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Review

Occurrence, causes and consequences of keel bone damage of laying hens

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KBD is a multifactorial problem. This problem applies to all types of housing systems, caged as well as cage-free systems, including free-range and organic. The common causes are in particular collisions with the elements of the environment, such as perches, as well as collisions between hens. Extremely high frequency and severity of damage adversely affects not only welfare of laying hens also their production and egg quality too. This article provides an overview of current knowledge about the occurrence of KBD, the causes of its occurrence and consequences for the quality of life of laying hens in intensive large-scale production conditions. In the introductory part, we describe what keel bone is, the high incidence and prevalence of the problem, which implies the importance of long-term dealing with this issue at the global level. In the next part, we deal with the factors that can cause the occurrence of KBD, the relationship between the occurrence of KBD and bone quality, nutrition with an emphasis on calcium, the relationship between KBD and welfare, individual housing systems, age, genotypes of hens, feathering, efficiency and quality of production of laying hens and in the final part section we present detection methods. As already mentioned, the occurrence of KBD is influenced by a number of factors, but due to the differences in the prevalence of this problem in different countries, further comprehensive research is needed. The deviations and fractures of the keel bone can have a negative impact on the welfare of laying hens, which will subsequently be reflected in the possible painfulness of feed intake, laying, product quality, which ultimately will always affect economic efficiency. The goal of long-term research should to try to reduce the incidence of these conditions, or their prevention. It is important to deal with genetic selection, nutrition, a very important area, as far as KBD is concerned, are the conditions of the breeding environment, especially the housing system and the elements that make up the equipment of the rearing and breeding area, as well as the standardization of the methods used to detect damage to the keel bone. Palpation, post-mortem palpation, multiple sensing technologies are used. Researcher training can significantly improve both the accuracy and reliability of assessment of sternal fractures and deviations. If the results of keel bone prevalence will be compared or combined between individual studies, all methods used to detect keel bone damage should be accurate, i.e. sufficient methodological details should be given for each study and the method of determining prevalence should be standardized.

Keywords: laying hens, keel bone damage, fracture, welfare, production

1 Introduction

1.1 Keel bone damage and keel bone fractures

The keel bone in birds is an extension of the sternum (Kittelsen et al., 2020). The keel is an extension of the sternum which protrudes partially into the abdomen and to which the bird's wing muscles attachis. Depending on the severity of the damage, fractures can be identified by the presence of callus material (material formed during healing process), alternatively bending, S-shaped, twisted, curved keels and other deformations may be observed.

Unlike behavioral problems (e.g. feather pecking), which are easy to observe, or coccidiosis with sharp increase in mortality, birds with the fractures typically look and act the same healthy individuals.

Keel bone fractures (KBF) are defined as complete or partial breaks of the keel bone, causing negative affective states such as pain, discomfort and/or distress (Nielsen,

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2023). Keel bone fractures are a serious animal welfare problem in laying hens (Eusemann et al., 2022; Harrison et al., 2023). Despite the high standard of livestock welfare in Europe, studies from different EU countries and different housing systems have revealed an extremely high incidence of keel bone damage. Some studies report a high prevalence, other studies a relatively low prevalence in similarly old laying hens raised under similar breeding conditions (Riber and Hinrichdsen, 2016). For example Toscano et al. (2018) report more than 50%, Hardin et al. (2019) report a prevalence of up to 85%. The differences in the way of interpretation of the prevalence of breast bone is made especially difficult by the very identification of the true extent of the problem.

KBD is of specific concern as it occurs at high rates, particularly in multi-tiered systems (Campbell, 2020). KBD to cause stress in birds, can alter hen behaviour, and reduce their production and egg quality posing financial concerns for producers (Nasr et al., 2013; Candelotto et al., 2017; Riber et al., 2018). The bone demineralization process seems to play a key role to the pathogenesis of keel fractures (Gebhardt-Henrich et al., 2018). The keel bone is prone to damages in terms of fractures and deviations due to the anatomical position, especially in modern layers with small breast muscle as discussed by Fleming et al. (2004). The keel bone fractures are associated with differences in the concentrations and activities of bone metabolism-related indexes, as well as bone mineral density in laying hens (Wei et al., 2021).

Fractures may extend from the ventral to the dorsal surface in the sagittal plane, but may also be cranial to caudal or a combination of these Casey-Trott et al. (2015).

1.2 *The influence of keel bone damage on welfare of laying hens*

Questions regarding the welfare of animals are coming to the fore of the interest of the public as well as producers and trade chains. According to the assessment of the European Food Safety Authority, among the most serious welfare problems currently facing the poultry industry are damage (fractures and deviations) of the keel bone (EFSA, 2012). Keel bone damage is found in all types of commercial production, however with varying prevalence across systems, countries, and age of the hens.

Laying hens with keel bone fractures show marked behavioral differences in highly motivated behavior, such as perching, nest use, and locomotion, indicating reduced mobility and potentially negative affective states. Irrespective of the underlying welfare concern, available scientific evidence showed that keel bone fractures reduce the welfare of layers in modern production systems. It remains unclear whether keel bone fractures affect hen mortality, but there seem to be relations between the fractures and other clinical indicators of reduced welfare. Evidence of several types showing pain involvement in fractured keel bones has been published, strongly suggesting that fractures are a source of pain, at least for weeks after the occurrence (Riber et al., 2018).

