Effect of breed and paddock activity on bone mass and strength in three beef cattle breeds

L Bijenc, MJ Gibsone, PJ Backc, RE Hicksonc, A van Knegselc and CW Rogersd

eSchool of Veterinary Science, Massey University, New Zealand, fSchool of Agriculture and Environment, Massey University, New Zealand; gWageningen University & Research, Wageningen, The Netherlands.

Corresponding author: Email: c.w.rogers@massey.ac.nz

Abstract

There are obvious phenotypic differences among beef cattle breeds, but, to date, there are limited data on the effect of breed and pasture-based management systems on the bone mass and strength of the distal limb bone (metacarpals). The left 3rd/4th metacarpal bones were collected from a cohort of Angus (AA) (n = 17), Angus × Friesian (AF) (n = 13), and Angus × Jersey (AJ) (n = 13) cows aged nine years at slaughter. Prior to slaughter the cohort had been intensively monitored as part of longevity- and GPS-based paddock-activity trials. Measures of metacarpal bone mass and strength were assessed using peripheral quantitative computed tomography (pQCT) scanning at the mid-diaphysis after slaughter. Locomotion parameters, based on GPS data when grazing, were collected when four and five years old. The AA and AF cows had significantly greater slaughter weight than AJ (598±14 vs 586±18 vs 514±17 kg, P<0.01 respectively). AA cows had lower wither height than AF and AJ (1288±6 vs 1311±8 vs 1269±7 mm, P<0.01) and shorter metacarpal bone length (198±2, vs 207±2 vs 210±2 mm, P=0.05). At the mid-diaphyseal site, AF and AJ cows had greater bone mineral density (BMD) than did AA cows (977±8 vs 1018±9 vs 1019±9 mg/cm³, respectively, P<0.001), but had less cross-sectional area (882±16 vs 816±18 vs 731±18 g/cm³, P<0.05 respectively). Across all breeds, there was a negative relationship of slaughter weight with BMD. No significant relationships were found between distance walked on moderate and steep terrain (GPS data) and the pQCT measures. Breed influenced the size and structure of the metacarpal bone, which altered the material properties (pQCT) measured. The limited amount of high-strain-rate exercise in these cattle may explain the lack of association between locomotion data and measures of bone mass and strength.

Keywords: bovine; bone; GPS; locomotion; beef

Introduction

Under commercial conditions, beef cattle are commonly grazed on areas of steep hill country, often in summer-dry regions with soil of low fertility. Most beef animals are farmed together with sheep, as the stock classes are complementary to one another with respect to animal health and pasture management (Geenty & Morris 2017). In addition to beef production, beef cattle contribute to pasture quality management and support optimal grass yield (McCall 1994).

To understand the effect of activity on bone mass and strength of cattle, knowledge on how cattle utilize differing slopes and terrain is important. Early work showed that cattle tended to use land with some slopes extensively, and others not at all, or only slightly (Cook 1966). The influence of slope steepness on the distribution of cattle on mountainous rangeland in the USA showed that 81% of the variation in relative grazing use was accounted for by slope steepness and distance upslope from the bottom (Mueggler 1965), and cattle preferred slopes less than 4% (Pinchak et al. 1991). More recent work in New Zealand (Martin et al. 2015) reported that beef breeding cows grazing hill country in winter generally avoided steep terrain; only about 5% of their movements were recorded on steep terrain. The preference of cattle for more level terrain is also influenced by herbage availability. Lower herbage availability resulted in a more-equal distribution of grazing over different types of terrain (Henkin et al. 2012).

In horses, increasing pasture exercise has been demonstrated to alter a number of measures of bone mass and strength (Rogers et al. 2008a; Rogers et al., 2008b). A study in the USA using Holstein calves demonstrated that the level of exercise, number of load cycles and relative velocity of the gait in particular, required to induce positive changes in the metacarpal bones were low compared to those published for horses (Logan et al. 2019). These data indicate that there may be an early developmental window for the stimulation of bone development in cattle and that the relative velocity required to induce change is lower than that observed in horses. The reasons for the between-species difference may be due to the initial starting values, as horses are a cursorial animal and start life with a very well-developed musculoskeletal system (Rogers & Dittmer 2019). In comparison, cattle as grazing ruminants would provide a much lower general baseline strain rate to the distal limb with a high proportion of activity based around standing and grazing, rather than bursts of high-speed activity such as canter and gallop.

Under commercial conditions however, management of cattle on steep hill country could provide exposure to brief periods of high-strain rates that, in theory, should be osteoinductive. Quantification of activity, and hence load cycles, on slopes of different aspect could help our understanding of the relative strains grazing on different slopes provides and the relative bone responses associated with these loads.

As present in New Zealand there are limited data published on measures of bone mass and strength in cattle managed under commercial conditions. Preliminary data on dairy cattle in relation to humeral fractures have demonstrated the value of using peripheral quantitative computed tomography (pQCT) to quantify bone mass and...
strength (Dittmer et al. 2016, Gibson et al. 2019).

