and conventional. Having reached a live weight of approximately 100–110 kg, the pigs were slaughtered at an abattoir.

Figure 4. The housing of the confined (C) and the free-range (F) pigs.

As the studies had different aims and inclusion criteria, the number of pigs included in each study varied. Fourteen of the original 150 pigs were excluded due to illness, loss of ID tag, or being slaughtered too late (> 29 weeks of age).

- Paper I: Includes data on the remaining 136 pigs (91 free-range and 45 confined).
- Paper II: Due to a misunderstanding, the farmer sent 30 pigs to slaughter in week 25, and not in week 26–29 (as in the planned protocol). As a consequence, some results from these pigs have been treated as missing at random (Little & Rubin, 2002), and the results are based on data on 106 pigs (70 free-range and 36 confined).

- Paper III: Includes right hind legs from 40 of the free-range pigs.

4.1.2 Wild boars (paper III)

Forty right hind legs from wild boars shot during normal hunting season were obtained for a comparative study of OC, synovial fossae and other articular indentations between free-range domestic fattening pigs and wild boars.

Wild boars grow more slowly and reach puberty later than domestic pigs (Reiland, 1978a). The inclusion age range of the wild boars was hence set to 6–18 months, which is prior to closure of the growth plate of the distal tibia (Bridault *et al.*, 2000). As one of the wild boars had hind legs that turned out to have a closed growth plate, it was excluded. Hence the results are based on hind legs from 39 wild boars.

4.2 Samples

An overview of the samples examined in papers I, II and III is shown in table 1. Details of the samples are given in the text below.

Table 1. Overview of the samples examined in papers I, II and III

		Number of samples		
	Sample	**Paper I**	**Paper II**	**Paper III**
Pigs	Blood	–	106 x 3 = 318	–
	Shoulder	–	212	–
	Elbow	272	212	–
	Stifle	–	212	–
	Hock	272	212	40
	Total number of joints	544	848	40
Wild boars	Hock	–	–	39

4.2.1 Joints (papers I, II, III)

The front and hind legs of the domestic pigs were collected after slaughter and transported to SLU, where they were frozen at -20 ºC until further examination.

Elbow and hock joints (in total 544 joints) from the 136 pigs that met the selection criteria were included in paper I. Shoulder, elbow, stifle and hock joints (in total 848 joints) from 106 of the same pigs were included in paper II.

The talus and the distal tibia from forty of the hock joints belonging to the free-range pigs included in papers I and II, were selected at random for paper

III. This paper also included the talus and the distal tibia from 39 right hock joints belonging to the wild boars.

4.2.2 Serum (paper II)

Plain blood samples were tapped from 106 domestic pigs at 11, 18 and 26 weeks of age, and the serum was extracted and saved at -20 °C.

4.3 Diagnostic methods

4.3.1 Post mortem evaluation of joints (papers I,II,III)

The joints were thawed, opened and examined as described below.

Osteochondrosis

After visual inspection of the articular surfaces, the bones were sawn into 3–4 mm thick slabs. The prevalence and severity of OC were scored on intact joint surfaces (paper I) and on slab sections (paper I, II, III) following the criteria presented in paper I (table 1). The magnitude of pathological changes in the AECC and the underlying bone were used to assess progressive severity of OCM on a scale from 1 to 5, where OCM 5 was equivalent to an OCD lesion (examples of lesions that are characteristic of each OC score are shown in paper I, figure 1).

In joints where it was impossible to grossly differentiate an OC lesion from another type of joint lesion, a tissue sample was fixed in 10% buffered formalin, decalcified, dehydrated, paraffin-embedded, sectioned, and stained with Mayer´s hematoxylin and eosin (HE) for light microscopic examination.

Other joint lesions, articular indentations and synovial fossae

In papers I and II signs of synovitis, such as thickened and hyperemic synovial membranes, discolorations, and increase of synovial fluid, were assessed. In joints with signs of synovitis, microscopic examination of the synovial samples was included, to verify the diagnosis.

Other lesions such as hemorrhages, ruptures, fractures, or inflammation in intraarticular ligaments or bone were recorded in paper I.

The frequency distribution and location of other articular indentations and synovial fossae were recorded in paper III, using both post mortem and computed tomography (CT) evaluation.

4.3.2 Evaluation of locomotion (paper II)

Gait scoring to evaluate locomotion in the domestic pigs was performed at 18 and 26 weeks of age. A gait scoring method described in the Welfare Quality reports (Geverink *et al.*, 2009) was modified, and the criteria are presented in table 1 of paper II. The gait was categorized as normal (score 0), irregular (score 1) or showing signs of mild-moderate (score 2) or severe (score 3) lameness.

4.3.3 Serology, immunohistochemistry and PCR for *Erysipelothrix rhusiopathiae* (ER) (paper II)

None of the pigs included in the studies were vaccinated against ER.

Serology

To acquire an indication of the pigs` exposure to ER before, during and at the end of the fattening period, the serum collected at weeks 11, 18 and 26 were examined by an indirect enzyme-linked immunosorbent assay (ELISA) as described in a previous paper (Wallgren *et al.*, 2000). This analysis detects antibodies against ER, and was performed at the National Veterinary Institute, Sweden (SVA).

The developers based the ELISA method on the pathogenic serotypes 1, and checked that there was complete cross-reactivity with serotype 2. The cut-off value was based on the antibody levels measured in 10–12 week old specific pathogen free (SPF) pigs (Wallgren *et al.*, 2000).

Immunohistochemistry

An immunohistochemical method (Opriessnig *et al.*, 2010) was used to examine whether synovial membrane samples with histologically confirmed inflammation were infected with ER. A polyclonal antiserum against the pathogenic ER serotypes 1a, 1b and 2 was used as the primary antibody.

PCR

Defrosted samples of synovial membranes, from joints with no OCD but a histologically confirmed synovitis, were examined using a conventional PCR assay. The PCR method applied primers ER1 and ER2 (Shimoji *et al.*, 1998) to detect and amplify an ER specific fragment (937 bp) as described earlier (Eriksson *et al.*, 2013).

4.3.4 Computed tomography and image analysis (paper III)

Computed tomography (CT) images of the talus and distal tibia of the domestic pigs and wild boars were acquired in a 64-slice CT scanner (Definition AS, Siemens Medical Systems, Erlangen, Germany) using a helical protocol. Sagittal plane images were reconstructed from the raw image data using the scanner work station. Further analysis and processing of the images was done using Digital Imaging and Communications in Medicine (DICOM) image processing software (OsiriX v 5.8.5. 64-bit, Pixmeo, Geneva, Switzerland).

