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Rib Fractures in Lambs in South Australia

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Abstract: The frequent occurrence of rib fractures in slaughtered lambs results in significant economic loss to producers and processors in South Australia and raises concerns about the welfare of the animals. The prevalence of rib fractures became evident through the Enhanced Abattoir Surveillance (EAS) program introduced in 2007. The present study aimed to investigate the association between rib fracture prevalence in lambs at slaughter and their nutrition and management on the farm of origin. The slaughter of 30,055 lambs from 60 farms was monitored at a South Australian abattoir in November 2016. Rib fracture prevalence was 4% (range 0 - 18% per consignment), with all consignments of more than 240 lambs having at least one with fractured ribs. Traceback investigation on 56 of the 60 farms suggests that rib fractures most probably occur during routine husbandry procedures and, based on soil mineral analysis, are associated with calcium inadequacy. There was substantial variation between lines of lambs from different farms, and factors contributing to the differences included line size, region, and soil characteristics, including available calcium. There is a need to modify sheep husbandry and management practices to improve sheep welfare and reduce the cost of rib fractures to the sheep industry.

Keywords: bone; carcass; copper

1. Introduction

Rib fractures in lambs are estimated to cost producers and processors in South Australia (SA) at least $3 million per annum and raise concerns about the welfare of the lambs [1]. Occasional observations of fractures in long bones and ribs in sheep in southern Australia have been reported [2]. Anecdotally, rib fractures have occurred frequently in South Australia and western Victoria. Only with the introduction of the Enhanced Abattoir Surveillance (EAS) program by Primary Industries and Regions SA (PIRSA) in 2007 has an estimate of the prevalence become available for SA.

The EAS program provided feedback to South Australian producers on their consignments (lines) to Thomas Foods International (TFI) of more than 50 sheep (Lobethal abattoirs) or 100 sheep (Murray Bridge abattoirs). Qualified meat inspectors made visual estimates in 5% increments of the carcass prevalence of rib fractures and 20 other conditions. Statistical evaluation of the EAS records in 2011-2018 found rib fractures were evident in 11.2% of affected lines of lambs from the higher rainfall regions of South Australia - Kangaroo Island (9.8%), Mid South East (12.1%), Lower South East (11.8%), and Adelaide Hills/Fleurieu Peninsula (11.1%). The corresponding average in the remaining regions was 2.5% – Upper South East (4%), Murray Mallee (2.2%), Lower North and Barossa (4.3%), York Peninsula and Mid North (2%), Eyre Peninsula (1.2%), and Northern Pastoral (1.2%). Reporting of rib fractures during the monitoring program's establishment phase (2007-2010) was inconsistent and deemed too unreliable to include in this study.

Fractures in 'normal' bones can be caused by excessive force applied to the bone [3,4]. Sheep husbandry procedures may predispose to this during group or individual restraint. Group restraint can include yarding and drafting of sheep through a narrow raceway, sometimes at acute angles, and during loading and transport. Individual restraint may involve physical restraint in a pen or

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squeezing in a sheep crate. Another restraint that may result in the application of excessive force is in the 'lamb-marking' cradle.

Bone fractures can also be caused by relatively minor trauma if the bones are weak, referred to as 'pathologic fractures' [3,4]. Weak bone may occur due to abnormal development, altered mineralization, or changes in bone tissue in formed bones. Abnormal bone development, including fragile bones, is often attributed to inadequacies or imbalances of dietary minerals and vitamins, including copper, calcium [5–12], phosphorus [7,13], sulfur [5,11], zinc, manganese, selenium, boron [8,10,14–18], and vitamin D [3,8,19,20]. Abnormal bone development may also be due to chronic under-feeding, in which there is a more general nutrient deprivation or chronic endoparasitism [21,22]. Due to the increased requirement for minerals during growth and lactation, deficiencies tend to have more of an impact on young, pregnant, and lactating sheep. In contrast, older, non-reproductive sheep can use mineral reserves to cover short-term inadequacies.

In Australia, the ribs are a commonly reported site of bone fractures in sheep carcasses. Each carcass with rib fractures takes additional time to process, resulting in a downgrading of carcass quality and weight [23]. A higher prevalence of rib fractures has been reported in lamb carcasses (EAS unofficial report; 2018). Despite the economic importance of rib fractures, studies have yet to investigate the on-farm circumstances that may contribute to rib fractures observed at slaughter.