Riber and Hinrichsen (2017) reported that the prevalence of hens with keel bone deviations, with both keel bone fractures and deviations and with body wounds, was very high significantly higher in non-trimmed flocks compared with beak-trimmed flocks at both ages.

Omitting beak trimming had negative consequences for the condition of plumage, skin, and keel bone, and tended to increase mortality, highlighting the risk of reduced welfare when keeping layers with intact beaks. In addition, injurious pecking damage was found to be positively linked to keel bone damage. The causal relation is unknown, but authors propose that fearfulness is an important factor. In an experiment by Wei et al. (2022), hens of both hybrids (Lindian and Hy-line Brown) at the age of 32 weeks were divided into normal, deviated, and broken according to the condition of the keel bones. After blood sampling to determine indicators of stress and fear, the results showed that the incidence of keel fractures was significantly higher in the Lindian hens than in the Hy-line Brown hybrid. KBD affected stress and fear responses, and this effect was more pronounced in hens with broken keel bone compared to hens with normal keel bone and deviated keel bone. The welfare of hens in aviary systems can be improved by means of adapted structural modifications. Nannoni et al. (2022) examined the effects of three different structural modifications (addition of ramps and/or removal of internal partitions) to increase the hens' freedom of movement in a commercial aviary system. No significant effect was observed on keel bone damage. Hens reduced the number of flights and increased the number of walks from 0.52 to 7.7% of the displacements on average (p <0.05).

1.3 *Causes of keel bone damage and keel bone fractures – risk factors*

Research of has indicated various causes of KBD – impact of a bird on a part of the housing technology in the hall, predisposing factors including bird genetics, lack of specific feed components, high egg production, management factors and hen fatigue (Thofner et al., 2020). Collision with housing structures combined with the weakened bone strength is considered the major risk factors for keel bone fractures in layers (Fleming et al., 2004; Harlander-Matauschek et al., 2015; Stratmann et al., 2015). Similarly, mutual collisions between laying hens pose a danger. There are several factors that can affect the number of laying hen collisions. An important role is played by the intensity of artificial light, the length of the jump, the body weight of the hens, the color of the perches. Artificial light affects manoeuvring of birds: very low light intensities (<5 lx) make hens more reluctant to jump (Taylor et al., 2003). Under low-light conditions reluctance to jump can be reduced by using a perch colour that contrasts well with the environment (Taylor et al., 2003). Longer jumps and steeper jumping angles lead to more balancing movements upon landing and greater forces on the keel (Rufener and Makagon, 2020). There is also a genetic influence on laying hens' jumping ability which may be due to differences in body weight between different lines (Scholz et al., 2014) in (Nielsen et al., 2023).

A recent study of behavior of laying hens focused on failed landings and discussed the potential of such events for flight-related injuries (Campbell et al., 2016). The study of Thofner et al. (2021) demonstrated a very high prevalence of keel bone fractures in hens from all production systems and identified hen size, age at onset of lay and daily egg weight at onset of lay to be major risk factors for development of KBF in the modern laying hen. Also Eusemann et al. (2020) prezent that keel bone fractures are influenced by several factors such as husbandry system and genetic background.The causes of keel bone damage are multifactorial. This problem applies to all types of housing systems, including free-range and organic. Direct causes are in particular collisions with the elements of the environment, such as perches, feeders or drinkers, as well as collisions between animals, especially during the light and dark transition period (Stratmann et al., 2015). Jung et al. (2019) focused on identify possible risk factors for KBD in organic hens by analysing cross-sectional data of 50 flocks assessed in eight European countries. Keel bone damage included fractures and/or deviations was recorded by palpation. Aviary v. floor systems, absence of natural daylight in the hen house, a higher proportion of underweight birds, as well as a higher laying performance were found to be significantly associated with a higher percentage of hens with KBD. The moderate explanatory value of the model underlines the multifactorial nature of KBD. Based on the results increased attention should be paid to an adequate housing design and lighting that allows the birds easy orientation and safe manoeuvring in the system. Furthermore, feeding management should aim at sufficient bird live weights that fulfil breeder weight standards. The selection for early sexual maturity and a continuous high egg production in commercial layer lines have led to increased bone fragility and susceptibility to fractures due to the high calcium requirement for formation of eggshells (Sandilands et al., 2009). Laying rate and adult body weight had an effect on the keel bone mineral density in the study of Habig et al. (2021). The bone mineral density greatly affects keel bone deformities. The growth rate has a rather subordinate effect on keels' BMD bone mineral density, while the BMD bone mineral density itself greatly affects KBD. Scholz et al. (2008) after performing a histological analysis of macroscopically evaluated keel bones (1: severe, 2: moderate, 3: slight, 4: no deformation) taken in the 3rd, 6th, 9th and 12th months of laying, from four carrier lines of hens, housed in cages with perches or in an aviary system in 97.9% of grade 4 keel bones, no histological deviations were found, whereas in keel bones manifesting deformities of grade 1and 2, the predominant histological observation was the incidence of fracture callus material (FCM) and new bone in the form of woven bone. FCM was also detected in 50.9% of grade 3 keel bones, whereas in 40.7%, only s-shaped deviations of keel bones were found, which were related to extended pressure loading while perching activities rather than short-duration trauma. The prevalence of keel bone damage of 2 pure lines divergently selected for high (H) and low (L) bone strength were investigated in 2 aviary systems under commercial conditions in the experiment of Stratmann et al. (2016). Fewer fractures and deviations of the keel were found in the line with high bone strength compared to the line with low bone strength. Authors suggests that selection of specific bone traits associated with bone strength as well as the related differences in body morphology (i.e., lower index of wing loading) have potential to reduce keel bone damage in commercial settings. Also, the housing environment (i.e., aviary design) may have additive effects.