The point ROI (Region of Interest) tool was used to mark OC lesions, other articular indentations, and synovial fossae on the talus and the distal tibia on the sagittal plane images. A different file for each category of finding was created. Thereafter the talus and distal tibia were manually segmented from surrounding bones, and the segmented images were reconstructed into three dimensions (3D) using 3D volume rendering (VR). The point ROIs that had been marked on the sagittal plane images were imported and displayed on the 3DVR images. Figures 1–6 in paper III illustrate an example of how pathological examination and CT image reconstructions were applied to mark an OC lesion on the medial trochlea of the talus of a domestic pig.

Manual orientation in proximal, dorsal and distal views for the talus, and distal views for the distal tibia, was performed using a reference image for each of these views. Each view was saved as a DICOM image where the CT image had no ROIs and was displayed in grey scale, and also a duplicate image where the red point ROIs were displayed on the CT image. Images for all of the joints were organised according to group (domestic pig/wild boar) and type of finding: OC lesion, synovial fossae, or other articular indentation (those located in the intertrochlear groove of talus were subcategorised as intertrochlear indentations).

Using image analysis software (Matlab, Mathworks, Natclick, Ma) and the Demon’s image registration method (Thirion, 1998), the talus and the distal tibia images were co-registered to a common coordinate system. Using mean affine deformation and reference images for the wild boars (shown in figure 5) and the domestic pigs, mean shapes of the talus and the distal tibia were created. The ROI marked talus and distal tibia images were deformed to the corresponding mean shapes using deformable registration. Frequency maps of the spatial position of ROIs were obtained by image registration between the images with ROIs belonging to the same category of findings. A smoothing filter (Gaussian) was applied to take uncertainties into account. For better visualization, the frequency maps were colour-coded by a standard colour map.

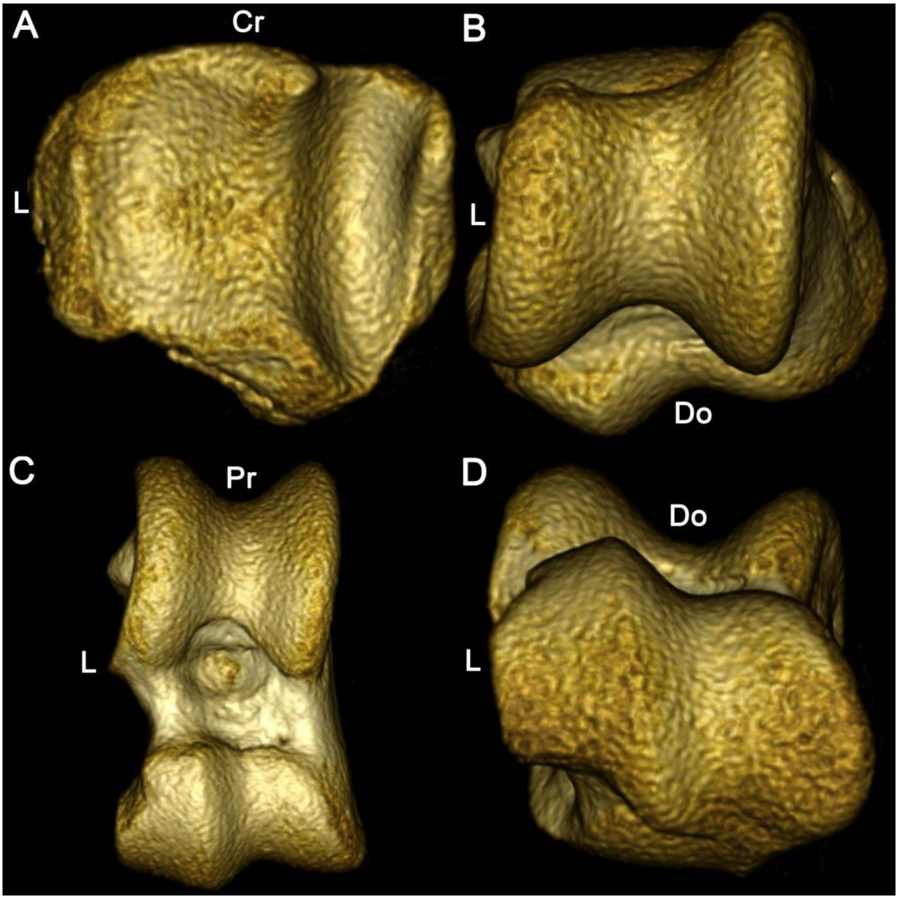

Figure 5. Three dimensional volume rendering computed tomography reference images for the wild boars. A: Distal tibia B: Proximal view of talus C: Dorsal view of talus D: Distal view of talus. Orientation given as Cr= cranial, L= Lateral, Pr= Proximal and Do=Dorsal.

4.4 Statistical analyses

Statistical differences between the free-range and the confined pigs were calculated using SAS v 9.3 (SAS Institute. Inc., Cary, NC) (paper I), Minitab Version 16 (Minitab Inc, PA, USA) or Microsoft Excel for Mac 10.1.9 (paper II) and Minitab Version 17 (Minitab Inc, PA, USA), SMP version 2.1 and Microsoft Excel 2010 for Windows (paper III).

Due to the unequal numbers of pigs and sex distribution in the two housing groups and the wild boars, the majority of the results in all three papers are analysed using a general linear model, with group and sex as fixed factors and in some cases including weight as a covariate. The different response variables are described in papers I, II and III.

Depending on the paper, the results are presented at the location (medial, lateral, proximal, distal aspects) and/or joint level (shoulder, elbow, stifle or hock), and/or for the whole pig.

$P \leq 0.05$ was defined as statistically significant for all analyses.

5 Results and discussion

The results presented in this thesis are based on a thorough examination of 968 joints from 136 domestic pigs and 39 hock joints from 39 wild boars. This is the first comprehensive study of the effect of free-range housing on the prevalence and severity of osteochondrosis (OC) in a crossbreed of fattening pigs commonly used in Swedish pig production. The results further provide updated insights into lameness, joint condemnations and *Erysipelothrix rhusiopathiae* (ER) seroprevalence in Swedish fatteners, as well as novel information on OC in wild boars.

5.1 Osteochondrosis in domestic pigs and wild boars

5.1.1 Considerations on OC methodology

The wide range (41.4–100 %) of reported OC prevalence in pigs (de Koning *et al.*, 2014; Olstad *et al.*, 2014; Van Grevenhof *et al.*, 2011; Ytrehus *et al.*, 2004a; Jørgensen & Andersen, 2000; Hill *et al.*, 1984) varies not only due to etiological factors but depends highly on the method applied to diagnose OC. Some researchers apply visual inspection of joint surfaces, others examine bone slabs or use radiography, and some use a combination of slabs and computed tomography (CT).

The results in this thesis show that, depending on location, 7 to 85% of the OC lesions diagnosed on slabs were not recognized on visual inspection of the articular surfaces (thesis figure 6 and paper I). The highest prevalence of OC in single joints (100%) was recorded in the hock joints of the free-range pigs, where both slab and CT examination was performed (paper III). CT was found to be superior to slab investigation at recognizing small OC lesions. The results in paper III (discussed below), however, show that if only CT examination is applied to diagnose OC this demands a good knowledge of normal anatomy, the predilection areas of OC and an awareness that other surface indentations exist and do appear similar to OC on CT.