The aim of this study was to quantify bone mass and strength in the metacarpus of a cohort of commercially-managed beef and beef-dairy cross cows that had been part of a productivity trial and, hence, had thorough documentation of management, reproduction and pasture activity.

Materials and methods

Animals

The beef breeding cows used in this study were a convenience sample (subset) of the cows (n=47) originating from the beef cow productivity study (Hickson et al. 2015; Martin et al. 2015). At the end of the experiment all cows were sent to slaughter at a local abattoir. At slaughter at the completion of the cows’ ninth year, the left metacarpal bone (third and fourth metacarpal, Mc3/4) were collected from all the cows. The cows were of the following crosses: Angus × Angus (AA, n=17), Angus × Friesian (AF, n=13), and Angus × Jersey (AJ, n=13) crosses. Description of the management of the cows, productivity, and collection of slaughter weight and height of the cows are published in detail (Martin et al. 2015).

GPS data

The detailed account of the GPS measurement and observation was reported by Martin et al. (2015). In brief, the cows wore custom-made GPS collars that logged positional data whenever a cow moved ≥4 m, or at one-minute intervals if the cow did not move. The total distance walked per day and the daily distance walked on gentle (slope < 17°), moderate (17° ≥ slope < 35°), and steep terrain (≥35° slope) were recorded for six days consecutively in either winter 2012 or 2013. Each breed (AA, AJ and AF) was assigned a separate paddock during the observation period. The average total distance walked per day (TDW), the average distance walked on gentle terrain per day (DWG), the average distance walked on moderate terrain per day (DWM), and the average distance walked on steep terrain per day (DWS) were calculated for each cow.

pQCT scanning

At slaughter, the left Mc3/4 was dissected out and frozen (−20°C) until subsequent peripheral quantitative computed tomography (pQCT) scanning with an XCT-2000 scanner (pQCT; XCT 2000, Stratec Medical). The mid-diaphysis of each bone was scanned using pQCT with the bone being scanned at 50% of the total bone length starting from the distal end with a voxel size of 0.3 mm³. Voxel were assigned, within the manufacturer’s software, as either “trabecular” bone (≥710 mg/mL), or as “cortical” bone (>710 mg/mL). Data derived from the scan included measures of total bone content, cortical and subcortical bone content, cortical and subcortical density, trabecular content, trabecular density, total area, trabecular area, cortical and subcortical area, cortical content, cortical density, cortical area, cortical thickness, periosteal circumference, endosteal circumference, and the stress strain index.

Statistical analyses

Data were tested for normality using the Shapiro-Wilks test. Differences among breeds for GPS and bone parameters were tested using a general linear model. Multiple comparisons with post hoc tests were corrected for using a Bonferroni correction. All analyses were completed within Stata 12 (StataCorp LP, College Station, TX, USA) with significance set at P < 0.05.

Results

The AA and AF cows had significantly greater slaughter weight than the AJ cows (598 ± 14 vs 586 ± 18 vs 514 ± 17 kg, respectively, P < 0.01). Angus cows had lower withers height than AF and AJ (1288 ± 6 vs. 1311 ± 8 vs. 1269 ± 7 mm, P<0.01) and shorter metacarpal bone length (198 ± 2, 207 ± 2 vs. 210 ± 2 mm, P<0.05). The distance walked on gentle terrain and distance walked on moderate terrain primarily contributed to the total distance walked per cow per day (Figure 1).

The pQCT-derived bone measures of the mid-diaphysis of each breed are presented in Table 1. Within each parameter there was a significant breed effect (P<0.001). Angus cows had the largest bones with the greatest periosteal circumference (PeriC) and bone mineral content (BA, PeriC, and BMC). Despite the Angus cows having a lower volumetric bone mineral density, the greater

<table>
<thead>
<tr>
<th>Breed</th>
<th>BA (mm²)</th>
<th>PeriC (mm)</th>
<th>vBMD (mg/cm³)</th>
<th>BMC (mg/mm)</th>
<th>EndoC (mm)</th>
<th>SSI (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>881.9±15.8c</td>
<td>105.2±6.9a</td>
<td>977.3±7.8a</td>
<td>860.9±12.6a</td>
<td>57.3±0.9a</td>
<td>6121.3±149.9c</td>
</tr>
<tr>
<td>AF</td>
<td>815.6±18.1b</td>
<td>101.1±1.1b</td>
<td>1018.5±8.9b</td>
<td>829.0±14.4b</td>
<td>52.3±1.1b</td>
<td>5549.6±171.5b</td>
</tr>
<tr>
<td>AJ</td>
<td>730.9±18.1a</td>
<td>95.8±1.1a</td>
<td>1019.4±8.9b</td>
<td>744.0±14.4b</td>
<td>49.5±1.1ab</td>
<td>4653.4±171.5a</td>
</tr>
</tbody>
</table>

Different superscript letters in the same row indicate significant differences among breeds (P<0.05).
measures of bone size and content contributed to the Angus cows having the greatest bone strength (SSI), with the least variation in SSI values across the three breeds.