The localization of the fractures at the distal end of the keel bone was highly consistent in all flocks in the study of Thofner a kol. (2021). Keel bone damage might result also from the strong muscular contractions of the breast muscles (Harlander-Matauschek et al., 2015).

1.4 The effect of the age of hens on the occurrence of keel bone damage

Richards et al. (2012) found that the severity of keel bone fractures increased with age. Considering the extent and severity of keel bone fractures at the end of lay, handling and transportation of end-of-lay hens is of great concern, but so far, research into the welfare consequences of keel bone damage during poultry transport does not exist (Riber et al., 2018). In recent years, high, and probably increasing as suggested by Nasr et al. (2012) prevalence of keel bone fractures has been reported in laying hens of 36–97% depending on housing system and age of the hens (Fleming et al., 2004; Rodenburg et al., 2008;

Wilkins et al., 2011; Petrik et al., 2015). The prevalence of keel bone fractures increased from 15.4% in week of age 20 to 64% in week of age 45 and was not linked with the number of falls Stratmann et al., 2019. Rorvang et al. (2019) conducted an on-farm assessment of damage to the keel bones, of hens housed in cages. A deterioration with age of the condition of the plumage and keel bone was found. At 77 weeks of age, 16% of the birds had poor plumage, and 43% of the birds had keel bone damage. In contrast, foot pad lesions were most prevalent at 32 weeks of age (13%), The results of Wei et al. (2020) showed that the incidences of keel fracture increased with the age of laying hens. The keel bone status was evaluated through palpation at 5 time-points (22, 27, 32, 37, and 42 week of age). Keel fracture in laying hens caused changes in behavior and reduced the welfare, production performance, feed intake, and eggshell quality. A higher score for keel bone protrusion was observed in lighter and older hens in the expriment of Saraiva et al. (2020). Heavier hens showed longer tonic immobility durations and older hens required fewer tonic immobility inductions, indicating that heavier and older hens were more fearful. The high cumulative mortality rates (23–26%), keel bone deformations (57%) and keel bone protrusion (89%) should be considered relevant welfare indicators in laying hens from housing systems.

1.5 The influence of genotype on the occurrence of keel bone damage

The results of the research of several author collectives indicate that the adaptation of housing systems and the selection of hybrids can be effective measures to improve the welfare of laying hens. Genetic selection for high bone strength may be necessary for hens to adequately adapt to loose-housed systems, but the best strategy for improving skeletal health is likely to be multifactorial Campbell (2020). High performing white (WLA) and brown (BLA) pure bred layer lines and low performing white (R11, G11) and brown layer lines (L68) kept in both single cages and a floor housing system were subject of research of Eusemann et al. (2018). Fracture prevalence increased with age. In the 72[nd] week of age hens in the floor housing system showed significantly more fractures than hens kept in cages. The results show a different development of keel bone damage in caged compared to floor-housed hens under experimental conditions. Keel bone and foot pad disorders are related to genetic predisposition. In the experiment of Heerkens et al. (2016) brown-egg hybrid hens sustained more keel bone fractures, but had fewer keel bone deviations, compared to white-egg hybrid hens. Age, housing and hybrid showed several interaction effects. The authors Soezcue et al. (2022) investigated two genotypes of free range Turkish laying hens, brown and white. White hens had less keel damage at 56 and 72 weeks of age, free-range Brown hens may be more prone to keel damage and the development of feather pecking, but showed fewer leg lesions and were less frightened. Research of Habig et al. (2021) prezent that keel bones of white-egg layers had a lower mineral density and were more often deformed compared with brown-egg layers. Different strains of commercial laying hens have been shaped by different selection pressures, which have affected their production, health and behavior. Therefore, assumptions that all strains of laying hens use given resources within aviary systems similarly and maintain the same health status and performance may be wrong (Ali et al., 2020). The authors investigated the interactions between the aviary resource use patterns of 2 strains of white and 2 strains of brown laying hens Brown hens showed a lower incidence of keel fractures. White hens had a higher probability of keel fractures (4.2) than brown hens. The odds of hernia fractures were 3.7 and 5.7 times higher at 54 and 72 weeks than at 28 weeks in all strains, respectively. Occupying the upper layer at night increased the likelihood of keel fractures by 5.4 times. In the expriment of Chew et al. (2021) there were no strain differences on KBD from palpated or dissected keel bones. Light intensity, within a range of 10 to 50 lux, did not influence KBD. The present study of Candelotto et al. (2017) sought to identify genetic variation in relation to keel bone fracture susceptibility of 4 distinct crossbred and one pure line. The 5 crossbred/pure lines differed in their susceptibility to keel bone fractures. Iincreased susceptibility to keel bone fractures was associated with thinner eggshells and reduced egg breaking strength, a pattern consistent among all tested crossbred/pure lines. The authors' findings indicate an association between egg quality and bone strength which appeared to be independent of crossbred/pure line. Malchow et al. (2022) compared two hybrids, of dual-purpose hens of Lohmann Dual and conventional laying hens Lohmann Tradition. LD had a higher radio-graphic density than LT hens, other keel bone parameters (fracture score, deformation) showed no differences. The vast majority of fractures occurring in both strains were located in the caudal part of the keel bone. In contrast, Wurtz et al.(2022) followed two hybrids under conditions of organic production. Both hybrids experienced keel bone fractures, though Dekalb White hens had more at the cranial portion and Bovans Brown at the caudal portion. Eusemann et al. (2020) assume that within a layer line, there is a strong association between egg production and keel bone fractures, and, possibly, bone mineral density, but not between egg production and deviations. Moreover, them results confirm that genetic background influences fracture prevalence and indicate that the selection for high laying performance may negatively influence keel bone health. Kittelsen et al. (2020) investigated whether less selected breeds have a lower occurrence of keel bone fractures compared to highly selected, modern laying hen breeds. The hens from four non-commercial layer breeds were housed in furnished cages and keel bones examined at 30 and 63 weeks of age using a portable X-ray equipment. The results study indicate a low prevalence of keel bone fractures in hens at both ages in all four breeds. No fractures were observed in the examined roosters.