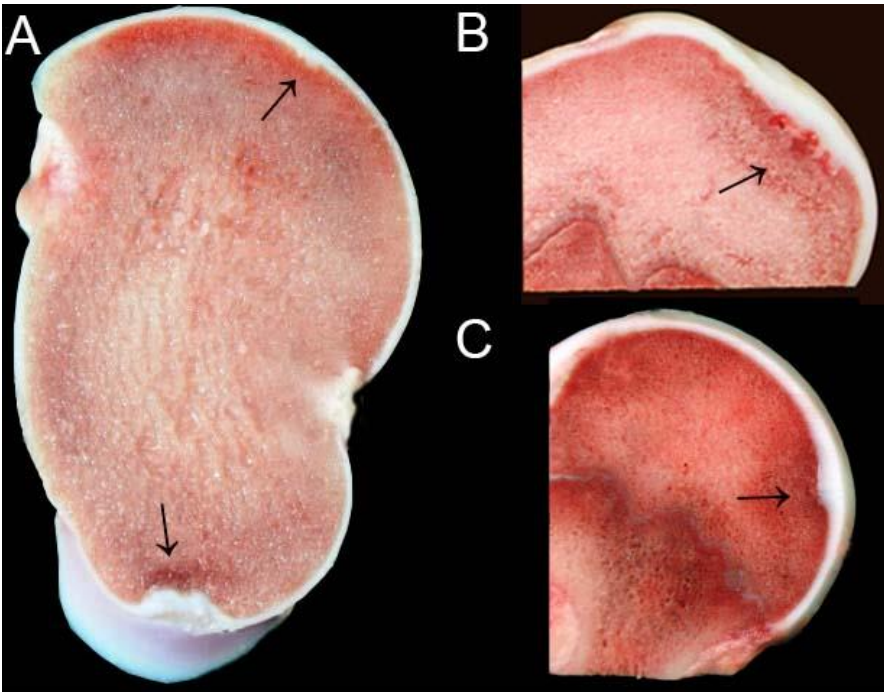

Figure 6. Examples of bone slabs showing minor to moderate OC lesions (arrows) on the proximal trochlea and the distal medial aspect of talus (image A), the medial femoral condyle (image B) and the medial aspect of the humeral condyle (figure C). These OC lesions were only recognized on slabs and were missed on inspection of intact joint surfaces.

5.1.2 Prevalence and severity of OC

The results in paper I showed that pigs in free-range housing had both a significantly higher prevalence and greater severity of OC in many locations of the elbow and the hock joints, compared to pigs in confined housing (tables 4 and 5, paper I). In paper II it was noted that 95% of all of the domestic pigs had OC in at least one of their four joints. OC occurred in all four of the examined joints of the domestic pigs, but the prevalence of OC in the shoulder was low in comparison to the elbow, stifle and hock (figure 2, paper II).

The results that were missing at random in 30 of the pigs (due to early slaughter) caused a loss of statistical power. Nevertheless, compared to the confined pigs, the free-range pigs still had a significantly higher prevalence of OC (figure 2, paper II) and severity (figures 3–5, paper II) in many of the joints and/or for the whole pig (i.e. the combined joints).

The stifle and the hock joints had the most severe OC lesions (figure 3, paper II), which agrees with another recent study on OC in conventional fatteners (de Koning *et al.*, 2014). The most serious of the OC lesions are OCD. Most to the significant difference in overall prevalence of OCD between the housing groups (free range 44%, confined 17%, figure 5, paper II) was contributed by OCD lesions on both the medial trochlea of the talus (free-range 17%, confined 5%, table 5, paper I) and the coracoid process of the calcaneus (free-range 31%, confined 4%, table 5, paper I) in the hock joints. This differed vastly from the OCD prevalence (1–21.2%) reported earlier in conventional fatteners (de Koning *et al.*, 2014; Van Grevenhof *et al.*, 2011; Ytrehus *et al.*, 2004c; Jørgensen *et al.*, 1995; Nakano *et al.*, 1984; Grøndalen, 1981; Grøndalen & Vangen, 1974).

The present study is the first to report OCD lesions on the coracoid process of the calcaneus (figure 2, paper I). This is notable because the free-range pigs seemed particularly vulnerable to developing OCD in this location. The frequency of OC manifest lesions (OC scores in the range 1–4) in this location was low in all pigs (table 3, paper I), and these OCD lesions occurred in a lateral, and not (as most other OCD lesions) in a medial location of the joint. An explanation for the relative lack of OC scores 1–4 may be that the majority of these OC lesions had commenced earlier and then healed, with only a few progressing and becoming OCD lesions. The dorsolateral border of the coracoid process in which these OCD lesions occurs may be vulnerable to acute trauma, which either could cause ischemia and initiate OC development or could cause an acute cleavage of the superficial articular cartilage, resulting in an osteochondral fracture (non-OC lesion).

Many studies of OC include sex as a factor in their statistical models (Van Grevenhof *et al.*, 2011; Kadarmideen *et al.*, 2004; Jørgensen, 2003; Jørgensen, 1995; Lundeheim, 1987; Reiland *et al.*, 1980), but the reported effects of sex on the prevalence of OC are inconsistent. In this thesis there were more gilts than castrates, and thus it was important to include sex as a factor in the statistical models. However, there were few significant differences in the prevalence of OC. Gilts had more numerous OC lesions in the lateral aspect of the humeral condyle (paper 1), whereas castrates had more numerous OC lesions in the medial and distal talus of the hock (paper 1) as well as a higher sum of OC in their stifle (paper 2).

The prevalence of OC on the talus of the wild boars was 13%, which was significantly lower than the 100% prevalence registered in the free-range pigs examined in paper III. In the domestic pigs, OC was most prevalent on the distal medial talus, followed by the proximal medial trochlea (figures 8–10, paper III). The OC lesions of the wild boars were only seen in a very local area of the distal medial talus (figures 11–12, paper III). Ehlorsson *et al.* (2006) and Klaessen (1987) reported that none of the wild boars in their studies had articular OC. Stukelj (2002) reports that 93% of the wild boars and all of the domestic pigs in her study had OC on the distal tibial articular surface. However, the described lesions seem to be compatible with synovial fossae.

Articular OC has been reported in the F2-generation of crossbreeds of wild boars and domestic pigs (Andersson-Eklund *et al.*, 2000; Uhlhorn *et al.*, 1995; Reiland, 1974), and metaphyseal OC has been described in wild boars (Stukelj, 2002; Klaessen, 1987; Fell *et al.*, 1967). The present study is, to the best of my knowledge, the first to delineate and present pictures (figures 15–17, paper III) of articular OC lesions in the hock joints of pure bred wild boars.

