Eurasia Specialized Veterinary Publication

International Journal of Veterinary Research and Allied Science

ISSN:3062-357X

2022, Volume 2, Issue 1, Page No: 101-113

Available online at: www.esvpub.com/

Herd and Within-Herd Incidence of Humeral Fractures in First- and Second-Lactation Dairy Cows in New Zealand: Evidence from Four Integrated Studies

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ABSTRACT

This study brings together information from four independent datasets to characterize the epidemiology of humeral fractures in New Zealand dairy cattle and to estimate how often these injuries occur at both herd and animal levels from 2007 to 2015. The first source was a national case collection reported by veterinarians over five lactation seasons (2007/2008–2011/2012). The second included post-slaughter findings from a Waikato pet food company that documented fractured humeri in casualty cows during the 2014/2015 season. The third dataset came from a veterinary practice in the same region that recorded its own fracture cases for that season. The fourth involved a nationwide phone survey of 505 randomly selected dairy farmers, who reported instances of severe, non–weight-bearing forelimb lameness in first- and second-lactation cows during 2014/2015. These survey responses were used to estimate within-herd and herd-level incidence. Across the national veterinary reports, 149 fracture cases were identified in 22 herds; the pet food dataset documented 61 cases on 41 farms; and the veterinary practice recorded 14 cases on 10 farms. All cases involved first- or second-lactation cows, with the highest frequency occurring between calving and early mating. According to the national survey, 11.7% of herds had at least one cow requiring euthanasia for severe forelimb lameness, with affected herds showing an average incidence of 2.6% in first-lactation cows and 2.8% in second-lactation cows. Overall, the combined evidence indicates that these fractures are more common than previously recognized and that they may recur across years in some herds. Additional research is needed to identify feasible management strategies to lessen both animal suffering and production losses.

Keywords: Fracture, Epidemiology, Dairy cattle, Incidence, Humerus, New Zealand

Received: 21 November 2021
Revised: 16 February 2022
Accepted: 17 February 2022

How to Cite This Article: Stein L, Feldmann M. Herd and Within-Herd Incidence of Humeral Fractures in First- and Second-Lactation Dairy Cows in New Zealand: Evidence from Four Integrated Studies. Int J Vet Res Allied Sci. 2022;2(1):101-13. https://doi.org/10.51847/rMBlgmNETT

Introduction

A cluster of first-lactation dairy cows showing severe forelimb lameness caused by spontaneous humeral fractures was first documented on a Manawatu farm in 2008 [1]. After this initial report, similar incidents continued to surface from a range of regions—including Waikato, Bay of Plenty, Manawatu, Canterbury, Otago, and Southland—through submissions to Massey University veterinarians, regional pathology laboratories (New Zealand Veterinary Pathology and Gribbles Veterinary Pathology), the *Surveillance* biosecurity magazine, and presentations at veterinary conferences [2–8]. *Surveillance* is a quarterly publication produced by the Ministry for Primary Industries (MPI) that summarizes national biosecurity monitoring and reports on the health status of New Zealand's animals and plants.

Over time, these accumulating reports revealed that some farms were experiencing more than one affected animal, and informal observations suggested that the frequency of herd-level involvement was increasing [5,8]. Although copper deficiency was initially considered a possible risk factor in a small number of cases, later investigations showed that this link was inconsistent and likely not causal [9]. Instead, histological assessment of bones from affected and unaffected first-lactation cows has prompted the theory that insufficient nutrition during key growth phases reduces bone development, leaving animals susceptible to osteoporosis and eventually spontaneous fracture [8,10,11].

The injuries described in these cases almost always involve a full spiral break through the middle of the humerus **(Figure 1)**. Clinically, cows typically adopt a distinctive posture, holding the damaged limb off the ground in a suspended "hanging" position **(Figure 2)**, and they move with a gait in which the affected leg swings forward but rarely bears weight (Videos S1 and S2, Supplementary Materials). In a few situations, farmers have reported hearing the fracture occur while cows were walking to the milking shed [2], though most animals are simply found injured in the paddock. The near-absence of similar reports from other countries since 2008 [12] suggests that this pattern of spontaneous humeral fractures may be a phenomenon unique to New Zealand's dairy production system.

Figure 1. Typical spiral fracture of the mid-shaft of the humerus seen in affected animals (Photo D. Butler)

Figure 2. Characteristic "hanging leg" stance of cows affected by spontaneous humeral fracture (Photo D. Butler)

The New Zealand dairy industry relies predominantly on grazing, with a strongly seasonal pattern of production. More than 95% of cows calve during the spring months of July through September. Heifers typically join the milking herd at around two years of age, and those that calve in spring are bred again during October, November, and December. Most farms milk cows twice a day, although some have shifted to once-daily milking to decrease operational expenses and reduce workload stress for farmers and employees [13].

Although the total number of dairy farms has fallen, individual operations have expanded considerably in both herd size and output. Average herd size increased from 251 cows producing 310 kg of milk solids per cow in the 2000/01 season to 419 cows producing 377 kg per cow by 2014/15 [14,15]. Compared with many international

systems, New Zealand dairying uses minimal housing and very little supplementary concentrate feeding; pasture remains the primary feed source for cattle of all ages [16].