1.6 The influence of housing systems on the ooccurrence of keel bone damage

The conditions of welfare and housing of laying hens in the production of table eggs are currently of interest to most egg sellers as well as consumers as they directly affect the economy of their production and their price (Zigo et al., 2020). Recent investigations on the incidence of keel bone damage in laying hens suggest that the overall situation may be worsening. Depending on the housing system, fracture prevalences exceeding 80% have been reported from different countries (Thofner et al., 2021). The prevalence, type, and severity of keel bone damage depend to some extent on the housing system. Among the major risk factors seems to be whether it is a cage or non-cage system, and for the latter, whether it has a single tier or multi-tiers (Riber et al., 2018). Keel bone damage seems to be more frequent in non-cage systems than in cage systems (Petrik et al., 2015) and more in multitier systems than in single-tier systems (Riber, Hinrichsen, 2016). The reduced mobility caused by keel bone fractures will have a greater impact on hens in multi-tier systems, where vital resources (feed, water, and nest boxes) are found on different tiers (Riber et al., 2018). KBD, while highly variable and likely dependent on a host of factors, extends to all housing systems (including traditional battery cages, furnished cages and non-cage systems), genetic lines, and management styles (Harlander-Matauschek et al., 2015). The main objectives of the study of Wilkins et al. (2011) were to provide an accurate assessment of current levels of old breaks in end-of-lay hens housed in a variety of system designs. All systems were associated with alarmingly high levels of keel damage flocks housed in furnished cages having the lowest prevalence flocks housed in all systems equipped with multilevel perches showing the highest levels of damage (over 80 per cent) and the highest severity. Rojs et al. (2020) compared an enriched battery cage system, an aviary, and a litter system with or without outdoor access. Among animal-based welfare indicators, keel bone damage was shown to be the most serious problem connected with hens' age and housing systems. Enriched cages and aviary system were associated with significantly more keel deformities compared to the litter systems.

1.6.1 The influence of cages on the occurrence of keel bone damage

Conventional caged layers are restricted in movement, which imbalances structural bone resorption and new bone formation, resulting in osteoporosis Campbell

Figure 1 Examples of keel bone damage
Source: Arpášová, Bilčík, 2022

(2020). In flocks from non-caged systems, fracture prevalence in the range 53–100%, was observed in the experiment of Thofner et al. (2021) whereas the prevalence in flocks from enriched cages ranged between 50–98%. Macroscopically the fractures varied morphologically from an appearance with an almost total absence of callus, most frequently observed in caged birds, to large callus formations in and around the fracture lines, which was a typical finding in non-caged birds. Casey-Trott et al. (2015) reported in furnished cages a decrease in standing and an increase in perching, on the contrary Wei et al. (2020) reported reducedperching, as well as reduced feeding, walking and jumping. Bodyweight, feed intake and eggproduction were also reduced in animals with keel bone fractures (Wei et al., 2020). Collisions accounted for nearly 81% of observed acceleration events in the experiment of Baker et al. (2020) in enriched cages hens. The majority of collisions were with the perch and were sustained mainly as the hen attempted to ascend onto it. The results presented by Bilčík et al. (2019) are the output of the pilot part of the project. The authors monitored the occurrence of fractures and deformations in adult laying hens in commercial breeding in enriched cages and in young animals (from the age of 6 weeks) in experimental breeding in enriched cages and on litter. The condition of the ridge was determined by palpation (Einhorn 005, J. Orthop. Trauma 9, 4–6). Preliminary results show that sternum injuries are not rare even in our conditions. The predominant type of damage in cage farms was deformities of varying degrees. The occurrence of deformities in young individuals already before and during the laying period is surprising.