**Discussion**

The management of the cows was typical of that of beef cows in the lower North Island of New Zealand and, thus, the load cycles and respective strain rates on the limbs would be similar to that observed under typical New Zealand management conditions. The advantage with this cohort of cows was that they had been part of a longitudinal productivity trial and, thus, had a well-documented history with respect to management and reproductive performance. This study appears to be the first to document the effect of locomotion under typical commercial pasture-based management systems on bone parameters in the distal limb of beef and beef-dairy cross cattle.

A breed effect was consistent across all the bone parameters measured. The data from the beef-dairy cross cows (AF and AJ) were similar to the data described by (Gibson et al. 2019) for beef-dairy cross yearlings. This may imply that bone development and maturation is close to completion and, therefore, adult values are reached by the time these animals are one year old. The metacarpus being a distal limb bone, is likely to achieve maturation earlier during growth than the bones in the proximal limb (Pomeroy 978). Gibson et al. (2019) demonstrated that, even though comparisons were between beef-dairy cross yearlings and mixed-aged dairy cows, there were no differences in many parameters, supporting the hypothesis that much of the maturation in the metacarpus has occurred by one year of age.

The mechanostat theorem provides a mechanism to describe that, in any given bone, or location within the bone, the material properties will be such that there is optimisation within a relatively narrow range. Loads above this range result in increased strength, and lack of load leads to a reduction in material content and strength (Frost 2004). Thus the material properties of the bone (structure and relative deposition of mineral content) describe the relative loading it is exposed to. The different strategies used to achieve bone strength depend on the type of loading (flexion vs torsional strain), sex (oestrogen supresses bone size) (PeriC), and genetics. Within our population, there was large variation in some of the parameters for the beef-dairy cross cows compared to those in the Angus cows. This phenotypic variation reflects the morphological differences between the two dairy-cross breeds. The metacarpus bones of the Angus cows had greater periosteal (PeriC) and endosteal circumference (EndoC) and this was able to generate a greater stress strain index. In contrast to this increase in size strategy, the dairy cross breeds, particularly the JA cows, had much lower periosteal and endosteal circumference but required a greater BMD v to achieve the appropriate SSI. There is a strong association of body weight (and hence, load) with measures of bone strength, particularly in the distal limb. However, the Angus cows had only 2% greater BW than did the Angus-Friesian but had a 10% greater SSI, and the relative difference between body weight and SSI was even greater compared with the Jersey cross (16% greater BW and 32% greater SSI). The lack of linearity of body weight with SSI across the breeds implies that the breed effect (Angus) may be having an amplification factor on the relationship of body weight and SSI. Hence, differences in morphology may mean that relative effect of body weight is distributed differently in metacapus of the Angus compared to the Angus dairy cross cows.

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**Figure 1** The cumulative contribution of distance walked on gentle, moderate, and steep terrain as components of the total distance walked by beef cows (per day) monitored with GPS collars.
The GPS data indicated that the majority of the loading was at moderate strain rates that were unlikely to be osteoinductive as most of the behaviour was grazing and on gentle to moderate slopes. We had hypothesised that the steep slopes may provide sufficient strain rate to induce a focal bone response at the mid-diaphysis area. In theory, the number of high strain rates required could be achieved with relatively little time spent on the steep slopes, as across mammals, the number of load cycles required to induce a bone response if sufficient strain rate is applied, is low. In Holstein calves, sprint exercise on a 71-m concrete track was sufficient to induce quantifiable changes in BMDv and resistance to fracture (Logan et al. 2019). The sprint exercise in these calves was approximately 3.6 ms⁻¹ which was a lower velocity compared to the sprint exercise required to generate similar responses in horses. In foals and adult horses without short bursts of high-strain-rate activity there is not sufficient stimuli to promote, or maintain, higher bone-mineral density (Rogers & Dittmer, 2019; Firth et al. 2007). Given that the GPS data were collected two years prior to slaughter, some caution should be used when interpreting the relative load cycles on the limbs with the pQCT-derived data. However, despite some differences between years, there was limited variation in the relative distribution of loading as described by the time spent on the different slope gradients. This indicates that the GPS data may provide a relatively good indication of typical locomotor activity in beef cattle under commercial conditions and that most of the load cycles are of low magnitude.

Conclusion

These data indicate that breed may have an affect on the relative loads on the metacarpus and its material properties. The GPS data imply that load cycles on the distal limb of beef cows managed under typical New Zealand pasture conditions are of moderate strain rate and unlikely to stimulate dynamic bone response. The similarity of the material properties reported here with those of Gibson et al. (2019) support the hypothesis that much of the bone material properties observed in our cows may have been achieved by the time they were yearling and remained persistent up to nine years of age and after multiple pregnancies.

References


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