Studies have reported that OC has a predilection for medial joint locations (Van Grevenhof *et al.*, 2011; Hill *et al.*, 1984; Reiland, 1975; Grøndalen, 1974b), and this was confirmed in both the domestic pigs and the wild boars examined in this thesis. The results further illustrate that, within the OC predilection regions of the talus, there are focal areas in which the majority of OC lesions are found (figures 9–12, paper III), strongly indicating that these locations are where most OC lesions initiate.

5.1.3 Housing factors

All of the domestic pigs were of the same crossbreed, and shared the same conditions until 11 weeks of age. Hence, the difference in prevalence and severity of OC between the two groups of domestic pigs must reflect the impact of the different environmental factors (e.g. housing) that the pigs were exposed to from 12 weeks until slaughter.

The influence of housing factors on the development of OC in indoor fatteners has been examined previously. These studies report non-consistent effects of different floors and bedding on the prevalence or severity of OC (de Koning *et al.*, 2014; Van Grevenhof *et al.*, 2011; Scott *et al.*, 2006; Jørgensen, 2003; Brennan & Aherne, 1986; Perrin *et al.*, 1978), as well as different space requirements/stocking density and group sizes (Van Grevenhof *et al.*, 2011; Jørgensen, 2003). Two of the most recent of these studies report that a higher prevalence of severe OC lesions, including OCD, occurred in indoor fatteners that had extra space allowance (Van Grevenhof *et al.*, 2011) and/or deep straw beddings or wood shavings (de Koning *et al.*, 2014; Van Grevenhof *et al.*, 2011), compared to fatteners in conventional indoor pens. These findings indicate that environments intended to enrich and improve the living conditions of domestic pigs may, instead, have enhanced the severity of OC lesions. This can also be concluded from the results of this thesis.

The environment of the free-range and the confined pigs in the study differed a lot. The free-range pigs were housed in large groups, with a large space allowance, bedding, and variation of floors. The free-range pigs also experienced variation in the qualities of their pasture (grass/soil/stones/mud), climate (temperature, sun, rain,), and also experienced hurdles such as a threshold between the resting and the eating area, which varied in height depending on the amount of bedding. The effect on OC prevalence and severity of all of these factors could not be evaluated in the present design of the studies. Nevertheless, it is evident that conventional confined indoor housing compared to free-range housing harbours different challenges for pigs, and that this may affect their joint health.

5.1.4 Biomechanical forces

It is not clear what mechanism explains why some housing factors may affect development of OC, but it may be associated with what effect housing has on the behaviour and physical activity of the pigs.

It has been reported that conventionally housed pigs spend up to 80% of their time resting (Nakano *et al.*, 1987). Others report that organic free-range pigs (Presto *et al.*, 2008), as well as pigs housed in enriched conventional environments indoors with more space or bedding (de Koning *et al.*, 2014; Van Grevenhof *et al.*, 2012; Van Grevenhof *et al.*, 2011; Bolhuis *et al.*, 2005; Beattie *et al.*, 1996), are more active (walking, running, playing or jumping), than are conventionally housed pigs. It is therefore likely that the free-range pigs in this study were more active than were the confined pigs, which essentially leads to a larger variation in the degree and frequency of load and strain on joint tissues.

Increased biomechanical stress could promote development of OC latens by harming the cartilage canals of the AECC (Ytrehus *et al.*, 2004b; Pool, 1993), and promoting progression of OC latens to manifest and OCD (Ytrehus *et al.*, 2007; Nakano & Aherne, 1988; Reiland, 1975). This may explain why both the prevalence and the severity of OC were higher in the free-range than in the confined pigs, and supports the hypothesis that biomechanical forces may promote development of OC in free-ranging pigs. It has been proposed that there may be an association between activity and OCD levels in outdoor herds of pigs (Potter, 1998), and although humans differ from pigs, it is interesting that most cases of OCD in humans occur in young people who actively engage in sports (Edmonds & Polousky, 2013; McCoy *et al.*, 2013; Bohndorf, 1998).

Four other studies report no association between the amount of indoor exercise and the prevalence and severity of OC in pigs (Petersen *et al.*, 1998b; Enfalt *et al.*, 1993; Perrin & Bowland, 1977; Grøndalen, 1974a). Three of these studies (Petersen *et al.*, 1998b; Enfalt *et al.*, 1993; Perrin & Bowland, 1977) examined only intact joint surfaces, which most likely underestimated the prevalence of OC, and this may be one reason why they registered no impact of activity on OC prevalence. However, it may also be the variation and types of activities, and not only the amount of exercise that influences the capacity of joint tissues to handle biomechanical stress.

The joint cartilage is designed to distribute, lower and transmit applied loads onto the underlying subchondral bone (Fox *et al.*, 2009). One question is therefore why biomechanical stress that seems to be within the presumed normal physiological boundaries might have an adverse effect on the joint tissue. It has been proposed that OC may occur partly as a consequence of inappropriate load or excess biomechanical stress on immature joint tissue not yet adapted to this (Aasmundstad *et al.*, 2013; Nakano *et al.*, 1987). Certain anatomical features in joints may also cause high loads in focal areas, and this may affect OC prevalence (Ytrehus *et al.*, 2007; Grøndalen, 1974e). Even minor differences in joint anatomy and their surrounding musculoskeletal tissues may alter the biomechanics of the joint and the distribution of load within a joint, which could have a local affect on the articular epihyseal cartilage complex. A larger magnitude and diversity of activity would hence, even within normal boundaries, increase the risk for developing OC.

5.1.5 Factors that may contribute to differential OC prevalence between wild boars and domestic pigs

Differences in conformation and biomechanics causing focal variations in joint load may be one explanation for why the wild boars had a lower OC prevalence than did the domestic pigs. There are, however, many features that differ between domestic pigs and wild boars, and thus the causes of the difference in OC prevalence between these two porcine groups are likely to be multifactorial.

Growth rate is often suggested as an etiological factor of OC (Jørgensen & Andersen, 2000; Lundeheim, 1987; Nakano *et al.*, 1987; Nakano *et al.*, 1984), and it has been suggested that low prevalence of OC in wild boars may be due to a low growth rate and a low genetical predisposition to OC (Reiland, 1978a). Nutritional factors may contribute to this difference in growth rate (Reiland, 1978a). Although the reported effects of nutrition on OC development in domestic pigs are inconsistent (Ytrehus *et al.*, 2007), it is possible that differences in nutritional factors may have contributed to the difference in OC prevalence observed between the domestic pigs and the wild boars.

Only middle to large sized dog breeds develop OC (Harari, 1998; Olsson, 1987), and in horses the smaller breeds (pony breeds) are seldom presented with OC (Hendrickson *et al.*, 2015). A suggested explanation for this in horses has been that pony foals have a thinner cartilage with fewer vessels making them less vulnerable for ischemia and subsequently OC (Hendrickson *et al.*, 2015). A study on pigs reporting that pigs have a thicker cartilage in some OC predilection sites than in non-OC sites supports this hypothesis (Jørgensen *et al.*, 1995). Hence the smaller size of the wild boars compared to domestic pigs may play a role in their difference in OC development.