Before 2008, lameness arising from injuries to the upper forelimb or shoulder—particularly fractures—in young dairy cattle was rarely documented either within New Zealand or overseas. For instance, among 99 bovine fracture cases (average age 5.6 months) seen at the University of Liège Veterinary Clinic in Belgium between 2000 and 2003, only three involved the humerus [17]. Earlier research also noted that fractures in cattle most commonly occur in the femur, with just 12 of 213 cases involving the humerus [18].

Multi-method research represents a branch of mixed-methods inquiry in which multiple approaches to data collection and analysis are used, but all remain within either the quantitative or qualitative tradition [19]. Supporters of mixed-methods designs argue that combining diverse forms of evidence enhances study validity and broadens the applicability of findings by providing multiple viewpoints [20]. Such designs may be implemented concurrently, with all components conducted at the same time, or sequentially, where early work shapes the direction of later studies [20].

In this study, we applied a multi-method strategy to bring together findings from three different case series—one conducted nationwide, one in the Waikato region, and one at a single veterinary practice in Waikato—alongside results from a nationwide randomized telephone survey. Collectively, these sources offer a clearer picture of a health issue that has caused extensive welfare problems and economic losses within the New Zealand dairy sector over the past 15 years.

The objectives of this research were:

• To summarize major epidemiological features of humeral fractures in young adult dairy cows, including age, breed, postpartum interval to injury, seasonal patterns, and geographic distribution.

• To estimate both within-herd and herd-level incidence of severe, non-responsive, non–weight-bearing forelimb lameness in first- and second-lactation dairy cows across New Zealand.

Materials and Methods

This work combined information from four separate quantitative investigations: a nationwide case series, a case series based on records from a Waikato pet food facility, a veterinary practice case series from the same region, and a nationwide randomly selected telephone survey. These datasets were brought together as part of an observational study design. The overall process of integrating the four sources to draw conclusions about the epidemiology and incidence of humeral fractures in New Zealand dairy cows between 2007 and 2015 is summarized in **Figure 3**.

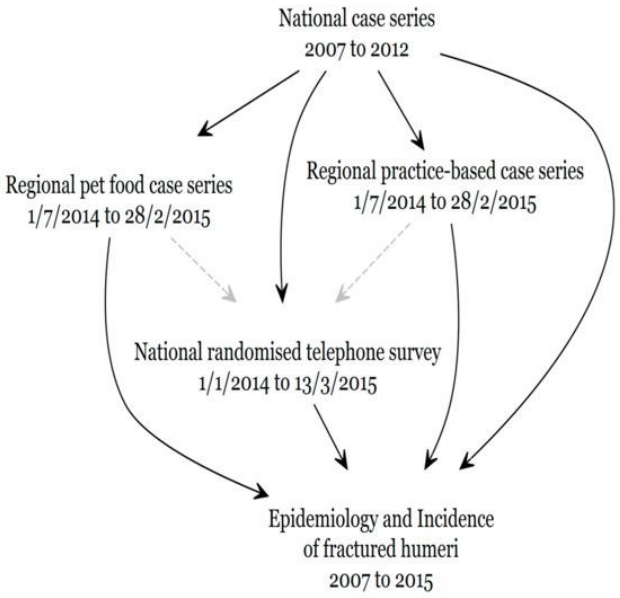

Figure 3. The diagram summarizes how information from the four separate studies was brought together. The grey dashed arrows represent connections that were considered weak, mainly because those datasets covered overlapping time periods rather than directly influencing one another

National case series

In December 2011, roughly 500 dairy veterinarians across New Zealand were reached through newsletters and email. They were asked to report any client herds that had experienced a spontaneous humeral fracture within the previous five years.

Farm owners or managers who reported cases were then asked to complete a detailed questionnaire. This form gathered descriptions of animals showing sudden, severe forelimb lameness that did not improve and showed no outward signs of trauma.

Information collected at the herd level included management background, herd demographics, and grazing patterns. For each individual animal, respondents provided a case description along with reproductive status, stage of lactation, and management factors at the time of the fracture [21].

Veterinarians who did not initially respond received reminder letters and questionnaires at roughly 30-day intervals.

Waikato pet-food collection case series

A livestock-collection company in the Waikato region supplied another dataset. This business gathers animals destined solely for pet-food processing—typically cows unsuitable for human consumption or unable to be transported.

They recorded information on first- and second-lactation dairy cows collected between 1 July 2014 and 28 February 2015. Humeral fractures were confirmed after slaughter, once muscle tissue had been removed and the bone could be examined directly during processing.

Waikato veterinary clinic case series

The third dataset came from Anexa Veterinary Services, a practice operating fourteen clinics and serving around 800 dairy herds across the Waikato region.

Veterinarians documented every skeletal fracture diagnosed in dairy cattle of any age between 1 July 2014 and 28 February 2015. Records included animal age, breed, calving date, fracture location, clinical presentation, the planned treatment or decision for euthanasia, and the veterinarian's opinion regarding the likely cause (such as traumatic injury).

Humeral fractures were identified using typical clinical signs, including severe non-weight-bearing lameness, detectable crepitus, and swelling over the suspected fracture.

National telephone survey

A nationwide phone survey was conducted to measure how often first- and second-lactation heifers developed persistent, non-weight-bearing forelimb lameness. The target was to obtain responses from at least 500 dairy herds, which would provide an estimated precision of 2.6% at 95% confidence if the true incidence was around 10% within New Zealand's total population of roughly 12,000 herds.