This study investigated the association between rib fracture prevalence in lamb carcasses at slaughter and their nutrition and management on the farm of origin. We hypothesized that rib fracture prevalence in South Australia in lamb carcasses results from husbandry practices predisposed by a mineral imbalance in ewes and lambs.

2. Materials and Methods

The study was initiated at an abattoir in 2016, observing rib fracture occurrence in lambs from southeast South Australia and western Victoria. To enable an investigation of the environmental associations with the frequency of rib fractures, the abattoir phase was followed up in 2017 by tracing these lambs back to the farms of origin. This was done under the University of Adelaide Human Research Ethics document, H-2016-272. Additionally, de-identified EAS data from 2011 to 2018 were available for analysis.

2.1. Data collection

The 2016 abattoir study was conducted in southeast South Australia during spring (November), based on EAS evidence of the higher prevalence of rib fractures in lamb carcasses from this region at this time of year. Farms submitting lambs with fractured ribs or calluses indicative of healing fractures were identified. Observations were made on 75 lines derived from 60 farms.

Liver specimens from five lambs sampled randomly from 50 consignments during the abattoir study were assayed for copper at Regional Laboratory Services as described by Paynter [24]. The copper content of <0.23 mmol/kg wet weight was assumed to indicate copper inadequacy [24].

The second stage (2017) involved a survey of the 60 farms of origin in the southeast of South Australia and western Victoria. Animal nutrition, husbandry and management details were recorded on 56 farms. On each farm, 20 soil samples, to a depth of 10 cm, were collected from the paddock primarily grazed by the lambs before slaughter. For each paddock, the 20 soil samples were combined and mixed. A subsample was sent to the Australian Precision Agricultural Laboratory (APAL) Pty Ltd for assay of effective cation exchange capacity (ECEC), pH (water and calcium chloride), organic matter, phosphorus, calcium, magnesium, potassium, sodium, sulfur, aluminum, iron, copper, boron, manganese, and zinc [25].

2.2. Statistical analysis

2.2.1. EAS data

The effect of consignment size (low, ≤ 200; lower mid, 201-500; upper mid, 501 – 1,000; and high, > 1,000), location of the farm, working shift, and abattoir on the prevalence of rib fractures was

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estimated using mixed model in PROC MIXED in SAS version 9.4 (Statistical Analysis Software Inc, Cary, USA). The main prevalence of interest was the regional prevalence of rib fractures, particularly in lambs slaughtered in 2016. The outputs were geometric means, their standard errors and 95% confidence intervals.

2.2.2. Abattoir survey

The effect of consignment size (low, ≤ 200; lower mid, 201-500; upper mid, 501 – 1,000; and high, > 1,000) and location of the farm (Eyre Peninsula, Kangaroo Island, Upper South East, Mid South East, Lower South East, and Victoria) on the prevalence of rib fractures was estimated using linear regression analysis in PROC GLIMMIX in SAS version 9.4. The outputs were geometric proportions, their standard errors and 95% confidence intervals. The original model tested the effect of the breed and working shift, but they were not significant (p=0.76).

2.2.3. On-farm survey

The statistical program R [26] and regression analysis examined relationships between soil parameters and rib fractures. XLSTAT (Lumivero, Denver, CO 80202) was used to test liver copper and soil parameters for rib fracture prevalence.

The threshold for significant differences was set at $P < 0.05$ and for highly significant differences at $P < 0.001$.

3. Results

3.1. EAS data

A large variability between the proportions of rib fractures reported in the EAS data for each region was observed over the years (Figure 1). The overall prevalence of rib fractures in sheep carcasses was 11.2% (95% CI = 11.0 – 11.4) for higher rainfall areas (Lower South East and parts of Kangaroo Island), 2.5% (95% CI = 2.4 – 2.7) for lower rainfall areas (Mid North, parts of Lower North, and Upper South East) and an overall state-based (for South Australia) prevalence of 4.5% (95% CI = 4.3 – 4.7).