Domestication has provided pigs with feed and has protected them from predators, subsequently diminishing the pigs' need for a robust locomotor system. For decades, industrial pig breeders' main focus was increasing meat percentage and growth rate, and they streamlined many of the production features found in modern pig breeds (Aasmundstad, 2014; Karlsson *et al.*, 1993). A phenotypic and genetic association between OC and these production features has been shown (Kadarmideen *et al.*, 2004; Hill, 1990). The same pig breeds (or crossbreeds of these) are used in most intensive pig production; and some people report breed differences in OC heritability or OC prevalence (Kadarmideen *et al.*, 2004; Jørgensen & Andersen, 2000; Lundeheim, 1987; Goedegebuure *et al.*, 1980; Reiland *et al.*, 1980), whereas others report no or inconsistent differences in OC heritability (Yazdi *et al.*, 2000) or OC prevalence (Jørgensen, 2003; Perrin *et al.*, 1978) between breeds. OC is nevertheless considered to be common in all "modern" domestic breeds (Jørgensen & Vestergaard, 1990; Hill *et al.*, 1984; Grøndalen, 1974b). As OC is regarded a low–moderately inheritable trait (Aasmundstad *et al.*, 2013; Kadarmideen *et al.*, 2004; Jørgensen & Andersen, 2000; Lundeheim, 1987), it is possible that selective breeding may inadvertently have contributed to selection for OC in "modern" domestic pigs (Kadarmideen *et al.*, 2004).

Breeding regimes with the aim of lowering the prevalence and severity of OC and improving conformational traits in pigs were started in the 1970s and 80s (Lundeheim, 1987; Grøndalen, 1981). The breeding goal in, for example, Norsvin Landrace started to include production aspects such as health and "robustness" during the 1990–2000s (Aasmundstad, 2014). Although locomotor traits are included in breeding index and selection procedures, the majority of pigs are still being raised in, and selected in, conventional indoor environments. Selection aimed at a certain production type should be performed on animals in the given production environment. The current selection pressure on locomotion traits may hence not be sufficient for pigs that are destined for free-range production.

All this considered, the results of this thesis suggest that "modern" pig breeds may have acquired locomotory traits that could lead to unaccustomed biomechanical stress and load on focal areas of joint cartilage during physical activities, and this may promote the occurrence and severity of OC.

Wild boars are hunted, have natural predators and roam for food, and therefore they depend on a robust locomotor system for survival. As OC is a moderately inheritable trait (Aasmundstad *et al.*, 2013), which contributes to unsound joints, it is likely to be selected against naturally in the wild boar population. Hence, it is probable that evolutionary pressure has favoured wild boars with healthy joint structures and good biomechanics that are well adapted to an active life.

5.2 Articular indentations, synovial fossae and other joint lesions.

Articular indentations on the trochlea and intertrochlear groove of the talus (paper III)

The domestic pigs and the wild boars had articular indentations in similar locations on the axial aspects of the medial and lateral trochlea of the talus (figures 18–23, paper III.) The prevalence of these indentations in the wild boar (18%) was not significantly different from the prevalence in the domestic pigs (30%). The histology of representative indentations varied, showing focal areas of chondronecrosis or indentations of normal articular cartilage (figures 24–26, paper III). The indentations had some features that also occur in OC, and they may also have initiated as ischemic lesions, leaving only remnants and healed lesions to be documented. Given that the wild boars had only a few OC lesions elsewhere on the talus, and the prevalence of these indentations did not differ between the wild boars and the domestic pigs, this suggests that these indentations may differ from those of OC.

Indentations that were present in the intertrochlear groove of the talus covered a larger area in the domestic pigs (figures 27–28, paper III) than in the wild boars (figures 30–31, paper III). The prevalence (100%) in the domestic pigs was significantly higher than the prevalence (33%) in the wild boars.

The macroscopic and histological appearance of intertrochlear indentations varied from minor articular indentations (in a normal articular cartilage) to areas of focal necrosis of the articular cartilage, focal cessation of the EO and infiltration of granulation tissue. These intertrochlear indentations may, as described in calves, represent differential stages in the development of normal synovial fossae (Wegener *et al.*, 1993). Linear grooves that occur between the medial and the lateral aspect of the humeral trochlea in domestic pigs have been described as normal anatomical features in pigs (Doige & Horowitz, 1975), and they appear to be similar to some of the intertrochlear indentations of the talus that occurred in some of the domestic pigs presented in paper III. A thesis on synovial fossae in domestic pigs, however, states that the proximal talus lacks synovial fossae (Strehler, 1978). It is further difficult to exclude the possibility that the intertrochlear indentations that had focal areas of chondronecrosis do not represent remnants of a previous OC lesion. This is supported by another study in fatteners that interpreted the "depressions" in the intertrochlear groove as OC (Jørgensen *et al.*, 1995).

The inconsistent reports indicate that longitudinal studies are needed to clarify the origin and development of the articular indentations on the axial aspects of the trochlea and the intertrochlear indentations, in order to decide whether they represent normal anatomical features, such as synovial fossae, or represent OC lesions and/or remnants of such.

Kissing lesions and synovial fossae on the distal tibia (paper I and III)

Kissing lesions are characterized as articular cartilage destruction with fraying and ulceration on an opposite surface from a joint lesion. In the domestic pigs, they occurred on the lateral malleolus of the fibula (and rarely on the fascies articularis malleolaris of the talus) in hock joints with OCD lesions on the coracoid process of the calcaneus (paper I; figure 2C). Kissing lesions opposite to OCD lesions on the proximal trochlea of the talus occurred on the distal tibia in 4.4% of the confined domestic pigs (paper I), and between 13.2–20.8% of the free-range domestic pigs (papers I and III, and figures 36–37 in paper III). No kissing lesions were registered on the distal tibia of the wild boars (paper III).

The synovial fossae of the distal tibia in the domestic pigs covered a larger area, and the prevalence (100%) was significantly higher, than in the wild boars, in which the synovial fossae were smaller and the prevalence was 87% (figures 38–41, paper III). Synovial fossae are not present at birth but develop with age (Strehler, 1978). Wild boars mature at an older age compared to the domestic pigs (Reiland, 1978b), and hence they may develop the synovial fossae later in life. However, as all of the examined wild boars were older than the domestic pigs, and the difference in results between the younger (6–9 months) compared to the older (10–18 months) group of wild boars was not significant, age differences do not sufficiently explain why the synovial fossae were more prevalent in the domestic pigs compared to the wild boars.