To achieve this, 2,500 herds were randomly selected from the DairyNZ CRM database, based on an expected response rate of about 20%. The number of selected herds in each region matched the geographic distribution of dairy herds during the 2013/2014 season. Within each region, the sample was randomly drawn.

Table 1. presents the regional distribution of herds that participated, compared with national dairy-industry figures from 2013/14

Region	Study Herds		New Zealand [1]
	n	%	%
Northland/Auckland	49	9.7	11.3
Waikato	144	28.5	29.6
Bay of Plenty	27	5.3	5.0
Taranaki	59	11.7	14.4
Lower North Island	71	14.1	13.9
Marlborough/Westland	26	5.1	5.1
Canterbury/Otago	78	15.4	12.8
Southland	51	10.1	7.9
TOTAL	**505**	**100.0**	**100.0**

[1] Data from DairyNZ; LIC. New Zealand Dairy Statistics 2013–2014 [22].

Data collection and analysis

Between 23 February and 13 March 2015, telephone interviews were conducted with the main contacts of 1,278 dairy herds. Six trained interviewers from Versus Research Limited (Hamilton, New Zealand) carried out the calls. The survey was closed once the target number of responses was reached. Farmers were asked eleven questions covering herd demographics, history of heifers and cows, and their awareness of upper forelimb or shoulder lameness in first- and second-lactation cows, recorded monthly from January 2014 onwards.
A cow was considered a case if it had persistent non-weight-bearing forelimb lameness, defined as lameness originating in the upper forelimb or shoulder that either did not improve with rest or led to immediate euthanasia (for pet food or home kill). Animals whose lameness resolved after resting were excluded from the study.

National case series
Data from the national case series were entered into Microsoft Excel 2010 and clarified with herd managers where needed. Descriptive statistics were generated using SAS 9.3, with the `FREQ` and `UNIVARIATE` procedures. Analyses summarized fractures by region, season, month of occurrence, months postpartum, cow age, and number of seasons each farm experienced fractures.

Waikato pet-food case series
For the pet-food dataset, the proportion of first- and second-lactation cows with humeral fractures was calculated relative to all cows processed by the company, along with 95% confidence intervals.

Waikato veterinary clinic case series
For the veterinary clinic data, summary statistics were generated to describe the breed, age, and days postpartum of affected animals.

National telephone survey
Proportions and confidence intervals were estimated using the exact binomial test. Incidence rates of non-responsive forelimb lameness in affected herds were calculated using a mixed-effects negative binomial model, where the number of affected cows was the dependent variable, total herd size served as an offset, and region was included as a random effect. The analyses were conducted in R 4.1.1 with the `glmmTMB` package [23].
Each dataset was analyzed independently. No attempt was made to merge them statistically; instead, results were compared to identify consistent trends across the studies.

Results

National case series
Among the 30 herds identified, detailed responses were received from 22 herd owners or managers. These responses described episodes of sudden, non-responsive forelimb lameness in young dairy cows, suspected to be humeral fractures, with no evidence of external trauma. Over the 2007/08 to 2011/12 lactation seasons, these herds reported a total of 149 fracture cases, of which 58% were physically examined and confirmed by a veterinarian **(Table 2)**.
The affected herds were spread across several regions: Waikato (14 herds), Manawatu (4), Auckland (1), Bay of Plenty (1), North Otago (1), and Canterbury (1). Ten herds (45.5%, 95% CI = 24.4–67.8%) experienced fractures in more than one season, and one farm reported cases in four consecutive seasons **(Figure 4D)**.
At the farm level, the number of cases per season ranged from 1 to 18, averaging 4.3 cases per season, while the total number of cases per farm over the five years varied from 1 to 27, with a mean of 6.7 cases per farm.

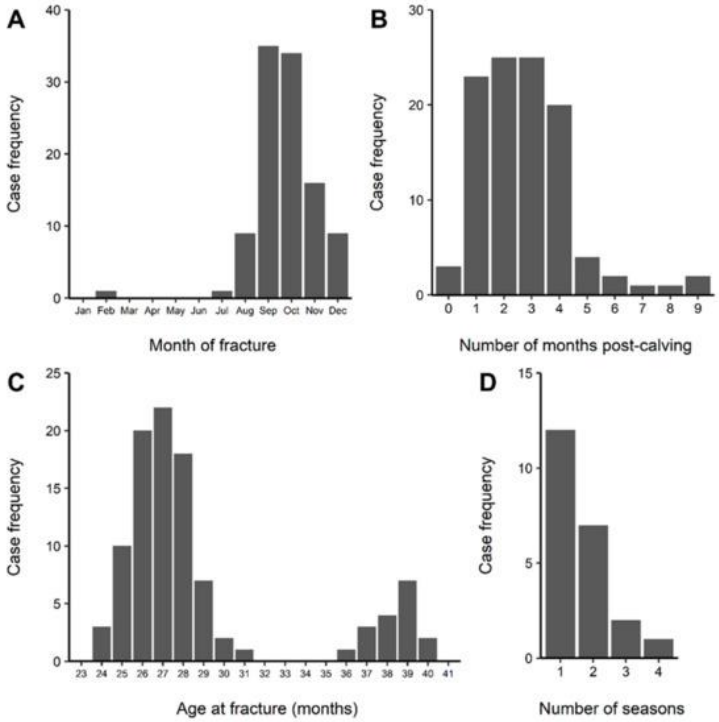

Figure 4. Histograms illustrating the national case series data: (A) distribution of fractures by month, (B) number of months after calving when fractures occurred, (C) age of cows at the time of fracture, and (D) number of seasons in which each farm experienced fractures