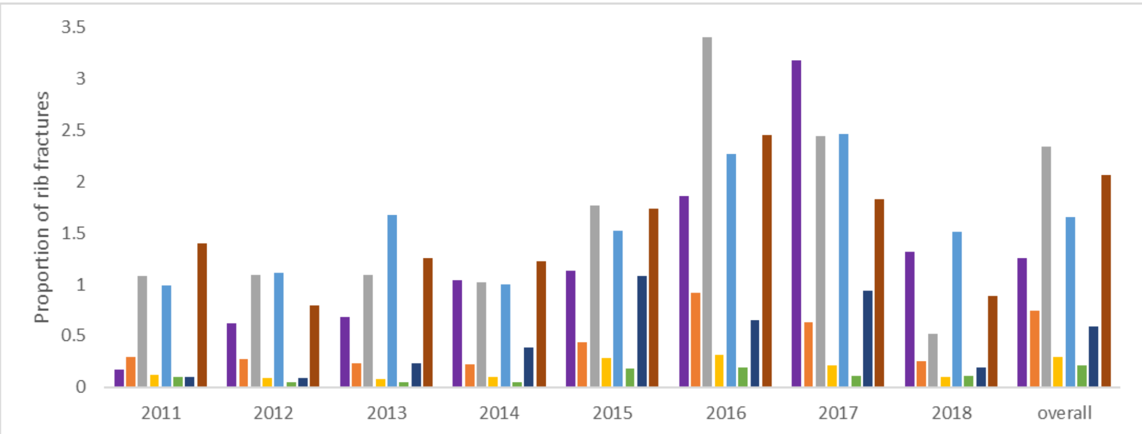

Figure 1. The proportion of rib fractures in different regions over the years and for the entire 2011 – 2018 period (overall). Kangaroo Island – Purple bars; Lower North – Orange bars; Lower South East – Grey bars; Mid North – Yellow bars; Mid South East – Light blue bars; Upper North – Green bars; Upper South East - Dark blue bars; and Victoria – brown bars.

As our study was carried out in SA in 2016, the variability between the proportions of rib fractures in lamb carcasses reported in the EAS data for each of the regions observed in 2016 in lamb carcasses is shown in Figure 2. The overall prevalence of rib fractures in lamb carcasses was 15.1%

(95% CI = 13.3 – 16.9) for high rainfall areas (Lower South East and parts of Kangaroo Island), 5.3% (95% CI = 4.4 – 6.2) in lower rainfall areas (Mid North, Parts of Lower North, and Upper South East; P < 0.001) and overall state-based (for South Australia) prevalence of 4.5% (95% CI = 4.3 – 4.7).

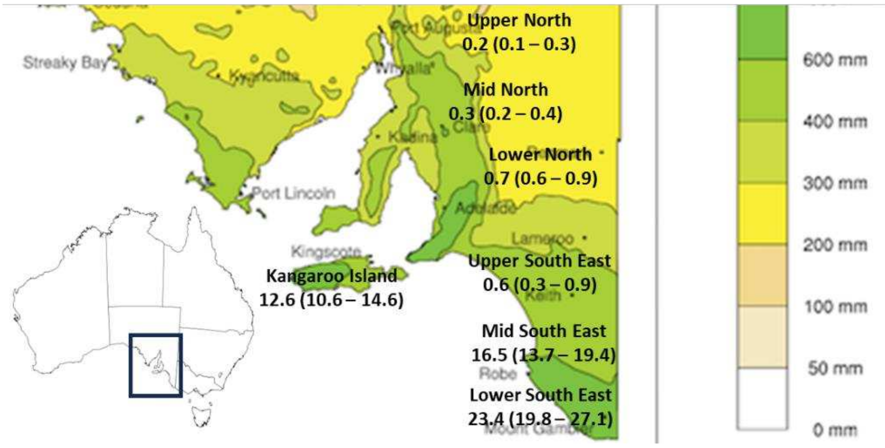

Figure 2. The proportions of rib fractures in regions reported for the Enhanced Abattoir Surveillance program for 2016. The scale on the right is average rainfall. The square on the outline of the Australian map covered in this study (left corner, bottom of Figure 2; https://enviro-friendly.com/information/average-rainfall/adelaide-rainfall).