1.6.2 The influence of cage-free housing systems on the occurrence of keel bone damage

The breeding system is related to the integrity of the skeleton. Breeding laying hens with the possibility of movement strengthens the skeleton, reduces bone fragility, prevents overgrowth of claws on runners and reduces mechanical damage to feathers. Non-cage systems provide laying hens with considerable space allowance, perches and access to litter, thereby offering opportunities for natural species-specific behaviors. Conversely, these typical characteristics of non-cage systems also increase the risk of keel bone and foot pad disorders (Heerkens et al., 2016). Keel bone damage (KBD) is more prevalent in alternative laying hen housing systems than in conventional cages, and its incidence differs from strain to strain. The EU Directive on laying hens bans standard battery cages since 2012, which has implications for animal welfare, especially as rearing hens in extensive systems improves bone strength. However, this method of rearing is associated with a higher rate of bone fractures, especially of the keel, compared to hens kept in cages (Sandilands et al., 2009). Hens within alternative housing systems have opportunities to exercise for strengthening bones, but as noted above, they may also suffer from higher rates of keel fractures and/or deviations, that are likely to have resulted from collisions or pressure force (Campbell, 2020). Thofner et al. (2020) state that in Denmark observed fracture prevalence in the range of 53% to 100% in flocks from cage-free systems whereas flock prevalences in birds from enriched cages ranged between 50–98%.

Three-dimensional complexity during rearing, i.e. providing pullets with the opportunity to move up and down structures, contributes to reducing bone lesions by improving bone strength (Pufall et al., 2021) and spatial awareness (Norman et al., 2021) which reduces the risk of falls and collisions. Methods to reduce keel bone fractures by preventing falls and collisions include also: optimising light conditions and providing sufficient space on safely accessible perches. Sufficient light is essential to facilitate orientation and safe manoeuvring (Jung et al., 2019).

1.6.3 The influence of aviary housing system on the occurrence of keel bone damage

In the experiment of Fulton (2019) keel bone fractures were greatest for aviary system, next greatest for enriched colony cages, and least for conventional cages birds. Analysis of Sholz et al. (2008) corroborates the findings that in aviary systems deformities of keel bones are predominantly caused by painful fractures. The occurrences of keel-bone damage, was higher at 62 compared to 32 weeks of age. There was no difference between barn and organic production systems. Hens in multi-tiered systems were more likely to have keel-bone fractures compared to hens in single-tiered systems (62 weeks: 11.6 vs 4.9%) in the expriment of Riber, Hinrichsen (2016). In the experiment of Pullin et al. (2020) were reared Lohmann LSL-Lite hens in either aviaries or non-enriched cages until 19 weeks of age, then moved into enriched colony cages. Hens reared in aviaries sustain fewer keel bone fractures than those reared in non-enriched cages through the age of 73 weeks. Hens reared in non-enriched cages experience more collisions than aviary-reared hens. Aviary-reared hens also prefer to utilize a higher perch than the cage-reared hens. Even though aviary systems provide a range of benefits for laying hens in terms of animal welfare, falls and collisions have been observed in experimental settings. These falls are likely stressful for the birds and are thought to be linked to the known high prevalence of keel bone fractures in aviary-housed hens (Stratmann et al., 2019). Stratmann et al. (2019) found that fall frequency was highest during the dusk phase. The majority of falls were observed to occur from the top level of the aviary compared with the middle or lower levels. A longer dusk phase did not reduce the number of falls but affected their cause: falls were less likely to be caused by failed landings with increasing dusk length. The prevalence of keel bone fractures increased from 15.4% in week of age 20 to 64% in week of age 45 and was not linked with the number of falls (Stratmann et al., 2019). Providing ramps proved to be very effective in both reducing keel bone and foot pad problems in non-cage systems in the study of Heerkens et al. (2016). Delaying birds' access to perches and elevated nests (from 17 weeks to 25 weeks) compromises movement and increases the risk of injury from falls (Ali et al., 2019). Providing young chicks and pullets with ramps to enable easier access to elevated structures has additional benefits, with grid ramps preferred over ladders (Pettersson et al., 2017; Zheng et al., 2019). Pullets reared commercially with elevated structures and additional ramps from 3 weeks of age were more mobile and confident in moving between tiers at 12–14 weeks of age than pullets reared with elevatedstructures but no ramps (Norman et al., 2018). Campbell (2020) indicated that management strategies such as the provision of ramps to access perches and tiers can reduce the incidence of keel-bone damage to a degree. Bone strength can be improved through exercise opportunities, particularly when available during pullet rearing. In commercial situations, laying hens must negotiate levels to reach resources such as food, water and litter. Providing ramps in aviary systems reduces collisions and resultant keel bone fractures in adults (Norman et al., 2018). To access resources in commercial laying houses hens must move between levels with agility to avoid injury (Norman et al., 2021). Based on research the authors conclude that there are positive effects of providing a ramp experience during rearing that manifested by any combination of bird mobility, strength, or cognitive ability (Norman et al., 2018).