Table 2. Number of cases of spontaneous humeral fracture observed in young New Zealand dairy cows in 22 herds over 5 lactation seasons (National case series)

Herd	Region	Lactation Season					TOTAL
		2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	
1	Auckland	0	0	0	0	1	1
2	Bay of Plenty	0	0	4	0	0	4
3	Waikato	0	0	0	0	2	2
4	Waikato	0	0	0	0	2	2
5	Waikato	0	1	4	0	0	5
6	Waikato	0	0	0	0	2	2
7	Waikato	0	0	0	0	1	1
8	Waikato	0	3	2	3	5	13
9	Waikato	0	0	4	7	16	27
10	Waikato	0	0	1	0	1	2
11	Waikato	0	0	0	1	4	5
12	Waikato	0	0	0	0	18	18
13	Waikato	0	0	8	1	0	9
14	Waikato	0	0	2	8	2	12
15	Waikato	0	0	7	0	6	13
16	Waikato	0	0	0	0	3	3
17	Manawatu	0	0	0	0	2	2
18	Manawatu	0	0	1	0	3	4
19	Manawatu	7	0	0	0	0	7
20	Manawatu	0	0	0	2	3	5
21	North Otago	0	0	0	0	2	2
22	Canterbury	0	0	0	0	10	10
TOTAL		7	4	33	22	83	149

Data were available for 115 cows, with 20 percent Friesian, 21 percent Jersey, and 59 percent crossbred. From 2007 to 2012, the proportion of crossbred cows in the national herd increased from 31.6 percent to 40.8 percent [24, 25]. When compared to the 2012 national proportion, crossbred cows were significantly overrepresented among fracture cases according to an exact binomial test ($p = 0.0002$).

Fractures occurred in every month between July and February, with the highest numbers reported in September (35 of 105 cases, 33.3 percent) and October (34 of 105 cases, 32.4 percent) **(Figure 4A)**. Age data were available for 101 cows, ranging from 24 to 40 months. The distribution was bimodal, with one peak in the 24–31 month group (84 cows, mean 26.8 months) and another in the 36–40 month group (17 cows, mean 38.4 months) **(Figure 4C)**.

Most fractures affected first-lactation cows (95 cases, 82.6 percent), with 17 cases (14.8 percent) in second-lactation cows. Only three first-lactation cows (2.6 percent) fractured during the last month of their first pregnancy. The majority of fractures (93 out of 106, 88 percent) occurred within the first four months postpartum **(Figure 4B)**. For cases where limb data were available, 37 occurred in the right limb, 31 in the left, and one cow had fractures in both forelimbs.

Waikato region pet food series

During the 2014/2015 lactation season, 61 first- or second-lactation cows from 41 Waikato farms were confirmed to have humeral fractures by staff from a pet food company. Most properties had only one affected cow, although one farm had nine cases and another thirteen. Fractures were recorded throughout the study period, with the highest frequency observed between late September and early December 2014.

From 1 July 2014 to 28 February 2015, the company processed 2,310 animals, with monthly totals ranging from 192 in December 2014 to 496 in August 2014. Overall, 2.6 percent of all first- and second-lactation cows processed (61/2,310; 95% CI = 2.0–3.4%) had humeral fractures, with a peak monthly incidence of 12 percent in November **2014 (Figure 5)**.

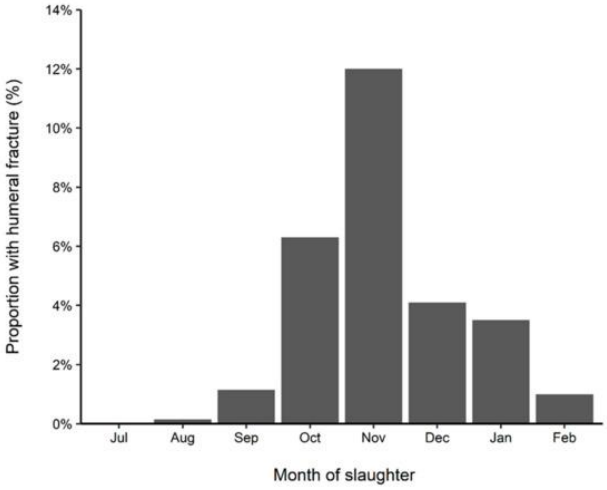

Figure 5. Monthly percentage of first- and second-lactation dairy cows identified with humeral fractures among all animals processed by a Waikato-based pet food company from July 2014 to February 2015

Waikato region veterinary clinic case series

Between July 2014 and February 2015, veterinarians from Anexa Veterinary Services reported 14 cases of humeral fractures in dairy cows across 10 different farms. Every affected cow was in its first lactation. Six farms had a single case, while four farms experienced two cases each. The breed distribution included eight Friesian cows (57%), two Jersey cows (14%), and four crossbred cows (29%). Most fractures occurred in the left forelimb (10 cows, 71%), with the remaining four affecting the right forelimb. Data on days postpartum were available for seven animals, showing a range from 1 to 105 days. Notably, three of the farms had previously observed similar fractures in first-lactation cows during the 2013/14 lactation season.