3.1. Abattoir survey

The 75 consignments comprised 37,942 lambs from 60 farms. Ten farms submitted two (five farms) or three consignments (five farms) during the study period. The number of lambs per consignment ranged from 81 to 1,362, with an average of 506 and a median of 449.

For 57 consignments, all carcasses were inspected for rib fractures. For 18 consignments, some carcasses were missed, and the prevalence estimate was based on a sample (observed carcasses). In total, 30,055 carcasses were inspected.

Rib fractures were detected in 1,268 (4.2%) of the 30,055 carcasses inspected, averaging 21 affected carcasses per consignment. Fractures were observed in consignments from 90% of farms and in all 54 consignments with more than 240 lambs. The mean prevalence was 3.8% (median 3.1%), and the prevalence in only three lines exceeded 10%. The effect of the consignment size on the prevalence of rib fractures is presented in Table 1.

Table 1. Prevalence and 95% confidence intervals of rib fractures dependent on the consignment size in the abattoir study in November 2016.

Consignment size	Prevalence	Lower 95%	Upper 95%
Low (≤ 200)	1.5	0.0	3.9
Lower mid (201 - 500)	2.9	1.4	4.4
Upper mid (501 – 1,000)	4.6	2.7	6.5
High (> 1,000)	4.2	1.4	7.1
Overall	3.8	3.0	4.6

Figure 3 shows substantial variation in rib fracture prevalence and consignment size. Still, the regression analysis in Table 2 indicates the two were associated (p=0.02), with larger consignments tending to have higher prevalence (Table 1). The prevalence was highest (p=0.01) in consignments with more than 500 lambs - 4.6% (2.7-6.5) and lowest in consignments with less than 200 lambs - 1.5% (0.0-3.9).

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Table 2. Regression analysis results comparing the prevalence of rib fractures by consignment size in the abattoir study in November 2016.

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	2.40	0.60	4.03	0.0001	1.22	3.59
Consignment size	0.002	0.001	2.38	0.02	0.0004	0.0043

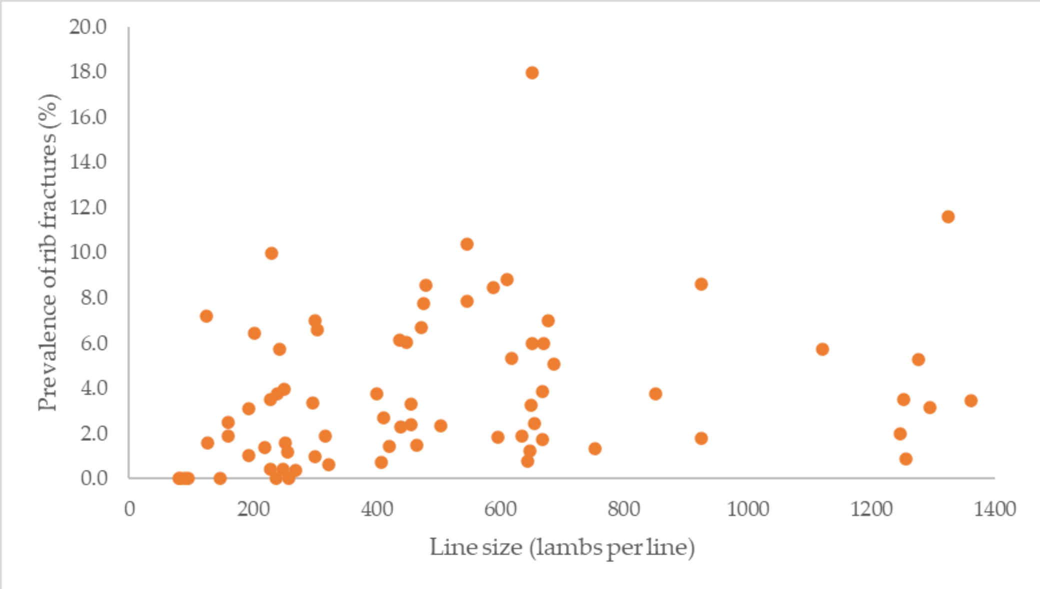

Figure 3. The number of lambs per consignment (consignment size) and the prevalence of rib fractures within lines of lambs were detected during an abattoir study at Bordertown in November 2016, with 30,055 carcasses observed.