It has been suggested that other factors such as the presence of synovitis and osteoarthritis (Dämmrich *et al.*, 1976; Dämmrich, 1970) and the level of activity (Mehlfeld *et al.*, 1984), may affect the development or size of synovial fossae (Jørgensen *et al.*, 1995; Dämmrich *et al.*, 1976; Dämmrich, 1970). A higher activity level and a low prevalence of joint lesions in the wild boars may therefore be another reason why the prevalence and size of distal tibial synovial fossae of the wild boars differed from those of the domestic pigs.

Other joint lesions (papers I, II)

A few domestic pigs had fractures in the anconeus growth plate, hemorrhages in synovial membranes and joint capsules, and partial ruptures along collateral ligaments of the humeral head. The frequency of these lesions did not differ between the free-range and the confined pigs (paper I).

Non-purulent synovitis was recorded in 8.7% of the 848 joints examined in paper II, and the majority of these (7.8%) had OCD.

5.3 Gait remarks and lameness in the domestic pigs (paper II)

5.3.1 Prevalence

On two occasions each pig was visually scored for its locomotion (gait scoring) on a scale of 0 (normal) to 3 (severe lameness). The prevalence of gait remarks (i.e. scores 1, 2, 3) and clear lameness (i.e. scores 2, 3) in the free-range and the confined pigs were not significantly different at 18 or 26 weeks of age (figure 1, paper II).

The prevalence (22%) of gait remarks at the age of 26 weeks in the free-range pigs was slightly higher than the lameness prevalence range (1.6–15%) reported in international studies of free-range fatteners (KilBride *et al.*, 2009; Bonde *et al.*, 2006; Herzog *et al.*, 2006; Cagienard *et al.*, 2005), but was similar to the 21% lameness prevalence reported in nearly 700 free-range organic Swedish fatteners (Wallenbeck *et al.*, 2013). This indicates that the overall prevalence of gait problems in Swedish free-range fatteners may be relatively high. However, the number of pigs with severe lameness was low in both studies (paper II, Wallenbeck *et al*., 2013).

The prevalence of gait remarks (14%) in the confined pigs did not differ from the lameness prevalence range (1.5–19.7%) reported in confined fatteners (KilBride *et al.*, 2009; Bonde *et al.*, 2006; Cagienard *et al.*, 2005). The results from these studies further supported the finding of no significant difference in lameness prevalence between free-range and confined fatteners. Nevertheless, one other study (Badertscher & Schnider, 2002) has reported that group-housed fatteners with access to an outdoor paddock were more lame than were conventionally housed fatteners.

5.3.2 The association between gait scores and OC

Table 3 in paper II defines the response variables that were examined to evaluate the possible association between the gait scores and OC. The sum of all OC scores in all examined locations ("Sum of OC") in the hock and in the whole pig had a significant relationship with the gait scores at week 26. The higher the sum of OC was, the more likely it was that the pig received a gait remark. However, there was no significant relationship with the gait scores for "Sum of OC" in the shoulder, elbow or the stifle joint, "No OC", "Highest OC" or "Highest OC 1,2,3,4, or 5" at the joint or pig level.

The significant association between gait remarks and "Sum of OC" for the whole pig indicates that a threshold level may exist at which point a pig has so many and/or such severe OC lesions (high Sum of OC) that it is more likely to experience gait problems. A number of studies have reported a significant association between OC and conformation and/or gait deviations in the pigs (Stavrakakis *et al.*, 2014; de Koning *et al.*, 2012; Jensen & Toft, 2009; Jørgensen & Andersen, 2000; Jørgensen & Vestergaard, 1990). However, other researchers (Nalon *et al.*, 2013; Jørgensen, 1995; Jørgensen *et al.*, 1995; Reiland *et al.*, 1980; Grøndalen, 1974a) have reported no or only a weak association between OC and gait remarks/lameness in pigs; and so this association appears to be intricate.

Jørgensen *et al.* (1995) proposed that OCD lesions may be the "threshold lesion" at which an OC lesion causes gait problems. OCD is also regarded as the second most painful joint disease in fatteners (Jensen *et al.*, 2012). The size, magnitude and locations of OCD varies, however, and whether the OCD lesion is acute or more chronic at the time of gait scoring is likely to affect the clinical impact of the lesion on the gait. The present study did not find a significant association between "Highest OC 5" and gait remarks, but OCD lesions contribute to high "Sums of OC" and hence may also contribute to gait remarks. Pigs are reluctant to show signs of lameness (Nalon *et al.*, 2013), which supports the idea that only when a threshold of many and severe OC lesions is exceeded is it possible to detect lameness.

As the free-range pigs had significantly more and severe OC lesions than did the confined pigs, it was a surprise that the free-range pigs did not receive more gait remarks than the confined pigs. However, free-range pigs are more active than confined pigs (Presto *et al.*, 2008) and, apart from possibly promoting development of OC, physical activity strengthens the tendons, muscles and bones (Gondret *et al.*, 2009; Petersen *et al.*, 1998a; Petersen *et al.*, 1998b; Woo *et al.*, 1980). This may improve the biomechanics of free-range pigs, and strengthen the tissues that surround the joints, enabling better compensation of or support for painful joints. Severe OC lesions are probably just as painful in free-range as in confined pigs, but as exercise is known to relive pain in humans with osteoarthritis (Tanaka *et al.*, 2013; Ettinger *et al.*, 1997), it could also be that active pigs tolerate, up to a certain threshold, more severe OC lesions than do inactive pigs.

5.3.3 Visual gait scoring as a welfare indicator

The complex association between OC lesions and visual gait scores, and the lack of consistency in reported associations between OC and gait problems, implies that visual gait scoring is an unreliable method for evaluating joint health. Another known disadvantage of visual gait scoring is variable repeatability (Main *et al.*, 2000).

The wide use of visual gait scoring to evaluate locomotor health and pig welfare (RSPCA/AssureWel, 2013; Welfare Quality© Assesment Protocol for Pigs, 2009) is therefore problematic, and methods that are more sensitive and objective are desirable. Objective test methods such as camera-based motion captures, with skin markers attached to landmarks on the legs, have been tested, and these seem to be more sensitive than visual gait scoring; but they may be difficult and impractical to apply on farms and on many pigs (Stavrakakis *et al.*, 2014).

5.4 Joint condemnations at slaughter (papers I and II)

In summary:

- Five elbow and hock joints from four of the 91 free-range pigs were condemned at slaughter and all five condemned joints had OCD (paper I).
- No shoulder or stifle joints were condemned.
- ERA was not detected in any of the joints condemned at slaughter.
- None of the 45 confined pigs had joints condemned at slaughter.