National phone survey

A total of 1,278 dairy herds were approached for the national phone survey. Of these, 542 farmers (42.4%) declined participation, 81 (6.3%) no longer managed dairy operations, 16 (1.3%) were business partners but not the farm managers, and 79 (6.2%) phone numbers were inactive. Additionally, 55 respondents (4.3%) did not have primary herd management or calved cows outside the spring season. Despite these exclusions, roughly 20% of pre-selected herds in each region completed the survey.

Surveys were completed by 505 farmers who managed spring-calving herds for at least two consecutive years. In 59 herds (11.7%; 95% CI: 9.0–14.8%), at least one first- or second-lactation cow exhibited non-responsive, non-weight-bearing forelimb lameness that either required immediate euthanasia (home kill or pet food) or did not improve with rest between 1 January 2014 and 15 March 2015. Within these affected herds, 22 farms (37.3%; 95% CI: 25.0–50.9%) had both first- and second-lactation cows affected. In 24 herds (40.7%; 95% CI: 28.1–54.3%), only first-lactation cows were involved, while 13 herds (22.0%; 95% CI: 12.3–34.7%) reported only second-lactation cases.

Affected first-lactation cows were present across all regions except Marlborough/Westland. Second-lactation cases were absent from Auckland/Northland, Bay of Plenty, and Marlborough/Westland herds **(Table 3)**.

Table 3. Number (%) of herds that had one or more first-lactation cows, second-lactation cows, or either age-class with a humeral fracture ("Case herds") from 1 January 2014 to 15 March 2015 based on a national phone survey of 505 New Zealand dairy herds, by region

Region	Study Herds											
	First-Lactation Cows				Second-Lactation Cows				Either Age-Class			
	Case Herds		Non-Case Herds		Case Herds		Non-Case Herds		Case Herds		Non-Case Herds	
	n	%	n	%	n	%	n	%	n	%	n	%
Auckland/Northland	3	6.5	44	93.5	0	0.0	46	100.0	3	6.1	46	93.9
North Waikato	6	9.7	56	90.3	6	9.8	55	90.2	9	13.4	58	86.6
South Waikato	6	8.6	64	91.4	4	6.0	62	94.0	7	9.1	70	90.9
Bay of Plenty	1	4.0	24	96.0	0	0.0	23	100.0	1	3.7	26	96.3
Taranaki	1	1.8	54	98.2	1	2.0	49	98.0	2	3.4	57	96.6
Lower North Island	6	8.6	64	91.4	7	10.9	57	89.1	9	12.7	62	87.3
Marlborough/Westland	0	0.0	22	100.0	0	0.0	25	100.0	0	0.0	26	100
Canterbury/Otago	15	20.3	59	79.7	10	15.6	54	84.4	16	20.5	62	79.5
Southland	8	17.0	39	83.0	6	16.3	31	83.7	12	23.5	39	76.5
TOTAL	**46**	**9.8**	**426**	**90.2**	**34**	**7.8**	**402**	**92.2**	**59**	**11.7**	**446**	**88.3**

First-lactation cows

Before analysis, data from seven respondents who did not provide the number of calved first-lactation cows and 26 farmers who were unsure about lameness occurrence were excluded. In the remaining herds, the average number of first-lactation cows in 2014 was 105, with a median of 85 (range: 3–700). Across these herds, 46 out of 472 farmers (9.8%; 95% CI: 7.2–12.8%) reported observing at least one first-lactation cow with persistent non-weight-bearing forelimb lameness. In total, 134 first-lactation cows were affected, representing approximately 0.27% of the overall first-lactation population (n = 48,866). Within affected herds, the average proportion of affected cows was 2.6% (95% CI: 2.0–3.4%), ranging from 0.3% to 11.2%.

Second-lactation cows

For second-lactation cows, 30 respondents did not provide the number of cows entering their second lactation, and 23 were unsure if any lameness occurred, so these records were excluded. Additionally, 16 farms had no second-lactation cows and were removed from the analysis. Among the remaining herds, the mean number of second-lactation cows was 101, with a median of 70 (range: 1–800). Lameness was observed in at least one cow on 34 out of 436 farms (7.8%; 95% CI: 5.5–10.7%). Across these farms, 115 second-lactation cows were affected, accounting for 0.23% of the total second-lactation population (n = 47,997). The average within-herd incidence in affected farms was 2.8% (95% CI: 2.0–4.0%), with a minimum of 0.14% and a maximum of 13.8%.

Summary across studies

Combining evidence from all four studies indicates that humeral fractures occur widely across New Zealand dairy farms and are not as rare as previously thought, potentially affecting up to 12% of farms annually. The condition is confined to first- and second-lactation cows from spring-calving herds, primarily within the first four months postpartum, and may involve multiple cows within the same herd, season, or even across successive seasons. Crossbred cows appear disproportionately affected, and fractures are most frequently observed between September and November, highlighting a seasonal peak in incidence.

Discussion

The integration of multiple data sources confirms that spontaneous humeral fractures were a significant and widespread issue in New Zealand dairy herds between 2011 and 2015. Subsequent evidence suggests that this problem has persisted and may have intensified over time [26–31].