Figure 4 shows the prevalence and regional variation of rib fractures within lines and associated 600 mm isohyet. A difference (p=0.02) in rib fracture prevalence between the moderate rainfall Upper South East (400-500 mm annual average) and the higher rainfall Lower South East (>600 yearly average mm) was observed. The overall prevalence of rib fractures in lamb carcasses was 5.0% (95% CI = 3.2 – 6.8) for higher rainfall areas (Lower South East and parts of Kangaroo Island), 1.0% (95% CI = 0.0 – 3.2) in lower rainfall areas (parts of Eyre Peninsula) and Upper South East; P = 0.007) and overall state-based (for South Australia) prevalence of 3.5% (95% CI = 1.9 – 5.1).

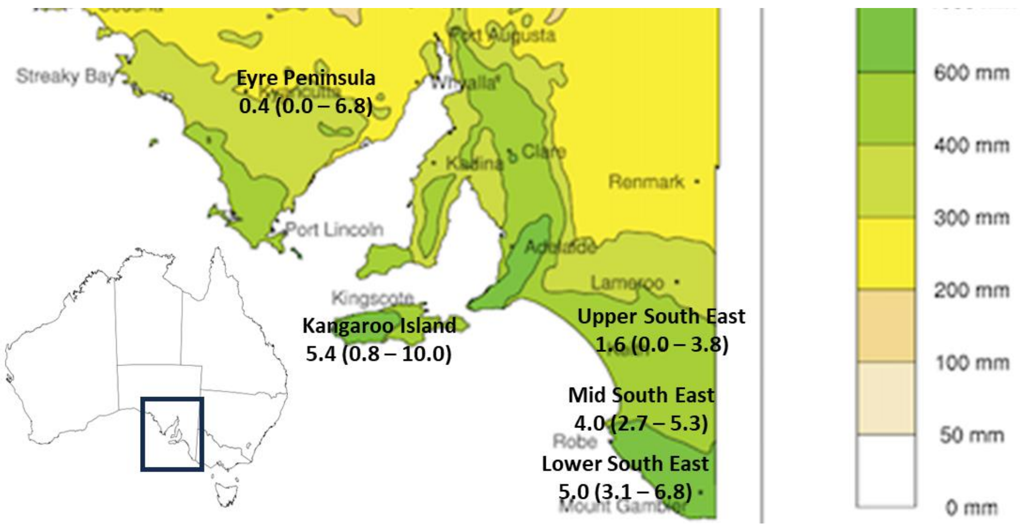

Figure 4. Map of South Eastern Australia showing the regional prevalence (with 95% confidence intervals) of rib fractures within lines of lambs detected during an abattoir study at Bordertown in

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November 2016 with 30,055 carcasses observed. The scale on the right is average rainfall. The square on the outline of the Australian map covered in this study (left corner, bottom of Figure 4; https://enviro-friendly.com/information/average-rainfall/adelaide-rainfall).

3.1. On-farm survey

Copper inadequacy was evident in 18 of 50 lines sampled for liver copper assay during the abattoir study, and all 18 had rib fractures. However, 27 lines with normal liver copper also had rib fractures. In addition, two of the five lines without rib fractures had low liver copper.

Table 3 shows the estimated regression coefficients for each soil parameter compared to rib fracture prevalence on the 56 farms surveyed in southeast South Australia and Western Victoria. Associations were found between rib fracture prevalence and soil iron (p=0.001), exchangeable aluminium (p=0.003), manganese (p=0.01), exchangeable calcium (p=0.004), pH water (p=0.02), pH CaCl2 (p=0.03), and organic matter (p=0.03) in the soil samples from farms where the lambs were grazed before slaughter. Soil properties that showed no association with rib fracture prevalence, including sulphur, molybdenum, and copper, are also shown in Table 3.

Table 3. Estimated regression coefficients, the standard errors and P values for soil parameters compared to rib fracture prevalence on the 56 properties in southeast South Australia and western Victoria.