Not all joints with OCD lesions have a marked synovitis. As these joint are visibly less swollen, they are less likely to be recognized in an unopened joint, and subsequently are less likely to be condemned at slaughter. The large discrepancy between the number of joints that were condemned at slaughter (5) and the number of joints that had an OCD lesion with a concurrent marked synovitis (41) is note-worthy (paper I). Joint condemnation rates at slaughter in pigs are often discussed as indicators of joint diseases (Heldmer & Ekman, 2009 ; Engström, 2008; Svendsen *et al.*, 2006; Beskow *et al.*, 2003; Kugelberg *et al.*, 2001; Hansson *et al.*, 2000; Wallgren *et al.*, 2000; Lindsjö, 1996). The results in paper I and II, however, indicate that the joint condemnation rate is a very poor estimate of joint health.

A lack of association between lameness and joint condemnation, as found in this study, has also been reported in another study that investigated lameness in pigs in organic Swedish fatteners (Wallenbeck *et al.*, 2013). This supports the conclusion that joint condemnation rates provide very little information about joint health in fatteners.

5.5 *Erysipelothrix rhusiopathiae* seroprevalence and arthritis (paper II)

The seroprevalence of ER in free-range and confined pigs was 100% at 11, 18 and 26 weeks of age and the housing environment did not have a significant effect on these results. This differs from the results of Presto *et al.* (2007), who applied the same ELISA method but reported a higher seroprevalence of ER in an organic herd (22%) compared to in a conventional herd (4.6%) of fatteners.

The ER seroprevalence in the domestic pigs was higher than the range (10–90%) reported in other studies of unvaccinated Swedish organic fatteners (Svendsen *et al.*, 2008; Svendsen *et al.*, 2006; Kugelberg *et al.*, 2001), possibly reflecting differences in herd immunity or a higher exposure to ER. As the cross-reactivity between serotypes 1 and 2 was complete in the applied ELISA method (Wallgren *et al.*, 2000), and a high level of cross-protection between different serotypes of ER is known to occur (Opriessnig & Wood, 2012), we cannot exclude the possibility that nonpathogenic strains of ER may have cross-reacted and thus contributed to the high seroprevalence.

No bacteria were identified in histological samples of synovial membranes, and immunohistochemistry and PCR investigation of synovial samples with synovitis did not detect ER. No joints had ERA, and hence the association between ERA and gait scores during rearing could not be evaluated. These results may suggest that the prevalence of ERA is lower than the prevalence of OCD in both free-range and confined fatteners.

Several studies of organic fatteners have either measured, or speculated on, an association between joint condemnation rate and: ER seroprevalence and/or ER vaccination status and/or prevalence of ERA (Engström, 2008; Kugelberg *et al.*, 2001; Hansson *et al.*, 2000; Lindsjö, 1996). Another study on organic fatteners, however, failed to document an association between ER vaccination status, ER seroprevalence and joint condemnation rates (Svendsen *et al.*, 2008; Svendsen *et al.*, 2006). In none of these studies were the condemned joints opened, and hence the etiology and pathology of the joints remains unknown.

The pigs in the presented study were not vaccinated against ER, and all were ER seropositive, and yet few joints were condemned and none were diagnosed with ERA. This indicates that the association between ERA prevalence and these parameters (ER seroprevalence, vaccination status and joint condemnation rates) is uncertain, and that opening joints and examining for ER is the only reliable way to evaluate the prevalence of ERA.

6 Conclusions

The effect of free-range and confined housing in domestic fatteners on:

- Joint pathology
  - Free-range fatteners developed more numerous and more severe OC lesions than did confined fatteners. The mechanism behind this may be that free-range fatteners experience a greater extent and diversity of biomechanical forces on the joint tissues.
  - The prevalence of joint lesions other than OC was not affected by the difference in housing.

- Lameness
  - Fatteners that had a combination of numerous and severe OC lesions showed more gait problems than did those that had fewer such lesions.
  - Free-range fatteners did not show more lameness than did the confined fatteners. This suggests that free-range pigs may be less clinically affected by OC, possibly due to pain relief and strengthening of locomotor tissues (muscle, tendon and skeletal) promoted by physical activity.
  - Visual gait scoring appears to be an insensitive and hence unreliable method for evaluating joint pathology, and thus questions the use of this method as a welfare assessment method for locomotor health in pigs.

- Joint condemnations at slaughter
  - Gait problems during rearing were poorly associated with joint condemnation at slaughter.

- OCD is a cause of joint condemnation, but routine meat inspection of unopened joints failed to recognize a majority of the joints that had severe OC lesions.
- The rate of joint condemnation at slaughter was a poor estimate of the prevalence of severe joint lesions, and it is probably an unreliable indication of joint health in fatteners.

- *Erysipelothrix rhusiopathiae* infection
  - All pigs had been exposed to ER, but none had developed ERA.
  - ER seroprevalence was common in both free-range and confined fatteners.
  - ER seroprevalence appears to be a poor indicator of ERA.

Joint changes in free-range domestic pigs compared to wild boars:

- Domestic pigs had more numerous OC lesions on the talus than did the wild boars.
- Articular indentations on the trochlea were equally frequent in the domestic pigs and the wild boars, whereas those present in the intertrochlear groove of the talus were more prevalent in the domestic pigs than in the wild boars.
  - The etiology of these indentations was uncertain, but some may represent OC remnants, while others appear similar to what has in calves been described as developing synovial fossae.
- The prevalence of synovial fossae on the distal tibia was higher in the domestic pigs than in the wild boars.
- A possible mechanism that may explain some of the observed differences between the two porcine groups is that wild boars are exposed to a natural selection, which may have favoured wild boars with healthy joints that are well adapted to an active life. In contrast, domestic pigs have been subject to artificial selection for maximizing meat production.

Conclusion:

An essential part of the welfare concept in organic production is to let pigs range freely. This thesis indicates that free-range housing may increase the risk of fattening pigs acquiring many and severe OC lesions. These results are based on one herd only, and hence need to be verified across farms and growing seasons. However, the results do suggest that modifications in housing systems, and/or a pig breed (or selection for such a pig breed) with more robust joints, may be needed for sustainable organic pork production.

7 Future perspectives

Organic pork production is increasing, and hence it is important to evaluate more closely what impact this production type and environment may have on joint health in pigs. To verify the results in this thesis, studies are needed on joint health in more and larger herds of free-range fattening pigs.

- The housing types within organic farming vary, and so it is important to examine whether housing differences, such as variation in hurdles, area, bedding and amount of outdoor exposure, influence the pigs' prevalence and severity of OC lesions.

- The domestic pigs in this study were of a common crossbreed of pigs that has been bred for intensive indoor production. Other more conserved breeds that traditionally are kept in housing with outdoor access may have kept some original and more robust joint traits, and these breeds would be interesting to examine for OC. Examination of different generations of crosses between domestic pigs and wild boars could also be of value.

- To examine how activity influences OC development, advanced objective methods to measure different types and amounts of activity are needed; for example, video tracking systems such as EthoVision® XT for the automatic tracking and analysis of animal movement.
    - Similar but simpler methods for registration of gait deviations are also needed, for objective and standardized gait scoring methods that can be used for evaluation of joint health during welfare inspection.