While certain findings were consistent across the four studies, discrepancies were also observed. The national case series highlighted a higher risk in first-lactation cows compared to second-lactation animals. In contrast, the national telephone survey indicated that second-lactation cows had slightly lower between-farm but slightly higher within-farm fracture rates than first-lactation cows. The practice-based case series aligned with the national case series, as all 14 reported cases involved first-lactation cows; however, the limited number of farms (10) restricted generalizability. The pet food survey could not clarify age-related differences because cattle ages were not accurately documented at slaughter. A closer examination of the telephone survey shows that while all farms with cases had first-lactation fractures, only about 59% reported fractures in second-lactation cows. Given the small sample sizes of the national and practice-based case series, it is plausible that these datasets disproportionately represented farms with fractures limited to first-lactation cows.

The national case series revealed a bimodal age distribution at fracture occurrence, with peaks at 24–31 months and 36–40 months. Although this pattern was not evident in the pet food or practice-based studies, the national telephone survey supports it, showing comparable fracture rates in both first- and second-lactation cows on affected farms.

The national survey also demonstrated that humeral fractures occur widely across New Zealand, with the exception of Marlborough/Westland. This broad distribution suggests that localized environmental factors, such as soil type, pasture composition, or climate, are unlikely to be primary contributors. One potential risk factor is breed. Over the past four decades, the proportion of crossbred cows in the national dairy herd has increased substantially [32]. Between the 1998/1999 and 2008/2009 seasons—the latter coinciding with the first reported humeral fractures—crossbred populations rose by 15.9%, while Holstein-Friesian numbers declined by 14.2% [33, 34]. By the 2021–2022 season, crossbreds represented 59.2% of the national herd [35]. Evidence from the national case series suggested that crossbred cows may be more prone to fractures, and a recent study reported that farms dominated by crossbred cows are 9.7 times more likely to experience humeral fractures than those with other breeds [36]. The telephone survey did not collect breed information, so it could not confirm or refute these findings.

Both the national case series and the Waikato pet food dataset showed that fractures were most common during the first half of lactation, peaking in late September and October. This timing corresponds to periods of peak calcium demand during early lactation, suggesting that transient osteoporosis could contribute to fracture susceptibility. Additionally, this period coincides with the resumption of estrous cycles, where increased activity related to mating behaviors may further increase fracture risk. Several studies have linked humeral fractures in New Zealand dairy cows to suboptimal feed quality, which reduces bone formation and increases abnormal bone resorption, thereby weakening bone integrity [9,10,11,37,38]. Supporting this, research on yearling zebu steers demonstrated that dietary protein deficiency over 100 days led to mild rib osteoporosis, highlighting the influence of phosphorus and calcium availability on bone strength [39].

The studies presented here represent the first nationwide, cross-sectional assessment of non-responsive, non-weight-bearing forelimb lameness in New Zealand, specifically targeting humeral fractures in first- and second-lactation dairy cows. In the 2014/15 lactation season, the condition was identified on 9.7% of farms for first-lactation cows and 7.4% for second-lactation cows, with an average within-herd incidence of 2.6% and 2.8%, respectively. These findings suggest substantial economic losses for affected farms due to the premature culling or euthanasia of young, productive animals.

The telephone survey assumed that farmers would reliably detect cows with non-responsive, non-weight-bearing forelimb lameness, given the conspicuous nature of the clinical signs. Nevertheless, it is acknowledged that some observed lameness may have arisen from lower limb conditions rather than upper forelimb fractures. To improve specificity for humeral fractures, the case definition for the survey was restricted post-hoc to include only cows that required euthanasia. This approach rests on the rationale that severe lower limb conditions rarely result in euthanasia, whereas almost all humeral fractures necessitate it.

The authors could not identify published evidence of other causes of forelimb lameness severe enough to meet the survey's case definition in first- and second-lactation cows, apart from humeral fractures [40, 41]. Consequently, while the survey relied on farmer-reported cases, it is likely that the incidence figures largely reflect humeral fractures. At the same time, recall bias or incomplete memory of events may have led to underreporting

of cases, though conducting the survey during the same lactation season, targeting farmers with primary herd responsibility, and focusing on a visually obvious condition likely minimized this effect.

According to Section 138 of New Zealand's Animal Welfare Act 1999, animals should be euthanized if treatment is unlikely to result in recovery or if the animal would otherwise suffer undue pain or distress [42]. While there have been anecdotal reports of a small number of heifers or cows recovering from humeral fractures (<5%), the welfare implications are severe, and euthanasia is the standard course of action. This minor possibility of recovery suggests that the incidence of forelimb lameness derived from the telephone survey may slightly underestimate the true rate.

Beyond welfare concerns, there are considerable economic implications for farmers and the wider dairy industry. In the 2013/2014 season, New Zealand had 11,927 dairy herds [21]. Assuming median herd sizes of 85 first-lactation cows and 70 second-lactation cows, there were approximately 1.01 million first-lactation cows and 835,000 second-lactation cows in the country. If 11.7% of herds experienced one or more cases of non-responsive forelimb lameness, this corresponds to around 1,395 potentially affected herds. Applying the national incidence rates, an estimated 2,700 first-lactation cows and 1,920 second-lactation cows may have been affected, highlighting the urgent need for research into underlying causes.

While the estimated total of 4,620 cattle with humeral fractures may appear high, the pet food case series provides some corroboration. Farmers have multiple disposal options for severely affected animals: on-farm slaughter for human consumption, shooting and burial, or collection by local hunt kennels. If the pet food company collected from 500 Waikato farms and only half of the affected animals were sent to them, this extrapolates to roughly 2,910 first- and second-lactation cows nationally, which corresponds to approximately 63% of the estimate from the telephone survey.