Mean levels of keel bone damage were reduced in ramp reared flocks (52%) compared with control flocks (64.8%) at 40 weeks of age ($P = 0.028$). The early life experience of the ramp reared flocks enabled specific learning that translated and persisted in later life and resulted in overall welfare benefits (Norman et al., 2021). This includes, for instance, the use of materials less slippery than steel and avoiding thin round perches (Scholz et al., 2014). Visibility can also be improved by the use of contrast colours for perches. Furthermore, covering hard perches with soft polyurethane material can reduce keel fractures in non-cage systems by absorbing part of kinetic energy occurring during collisions (Stratmann et al., 2015). Rearing with perches reduces subsequent collisions for adult hens housed in colony cages (Pullin et al., 2020), and aids movement and reduces collisions in aviary systems (Ali et al., 2019). Grids may be more suitable as resting area than perches and may possibly help to decrease the prevalence of keel bone damage. During the laying period, usage of elevated structures was higher with grids compared to perches (Malchow et al., 2022). Hens should have access to perches because of their high motivation and preference for perching. At night, hens like to perch at the same time which requires a straight perch space of 12 and 15 cm for White Leghorn and brown hybrids, respectively. Besides meeting a behavioural need, perches in cages improve bone strength, but the improvement is not great enough to prevent adult keel fractures and deformities (Hester, 2016). The results of Stratmann et al. (2015) revealed that pens with soft perches had a reduced number of keel bone fractures and deviations. Due to its compressible material soft perches are likely to absorb kinetic energy occurring during collisions and increase the spread of pressure on the keel bone during perching, providing a mechanism to reduce keel bone fractures and deviations, respectively. Even if hens are kept in a cage system during lay, aviary rearing decreases the occurrence of keel fractures during lay (Casey-Trott et al., 2017). In the study of Habig et al. (2021) hens kept in cages showed more deformities, but fewer fractures and a lower bone mineral density of the keel bone than did floor-housed hens.

1.6.4 The influence of free range housing system on the occurrence of keel bone damage

Outdoor range areas provide laying hens with improved opportunities to perform natural behaviors and increase the available space per bird, however, birds are also exposed to potentially stress-ful factors including weather and predators. Ability to cope with challenging environments varies between different strains and must be considered to ensure good welfare Wurtz et al. (2022). Alternative systems for egg production, e.g. free-range and organic systems are preferred because they improve the ability of birds to perform important specific behaviors and thereby increase welfare conditions in commercial farms. Free-range systems are believed to improve the health and well-being of birds, thereby also meeting the demands of consumers (Soezcue et al., 2022). Also, the susceptibility of caged hens to osteoporosis and fatigue in caged hens has created interest in newer housing systems that favor increased weight-bearing activity. Non-cage systems provide laying hens with considerable space allowance, perches and access to litter, thereby offering opportunities for natural species-specific behaviors. Conversely, these typical characteristics of non-cage systems also increase the risk of keel bone and foot pad disorders (Regmi et al., 2016).

Results of experiment of Regmi et al. (2016) showed that cortical density for keel bone was significantly greater in cage free birds and cage-free with range (outdoor access birds) compared to conventional cages birds. Each housing system was associated with high prevalence (>90%) of keel deformities and the housing and genotype influenced the type of deformity (Regmi et al., 2016). The authors Soezcue et al. (2022) prezent in free range in white-egg hens less keel damage, but brown-egg hens showed fewer leg lesions and were less frightened. Free-range laying hens different according to body weight quantiles, were obtained in the experiment of Sibanda et al. (2020). The autors found that 55.8% of heavy hens (upper kvartil, 2.08 ±0.002 kg) had a single or multiple keel bone damage compared to 48.9% (middle kvartily, 1.86 ±0.010 kg) and 50.7% (lower kvartil, 1,65 ±0.002 kg) of medium and light hens, respectively.

1.7 The influence of keel bone damage on egg production and egg quality

The bone lesions can occur at any time during the laying period. Fractures of the keel bones are associated with inflammation and reduced feed intake. At slaughter, also new fractures due to catching, transport and shackling may be detected. These can be distinguished by a lack of callus formation and signs of bruising in the surrounding tissue (Gregory et al., 1990).