Soil parameter	Units	Estimate	Standard Error	P-value
ECEC	--	-0.0001	0.0004	0.75
Colloidal Organic Matter	%	0.009	0.004	0.03
pHwater	--	-0.01	0.006	0.02
pHCaCl	--	-0.01	0.005	0.03
Salinity (EC)	dS/m	-0.04	0.04	0.36
Phosphate (Olsen)	mg/kg	0.0004	0.0007	0.58
Phosphate (Colwell)	mg/kg	0.0002	0.0003	0.59
Sulphur	mg/kg	0.0006	0.0007	0.38
Exchangeable Calcium	%	-0.001	0.0003	0.004
Exchangeable Magnesium	%	0.0003	0.0008	0.72
Exchangeable Potassium	%	-0.002	0.002	0.32
Exchangeable Sodium	%	-0.0001	0.002	0.96
Exchangeable Aluminium	%	0.01	0.005	0.003
Iron	mg/kg	0.0001	0.00003	0.001
Boron	mg/kg	-0.005	0.006	0.39
Manganese	mg/kg	0.003	0.001	0.01
Copper	mg/kg	0.002	0.006	0.76
Zinc	mg/kg	0.02	0.02	0.43
Molybdenum	mg/kg	0.005	0.009	0.63

4. Discussion

This study aimed to estimate the prevalence of rib fractures detected in lambs at slaughter and to test for associations between the prevalence within lines and nutritional and management factors on the farm of origin. Rib fractures were observed in 4.2% of lambs with a 0.0 – 18.0% range per consignment. This was like the state (South Australia) average of 4.5% calculated from the EAS data (for 2011 to 2018 in all sheep and 2016 in lamb carcasses). Interestingly, an unofficial annual EAS report shows 1% (0 - 7) of rib fractures in lamb carcasses for 2016. The proportion of farms consigning lambs with rib fractures (90%) was much higher than reported from EAS data (7%, unofficial report of EAS, 2018). As reported in the EAS data, a higher prevalence of rib fractures occurred in regions with higher rainfall.

The interaction between line size and region of origin indicates they were confounded and potentially contributed to the rib fracture prevalence. In addition, the interaction between regional rainfall and prevalence detected in our study supports observations made from the EAS data. A peak

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of 9,455 detections of rib fractures in the 2016 EAS data coincided with the timing of the abattoir survey and the wettest year in South Australia for over 20 years. If we were to assume that rib fractures are associated with nutritional imbalances, the peak of rib fractures could be explained by the commonly observed increase in trace element deficiencies in grazing livestock during wet years [7,27]. Trace element deficiencies during wetter years are associated with the leaching and dissolution of some nutrients such as copper, dilution due to increased plant biomass, and competition from more available elements such as molybdenum, manganese, and iron [28]. In this study, however, the only association between rib fracture prevalence and soil mineral availability was for iron ($p=0.001$) and manganese ($p = 0.01$). This is only one of several possible explanations for the high prevalence detected in 2016 [27].

The sampling of green pasture can be a valuable guide to the mineral nutrition of grazing animals as it provides a more direct measure of the availability of minerals than the measurement of soil concentrations. However, this was not an option in this study because the farm survey was conducted after the abattoir survey when the environment represented dry summer pastures.

The significant association ($P = 0.02$) between soil pH and the presence of rib fractures in Table 2 is likely due to rainfall. Increased soil acidification is well recognized and is associated with nitrogen and sulfur application, high legume components in pastures, and rainfall leaching cations such as calcium and magnesium [29]. Nutritional imbalances of this character may affect bone quality, facilitating the incidence of rib fractures.

The discrepancy in the prevalence reported by EAS and our study probably reflected the granularity of our research, noting every carcass with rib fractures, in contrast to EAS in 5% increments. Consequently, the EAS data inevitably underestimate the true prevalence of rib fractures. In the EAS data, a much lower detection of rib fractures in lines of sheep over two years of age (15%) was observed, most likely due to increased bone strength and resilience with age. Notably, the large variability between years for the same regions (Figure 1) indicated that it is not only soil composition and rainfall that affect bone quality or rib fractures that are minimally affected by bone quality. The main effects may be the excessive physical force applied to ribs (e.g., during restraint procedures).