The practice-based case series reported a surprisingly low number of affected farms, with only 10 out of 800 (1.25%) clients showing any cases. This is far lower than estimates from the national telephone survey, suggesting that under-reporting by farmers is likely. Some owners may have been hesitant to disclose losses, and many of these farms were also clients of the pet food company, which further complicates accurate reporting. Under-reporting has been a persistent challenge in studying humeral fractures and contributed to delayed recognition of the condition by the New Zealand dairy industry. Notably, 30% of farms in the practice-based survey had reported cases in the prior season, consistent with findings from the national case series. This indicates that humeral fractures often recur across multiple seasons on certain farms, sometimes for up to four years, and not always consecutively.

The number of animals affected on individual farms can be distressing both emotionally and financially. In some cases, farms reported large numbers of fractures: two farms in the national case series had 16 and 18 cases, one farm in the telephone survey reported 30 combined first- and second-lactation cases, and the pet food company collected 13 affected cows from a single property. While the psychological impact on farmers has not been specifically studied for humeral fractures, research on disease-related culling suggests the stress is likely significant [43, 44].

In New Zealand, first-lactation heifers are often raised away from the main farm and may not be closely monitored until they return at about 21 months of age [45]. Historically, management has focused on achieving adequate liveweight at calving, as this is closely linked to milk production in the first lactation [46, 47]. However, more detailed investigation into the growth and nutrition of heifers before and after weaning is needed. Identifying risk factors for humeral fractures during these early stages could guide interventions to reduce the incidence of this condition while keeping costs manageable.

Conclusions

Humeral fractures in first- and second-lactation dairy cows are more widespread than previously believed. They occur throughout New Zealand and may persist over several years on the same farm. There is an urgent need for further research to develop strategies that reduce both the animal welfare impact and economic losses caused by this severe and recurring problem.

Acknowledgments: The authors gratefully acknowledge the farmers who participated in the phone survey and national case series: Anexa Veterinary Services veterinarians and Steve Payne (Cognosco technician). D. Butler from Rotorua is kindly thanked for providing the photographs and videos.

Conflict of Interest: None

Financial Support: The national case series study was partly funded by the dairy farmers of New Zealand via DairyNZ, 605 Ruakura Rd RD6, Newstead, Hamilton, New Zealand project number OF1310 and by Anexa Veterinary Services, 25 Moorhouse Street, Morrinsville, New Zealand.

Ethics Statement: None

References

1. Weston J. An outbreak of humeral fractures among dairy heifers. In: Proceedings of the Society of Dairy Cattle Veterinarians of the New Zealand Veterinary Association, Wellington, New Zealand, 25–28 June 2008; pp. 241-3.
2. Varney K, McLachlan S. Quarterly review of diagnostic cases—October to December 2008. Surveillance. 2009;36(1):8-13.
3. McLachlan S. Quarterly review of diagnostic cases—October to December 2009. Surveillance. 2010;37(1):18-21.
4. Anonymous. Quarterly report of diagnostic cases: July to September 2011. Surveillance. 2011;38(4):16-25.
5. Anonymous. Quarterly review of diagnostic cases: October to December 2011. Surveillance. 2012;39(1):14-22.
6. Anonymous. Quarterly review of diagnostic cases: July to September 2014. Surveillance. 2014;41(3):7-14.
7. Anonymous. Quarterly report of diagnostic cases: October to December 2014. Surveillance. 2015;42(1):4-9.
8. Weston J, Thompson K, Dittmer K, Rashid Z. Humeral fractures in dairy heifers. In: Proceedings of the Dairy Cattle Veterinarians of the New Zealand Veterinary Association, Hamilton, New Zealand, 19–24 June 2012; pp. 11-12.
9. Wehrle-Martinez A, Naffa R, Back P, Rogers CW, Lawrence K, Loo T, et al. Novel assessment of collagen and its crosslink content in the humerus from primiparous dairy cows with spontaneous humeral fractures due to osteoporosis from New Zealand. Biol. 2022;11(10):1387.
10. Wehrle-Martinez A, Lawrence K, Back PJ, Rogers C, Gibson M, Dittmer K. Osteoporosis is the cause of spontaneous humeral fracture in dairy cows from New Zealand. Vet Pathol. 2023;60(1):88-100.
11. Dittmer K, Hitchcock B, McDougall S, Hunnam J. Pathophysiology of humeral fractures in a sample of dairy heifers. N Z Vet J. 2016;64(4):230-7.
12. Loughnan T. A case of copper deficiency in heifers with pathological fractures. Aust Cattle Vet. 2012;65:16-17.
13. Clark D, Phyn CVC, Tong MJ, Collis SJ, Dalley DE. A systems comparison of once-versus twice-daily milking of pastured dairy cows. J Dairy Sci. 2006;89(5):1854-62.
14. DairyNZ; LIC. New Zealand Dairy Statistics 2000–2001. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 10 Feb 2022).
15. DairyNZ; LIC. New Zealand Dairy Statistics 2014–2015. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 24 May 2021).
16. Back P. Dairy production. In: Stafford K, editor. Livestock production in New Zealand. Auckland: Massey University Press; 2017.
17. Gangl M, Grulke S, Serteyn D, Touati K. Retrospective study of 99 cases of bone fractures in cattle treated by external coaptation or confinement. Vet Rec. 2006;158(8):264-8.
18. Crawford WH, Fretz PB. Long bone fractures in large animals: a retrospective study. Vet Surg. 1985;14(4):295-302. Wiley Online Library
19. Saunders MNK, Lewis P, Thornhill A. Research methods for business students. 5th ed. Pearson Education Ltd.: Essex, UK; 2009. p. 151-2.
20. Bell R, Warren V, Schmidt R. The application of concurrent or sequential mixed-methods research designs and their methodological implications: investigating tacit knowledge, its use, and application in automotive development. In: SAGE Research Methods Cases; 2022.
21. Abdul Rashid Z. An investigation of spontaneous humeri fractures in New Zealand dairy cattle. MSc (Epidemiology) thesis. Massey University, Palmerston North, New Zealand; 2012.