Most publications report the highest prevalence rate at the end of the clutch (Riber and Hinrichsen, 2016). In addition to acute pain caused by fracture (Nasr et al., 2012), the keel bone damage has been associated with lowered egg quality (Candelotto et al., 2017). Healing the fracture requires a lot of energy and calcium, the items that hens also need to produce eggs. On the other hand, high calcium demand in current commercial breeds can induce resorption and indirectly contribute to increased fragility of the keel (Fleming et al., 2004). Several researchers also found differences inbone characteristics and fracture risk in layer lines differing in laying performance. Layer lines with a high laying performance showed an increased prevalence of keel bone fractures and a lower breaking strength of the tibiotarsus compared to moderately performing layer lines (Habig et al., 2017). There is evidence that egg production and the selection for high laying performance may be an under-lying cause of keel bone fractures. Hens in which egg production was suppressed by administering an implant with the GnRH agonist deslorelin acetate showed a markedly decreased risk of keel bone frac-tures compared to egg-laying control hens (Eusemann et al., 2020). Non-egg-laying hens showed in the experiment of Eusemann et al. (2022) a higher total bone area and a higher relative amount of cortical bone compared to egg-laying hens. These differences in bone composition may explain different susceptibility to keel bone fractures in non-egg-laying compared to egg-laying hens as well as in hens of layer lines differing in laying performance. Similarly, in the experiment of Habig et al. (2021) keel bones were more often broken in hens of the layer lines with a high laying rate compared to the lines with a moderate laying rate. In a study by Hocking et al. (2003), radiographic density of keel bones and tibiotarsi was higher in traditional breeds with a comparatively low laying performance compared to commercial breeds with a high laying performance. Hens that died or were killed were analysed during the early, middle and late stages of the laying cycle by Kajlich et al. (2016). Deformation of the keel bones was the most common lesion observed. The highest occurrence of KBD was recorded during the middle phase of laying. The influence of moulting, the use of hens in the second laying cycle after moulting and the technology of the housing system in conventional and enriched cages on KBD were addressed by Onbasiler et al. (2020), who found that breastbone deformations were worst in the period after moulting. During the molt period, hens reared in enriched cages had lower egg production, but increased post-molt egg production at a high rate.

1.7.1 The influence of calcium on the occurrence of keel bone damage

The main stress factories include insufficient nutrition with poor transition and nutritional composition of feed mixtures for individual stages of growth (Halás et al., 2023). As discussed by Sandilands et al. (2009) selection for early sexual maturity and a continuous high egg production in commercial layer lines have led to increased bone fragility and susceptibility to fractures due to the high calcium requirement for formation of eggshells. The resulting bone weakness has mainly been associated with osteoporosis, which is a pathological condition characterized by progressive loss of structural bone throughout lay, rendering bones fragile and susceptible to fracture (Webster, 2004; FAWC 2010). The growth of laying hen's skeletal frame ceases at sexual maturity approximately from 16 to18 weeks of age (Korver, 2004). However, the ossification process of the keel bone continues until approximately 40 weeks of age (Buckner, 1950). Hence, at 16 weeks of age as the hen begins producing eggs, several centimeters of the caudal tip of the keel remain entirely cartilaginous (Casey-Trott, 2017) in (Riber et al., 2018). As large amounts of calcium are required for eggshell production, starting at the onset of lay, it is possible that – for high-producing layers – the cartilaginous keel bone receives less than adequate calcium for proper ossification during the early laying period. However, at present, data are not available to support this suggestion (Riber et al., 2018). Modern laying hens have been selected for an astounding rate of egg production, but the physiological calcium demand takes a significant toll on their skeletal health (Campbell, 2020).

According to Whitehead (2004), there is a surge in osteoclastic resorption during the shell formation period in laying hens. It is likely that egg production also influences keel bone health due to the high demand of calcium for the eggshell, which is, in part, taken from the skeleton. The high estrogen plasma concentration, which is linked to the high laying performance, may also affect the keel bone as sexual steroids have been shown to influence bone health (Eusemann, 2020). The aim of article Lazarov et al. (2022) was to present the possibility of reducing sternum fractures (KBF) in laying hens by using calcium particulate 2 hours before turning off the lights (CaT), alone or in combination with 25-hydroxyholecalciferol (Hyd). For the experiment used hens were exposed to one of four treatment combinations in a 2X2 factorial design (Factor 1: CaT+ or Control (CaT-); Factor 2: Hyd vs. Control (Hyd). The likelihood of an experimental fracture occurring in the CaT-/Hyd- was 3.6 times more likely compared to the CaT+/Hyd+ treatment (1.1 to 5.8). The study of Eusebio-Balcazar et al. (2018) was conducted to evaluate limestone particle size (LPS) in 2 strains of laying hens (white-egg and brown-egg strain) housed in conventional cages or aviaries on bone integrity. Feeding of blend of fine and coarse linmestone to pullets improved bone mineralization at the onset of sexual maturity and reduced keel damage during the pullet and layer phases, regardless of strain; however, LPS-BLEND was associated with lower egg production in Brown hens housed in aviaries compared to all others. In the experiment of Gebhardt-Henrich et al. (2017) expectations, peripheral quantitative computer tomography revealed higher cortical and trabecular contents in fractured than in intact keel bones. This might be due to structural bone repair after fractures. Likewise, birds with intact or slightly deviated keel bones had higher mineral and calcium contents of the keel bone than birds with fractured keel bones. Calcium content in keel bones was correlated with calcium content in tibias. Results of Wei et al. (2021) showed after supplementing 3% soybean oil in the feed mixture of laying hens in the oil-supplemented group, a higher incidence of keel damage (especially fracture), the keel length of birds in this group was significantly reduced compared to the control group.

1.8 Keel bone damage detection methods

Assessing keel bone damage reliably and accurately is a requirement for all research on this topic (Gebhardt-Henrich et al., 2019). Studies that have been conducted on this issue have relied on a number of methods of sternal assessment including palpation, autopsy radiography and computed tomography (CT) scanning (Casey-Trott et al., 2015; Chargo et al., 2018). These methods vary in reliability, sensitivity, and the type of screening evaluation required to accurately detect KBD damage. It would be necessary for the method of determining the prevalence to be standardized.