Our study was in 2016, so we used 2016 EAS data for lamb carcasses for comparison. We found a significantly higher prevalence of rib fractures in the South East regions (Lower, Mid, and Upper) and Kangaroo Island that was yet much smaller (5.0%) compared to EAS data analysis (15.1%). Similarly, we found a significantly lower prevalence in low rainfall areas (1.0%) yet lower than the EAS data analysis (5.3%). Differences in the prevalence of rib fractures in high and low rainfall areas between our study and the EAS study may be due to the variability in estimating the prevalence of rib fractures, as explained above. It is also possible that the areas with high rainfall are more likely to slaughter their lambs at the southeastern abattoirs.

The liver copper assay performed on 50 lines during the abattoir study did not show an association with the prevalence of rib fractures. Similarly, the regression analysis found no correlation between rib fracture prevalence and soil copper ($P = 0.43$), sulfur ($P = 0.38$), or molybdenum ($P = 0.63$), elements that are known to influence bone strength. These findings could be confounded by the fact that 26 (46.4%) farms provided additional copper to soil, pasture, or livestock in various forms. Consequently, the potential benefit of this management practice could not be verified. Follow-up sampling of green pastures during winter in the soil-sampled paddocks may have provided more dependable evidence of associations between these minerals and rib fracture prevalence.

The estimated regression coefficients in Table 2 for soil iron ($P = 0.001$), aluminum ($P= 0.003$), manganese ($P = 0.01$), and organic matter ($P= 0.03$), and rib fracture prevalence are not surprising because the elevation of these soil components coincides with acidic soil conditions. Similarly, the significant association between rib fracture prevalence and low exchangeable soil calcium ($P = 0.004$) concomitates with acidic soil conditions. Depending on soil type and location, a standard agricultural practice is to apply lime (calcium carbonate) to ameliorate soil acidification, primarily due to cation loss with growing crops, pastures, and leaching. It is anticipated that this practice would also assist in reducing lamb susceptibility to rib fracture through increased availability of calcium and trace elements when soil pH is raised to the desired range.

No significant relationships were found between management practices on the 56 farms surveyed, and the prevalence of rib fractures in their lambs consigned during the study period. This was most likely due to the wide variation in management practices and the small number of farms without rib fractures in their consigned lambs. Interestingly, 33 (66%) farms had supplemented sheep with calcium and/or copper, but 27 (82%) had rib fractures in their lambs. Applying lime and trace elements to acidic and mineral-deficient soils or as injections, drenches, stock blocks, licks, and water treatments to grazing livestock was expected in the region surveyed. However, during the on-farm survey, these practices were noted to be haphazard and often in response to perceived rather than diagnosed deficiencies. It was anticipated that a more efficient and targeted strategy would be beneficial in reducing rib fracture prevalence, but this requires further research.

Another significant finding ($P = 0.01$) was an increase in the prevalence of rib fractures with consignment size. However, a limitation of this study is the sample size, as there were only five consignments without rib fractures, and they were all relatively small lines of less than 240 lambs. This contrasted with the study average of 506 lambs per line; three small lines were atypical Dorper lambs. All other lines were either Merino, Crossbred, or Composite-bred lambs. While this is not a significant finding ($P > 0.05$), the breed may have influenced the lack of rib fracture detections in these three lines and requires further investigation.

5. Conclusions

The significance of rib fractures in lambs in South Australia and western Victoria has been demonstrated in this study and supports the initial findings of the EAS data analysis. Based on the significant associations identified on-farm with the observed prevalence of rib fractures in lambs at slaughter, it is anticipated that the occurrence of rib fractures in lambs could be dramatically reduced if strategic preventative programs were introduced. If we assumed that rib fractures have occurred as pathologic fractures, this would involve addressing specific mineral deficiencies identified by soil, plant tissue, and blood/liver testing, as well as more efficient and effective calcium and trace element supplementation on at-risk farms. Other strategies include addressing physical causes of incidental injury during yarding, handling, and transport. It would require a concerted awareness and incentive program for lamb producers but has the potential to substantially improve lamb growth rates and welfare and save the red meat industry several million dollars annually due to carcass downgrading in South Australia alone. A similar opportunity is anticipated in other lamb-producing States but has yet to be investigated.

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