22. DairyNZ; LIC. New Zealand Dairy Statistics 2013–2014. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 15 Nov 2023).
23. Brooks ME, Kristensen K, van Benthem KJ, Magnusson A, Berg CW, Nielsen A, et al. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. 2017;9(2):378-400.
24. DairyNZ; LIC. New Zealand Dairy Statistics 2006–2007. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 1 Sep 2023).
25. DairyNZ; LIC. New Zealand Dairy Statistics 2011–2012. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 1 Sep 2023).
26. Anonymous. Quarterly report of diagnostic cases: October to December 2015. Surveillance. 2016;43(1):12-18.
27. Anonymous. Quarterly review of diagnostic cases: October to December 2017. Surveillance. 2018;45(1):5-14.
28. Anonymous. Quarterly report of diagnostic cases: October to December 2018. Surveillance. 2019;46(1):15-25.
29. Anonymous. Quarterly report of diagnostic cases: October to December 2019. Surveillance. 2020;47(1):11-8.
30. Anonymous. Quarterly review of diagnostic cases: October to December 2020. Surveillance. 2021;48(1):15-24.
31. Anonymous. Quarterly review of diagnostic cases: July to September 2021. Surveillance. 2021;48(3):25-33.
32. Harris B. Breeding dairy cows for the future in New Zealand. N Z Vet J. 2005;53(6):384-9.
33. DairyNZ; LIC. New Zealand Dairy Statistics 1998–1999. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 10 May 2022)
34. DairyNZ; LIC. New Zealand Dairy Statistics 2008–2009. Available online: https://www.dairynz.co.nz/publications/dairy-industry/new-zealand-dairy-statistics-2008-09/ (accessed 10 May 2022).
35. DairyNZ; LIC. New Zealand Dairy Statistics 2021–2022. Available online: https://www.lic.co.nz/about/dairy-statistics/ (accessed 10 May 2022).
36. Wehrle-Martinez A, Lawrence K, Back PJ, Rogers CW, Dittmer KE. Farm management and husbandry practices associated with spontaneous humeral fractures in New Zealand dairy heifers. N Z Vet J. 2023;71(1):37-41.
37. Wehrle-Martinez A, Dittmer KE, Back PJ, Rogers CW, Lawrence K. Biochemical profile of heifers with spontaneous humeral fractures suggest that protein-energy malnutrition could be an important factor in the pathology of this disease. N Z Vet J. 2023;71(1):37-41.
38. Wehrle-Martinez A, Waterland M, Naffa R, Lawrence K, Back PJ, Rogers CW, Dittmer KE. Bone quality changes as measured by Raman and FTIR spectroscopy in primiparous cows with humeral fracture from New Zealand. Front Vet Sci. 2023;10.
39. Tuen A, Wadsworth J, Murray M. Absorption of calcium and phosphorus by growing cattle during dietary protein deficiency. In: Proceedings of the Nutrition Society of Australia, Armidale, NSW, Australia, November 1984; pp. 144-7.
40. Chesterton R, Lawrence K, Laven R. A descriptive analysis of the foot lesions identified during veterinary treatment for lameness on dairy farms in north Taranaki. N Z Vet J. 2008;56(3):130-8.
41. Chawala A, Lopez-Villalobos N, Margerison J, Spelman R. Genetic and crossbreeding parameters for incidence of recorded clinical lameness in New Zealand dairy cattle. N Z Vet J. 2013;61(5):281-5.
42. Anonymous. Section 138 Destruction of injured or sick animals (other than marine mammals), Animal Welfare Act 1999. Available online: https://www.legislation.govt.nz/act/public/1999/0142/latest/DLM51273.html (accessed 19 Jan 2024).
43. Peck D, Grant S, McArthur W, Godden D. Psychological impact of foot-and-mouth disease on farmers. J Ment Health. 2002;11(5):523-31.
44. Crimes D, Enticott G. Assessing the social and psychological impacts of endemic animal disease amongst farmers. Front Vet Sci. 2019;6:342.

45. McDougall S, Brownlie T, McNaughton L. Heifer management: the impact of undergrown heifers. In: Proceedings of the Dairy Cattle Veterinarians of the New Zealand Veterinary Association, Hamilton, New Zealand, 19–24 June 2014; pp. 3-23.
46. Carson A, Dawson L, McCoy M, Kilpatrick D, Gordon F. Effects of rearing regime on body size, reproductive performance and milk production during the first lactation in high genetic merit dairy herd replacements. Anim Sci. 2002;74(4):553-65.
47. Macdonald K, Penno J, Bryant A, Roche J. Effect of feeding level pre- and post-puberty and body weight at first calving on growth, milk production, and fertility in grazing dairy cows. J Dairy Sci. 2005;88(9):3363-75.