- Although not mentioned in the results section of the thesis, CT examination of the hock revealed variation in the anatomical shape and size of the talus and distal tibia between individual animals, and also between the domestic pigs and the wild boars. The influence on OC of variations in joint shapes and other anatomical features needs to be better elucidated.

8 Populärvetenskaplig sammanfattning

Osteokondros (OC) hos slaktsvin är en vanlig rubbning i tillväxtbrosket som orsakar ledinflammation och hälta samt ledkassation vid slakt. Ledinflammation orsakat av rödsjukebakterien är en annan orsak till hälta och ledkassation hos slaktsvin.

Grisar i ekologisk produktion får oftare leder kasserade vid slakt jämfört med grisar i konventionell uppfödning. Avhandlingen undersökte om skillnader i stallmiljön för dessa två produktionsformer påverkar förekomsten av OC och rödsjukeartrit hos slaktsvin. Sambandet mellan klinisk hälta under uppfödningen och ledförändringar samt ledkassation utvärderades också.

Frigående slaktgrisar i flock med tillgång till rastgård, betesmark utomhus och stall med djupströbädd, hade högre förekomst och mer allvarlig OC än slaktgrisar i konventionella boxar inomhus. Grisar med mycket och svår OC var mera halta än de med lindrigare OC, varför det var överraskande att de frigående grisarna inte var mer halta än grisar i boxar. En förklaring kan vara att frigående grisar är mer aktiva och belastar lederna mer, vilket leder till mer OC. Samtidig stärker motion muskulatur, senor och skelettvävnad vilket gör att gången hos de frigående grisarna påverkas mindre av OC. Resultaten indikerar dock att hältundersökning av gris är ett otillförlitligt mått på ledhälsa.

Sambandet mellan ledkassation och hälta var lågt och inga grisar utvecklade rödsjukeartrit.

Vildsvin tillhör samma art som tamsvin varför förekomsten av OC i hasleden hos vildsvin undersöktes med datortomografi. Få vildsvin hade OC vilket kan bero på att de är utsatta för ett evolutionärt tryck där de är beroende av bra ledhälsa för att överleva ute i naturen.

I ekologisk produktion är det ett krav att grisar ska kunna röra sig fritt över större ytor. Avhandlingen indikerar att detta kan leda till sämre ledhälsa hos tamsvin. Sammantaget föreslås att ändringar i stallmiljön eller att en annan grisras med mer robusta leder kan behövas för en hållbar ekologisk slaktsvin produktion.

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Acknowledgements

The studies were supported by grants from The Swedish Research Council FORMAS. Financial support for paper III was also provided by Albert Hjärrefonden and Gerhard Forssells stipendiestiftelse.

I met really many great, helpful and competent people during my PhD years!

Stina Ekman; a wise man told me when I started climbing this dissertation mountain that I had already done one thing correct and that was managing to get a good supervisor; Stina, you have been *fantastic*! It was a slightly bumpy research road at times, but I have understood that is the delight of research and I really enjoyed these years! Thanks for all the help and encouragement and all those endless hours you spent editing my never ending production of text and riddles ;-) /:-o / :-) THANK YOU!

The wise man in question was **Björnar Ytrehus**. Your understanding of OC is 4D and you have been a fantastic sounding board, friend and co-author. I have seldom laughed as much as when I work with you and that has nearly been the best of it. Björnar; move to Sweden!

Another person who has this great gift of making work fun is **David Morrison!** You are one of these rare people who is really interesting and entertaining working with (yes, statistics can in rare cases be entertaining!). You have an endless patience and a big heart, and this together with your wise comments makes you a really appreciated colleague. I really wish you
All the best :)

Charles Ley; the living embodiment of a competent man! What an amazing work ethic and commitment! You introduced the world of CT to me and it has been very rewarding. Thanks *Charles*, it is a great pleasure working with you.

Thanks to my two *co-supervisors* **Nils Lundeheim** and **Julia Österberg**.
Nils, A man of numbers. I sincerely thank you for insisting that I start tackling some of the statistics on my own, it was important. Thanks also for sharing your knowledge of all aspects of Swedish pig production, it was a great help.
Julia What a passion! A passion for organic pig production and *ER* arthritis; two ingredients that were immensely needed in my project!

Eva Heldmer you are a delightful person; thanks for bringing in the clinical aspects, and thanks for the fun (and hard work!) we shared when visiting E.

Agneta Boström, Beate Hillmann, Tapio Nikkilä and **Christina Nilsson**; Thanks for all the amazing laboratory assistance. Many of my histological slides became pure pieces of art (honestly!). You were all a great help!

Lars Hammarsten You helped me open, sample and saw 1088 pig joints and 70 joints from wild boars!! (I hate those sawing machines; the noise of bone cutting is enough to kill all living organisms in the vicinity.) So thank you so much for sharing all those endless hours with me in the necropsy room; you are such a kind person and I never could have done it without you.
And for that reason it was also good that **Peder Eriksson** took over at VHC! I only had the pleasure of sharing the joys of the last 10 wild boars joints with you, but I really appreciate your nice gestures.

Thanks to : **Desiree Janson** and **Sigbritt Mattson** at SVA for your great assistance in the ER analyses! **Eva Westerberg** at SVA for running the confirmatory ER immunoassay for me!

Robin Strand: I love what you did with the CT images, the frequency maps look great!

Christina Larsson for performing all the CT scans (always with a big smile on your face!).

The **farmers** (who for obvious reasons may want to be anonymous) who participated in this project.

<u>Thanks also to:</u>
Maria Löfgren for always being one step ahead of me in all PhD administrative work and sharing this knowledge with me. Always willing to assist; you are great!

Karin Olofsson; thanks for your kind instructions on photography and image refining; my images would never have held the quality they do without your initial instructions!

Anna Wallenbeck, **Per Wallgren** and **Kristin Olstad** for good scientific discussions/feedback and/or practical advice.

Karin Rudolfsson, Anne-Sofie Lundqvist and **Kersti Larsson** for administrative assistance. **Sten-Olof Fredriksson** and the whole IT crew at SLU for fixing most of my IT problems.

Ulla Schmidt for training me in gait scoring of pigs.

Rolf Grahm for collecting and coding legs at the abattoir.

Ola Schulzberg, Kaj and Yvonne Rehnholm for assistance in collecting the legs from the wild boars.

ALL the rest of my colleagues at **BVF**, especially at "Patologen." BVF is a really <u>great working place and you all</u> contribute to that!
Not forgetting **Yagmur Ýagdiran**; You are missed!

FINALLY

Thanks to **Family and Friends** for making life so much more than work!

MOST importantly:

All my love goes to ***Naemi***, ***Nathalie***, ***Cecilia***, ***Gabriel*** and ***Marcel Etterlin.***
Jobb i all ära,,,, life would be completely meaningless without the five of you.
Thank you for always being there for me.
You are the best ♥