Palpation is the most commonly used method because it is inexpensive, does not require special equipment, and can be easily performed in agricultural and research facilities. 75–93% of keelbone fractures are detected by palpation (Wilkins et al., 2004; Buijset al., 2019). However, palpation is prone to bias (Gebhardt-Henrich et al., 2019). The accuracy of palpation for fracture detection is limited (Casey-Trott et al., 2015) because it relies on the tactile perception of callus indicating old fractures, but it is very difficult to detect fresh or fatigue fractures as well as fractures at the dorsal site of the keel bone (Richards et al., 2011).The accuracy of the palpation method may also vary between housing systems, as fractures with little callus formation (which are harder to detect by palpation) are common in caged birds, whereas fractures with large calluses are typically found in non-caged birds (Thøfner et al., 2021). The high prevalence of keel bone fractures in most flocks coupled with this limitedsensitivity means that, in most cases, inaccuracy in the palpation method will lead to an underestimation of the occurrence of this problem (Buijs et al., 2019; Thøfner et al., 2021).

The commonly used palpation method is mostly focused on detecting healed fractures (Casey-Trott et al., 2015) although some authors have concluded that new fractures can also be identified (which is usually only possible for complete fracture of the keel bone (Nielsen et al., 2023).

Autopsy can detect new and old bone fractures, but it is performed post-mortem and therefore cannot be used to study the bone development of individual laying hens. To detect these, radiographic methods or post-mortem palpation of the inside of the keel bone is required.

In summary, visual assessment of keel bone fractures post-mortem e.g. ultrasound, radiography or an automated 3D camera system seems feasible as a standard method (Rufener and Makagon, 2020; Jung et al., 2021).

Sensing technologies require special equipment and training and are therefore not practical for use on the farm, but rather in experimental conditions. Accuracy or reliability tests are very important in training. Training is particularly important because of the large amount of detail these methods provide (Lougran, 1994). For example, increased radiographic density on an X-ray may not necessarily indicate a fracture but may be due to sclerosis (Baur et al., 2020), and insufficient training may lead to an overestimation of the prevalence of breast bone. On the other hand, with high-quality training, it is possible to quantify and describe a wide range of fractures in great detail. One of the methods of determining the severity of KBD damage is quantitative radiographic measurements. Quantitative radiographic measures of KBD severity are helpful for researchers who study causes for this problem and the effects of novel interventions (Harrison et al., 2023). The aim of study of authors were to develop and test intraobserver repeatability for a standardized protocol to quantify three categories of radiographic KBD using open-source image analysis software and discrete and continuous variables. Based on control chart analyses, measures within the acceptable range of intra-observer variation using the standardized protocol were the number of complete cranial fractures (97.02%), incomplete cranial fractures (96.38%), complete caudal fractures (95.32%), incomplete caudal fractures (98.09%), cranial calluses (99.79%), and caudal calluses (98.09%); proportion of deviation (POD) measurements (97.87%); and angle of displacement (AOD) measurements (93.60%). Jung et al. (2021) conducted an assessment of keel bone fractures post-mortem (after defeathering), based on a 3D camera-based assessment system. It remains to be determined whether a 3D camera-based assessment system is needed or whether a normal camera capturing light in red, green and blue wavelengths (RGB camera) can be used. The latter could have the advantage that several traits can be recorded by the same camera system. Given the fact that plumage may cover (part of) the keel bone, placement of the camera system after defeathering would be optimal.

2 Conclusions

Due to the fact that the occurrence of KBD is influenced by a number of factors, further comprehensive research is needed due to possible significant impact on the quality of life of laying hens in intensive conditions of large-scale production. Deviations and fractures of the breast bone can have a negative impact on the welfare of laying hens, which will subsequently be reflected, also due to possible pain, on feed intake, on laying, product quality, which in the end is always reflected in economic efficiency. The goal of long-term research should be to try to reduce the incidence of these conditions, or their prevention. The synthesis of the findings of the aforementioned studies shows the importance of focusing further research on genetic selection, nutrition, conditions of the breeding environment, which represent a very important area with regard to the occurrence of KBD, especially the housing system and structures located in the living space of animals, buildings completing the equipment rearing and rearing area. Another important area that researchers should address is the standardization of methods used to detect keel bone damage. Palpation, post-mortem palpation, multiple sensing technologies are used. The accuracy of palpation, which is the most frequent method for detecting fractures in practice, is limited. Fractures located in the caudal third of the keel bone are particularly difficult to detect with this method, and most fractures occur in this area.The accuracy of the palpation method may also vary between individual housing systems in terms of differences in callus formation. Thanks to these specifics, the inaccuracy of the palpation method can in many cases lead to an underestimation of the occurrence of this problem. Therefore, the training of researchers can significantly improve the accuracy and reliability of palpation as well as other methods of assessing fractures and deviations of the keel bone. If the results of keel bone prevalence are to be compared between individual studies or combined, all methods used to detect keel bone damage must be accurate, i.e. sufficient methodological details must be provided for each study and the method of determining prevalence should be standardized.

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