# The effect of preconditioning on production and antibiotic use in a South African beef feedlot

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## Abstract

**Context:** There is pressure on production veterinarians to reduce the use of antibiotics in intensive beef production systems.

**Aims:** The present study investigated whether preconditioning – the process whereby weaned calves destined for the feedlot are prepared over a period of time – reduced antibiotic treatment events, and improved health and production of calves in a South African feedlot.

**Methods:** Preconditioned calves ($n$ = 301) and control calves ($n$ = 332) were sourced from the same origin on two occasions, and arrived at the feedlot on the same day. Bovine respiratory disease (BRD) was defined as the 'pulling' of clinically sick calves from feedlot pens, followed by the standard protocol for treatment of BRD (including antibiotic treatment). Outcome variables related to health were BRD overall incidence (pulling), BRD re-pulling and lung lesion scores. Production outcome variables measured were carcass weight, carcass average daily gain (ADG) and days on feed (DOF). Initial carcass weight was estimated from shrunk liveweight in order to estimate the effect of preconditioning on carcass gain, the most economically relevant outcome. Statistical analyses were done using multiple linear, logistic and Cox regression. Predictor variables were preconditioning vs control, gender, starting weight, DOF, pulling for BRD and carcass ADG.

**Key results:** A lower proportion of preconditioned calves were pulled and a lower proportion of pulled calves were re-pulled for BRD compared with control calves (8 vs 17% and 8 vs 16%, respectively, $P < 0.01$). A higher proportion of preconditioned calves compared with control calves were market ready at 90 DOF (89 vs 67%, $P < 0.01$). In the multivariable models preconditioning was associated with a 200 g/d increase in carcass growth rate ($P < 0.01$) and with a 17.7 kg increase in overall carcass gain ($P < 0.01$) after adjusting for gender and DOF.

**Conclusions:** Preconditioning reduced the incidence and severity of BRD and feedlot standing time and improved production of calves in South African feedlots.

**Implications:** Preconditioning has the potential to add value to the beef feedlot by reducing the formation of antimicrobial resistance while improving the profitability of the feedlot.

**Additional keywords:** beef cattle, diseases, feedlot.

## Introduction

Bovine respiratory disease (BRD) is the most common reason for calves in a beef feedlot to be identified and 'pulled' for antibiotic treatment. Despite there not being a perfect correlation between pulling and actual respiratory pathology, it has been shown that lesions associated with BRD are negatively associated with production parameters of beef calves (Apley 2017; Thompson *et al*. 2006). Furthermore, the level of antimicrobial use is associated with the occurrence of antimicrobial resistance (AMR) (Apley 2017).

Preconditioning refers to the management of stress, immunity and nutrition around the time of weaning with the aim of improving health and production in the feedlot; however, definitions are vague and the term has been loosely applied in the beef industry (Cole 1984; Schipper *et al*. 1989; Nyamasika *et al*. 1994; King *et al*. 1996; Speer *et al*. 2001). The definition of backgrounding puts more emphasis on the weight gain (production) and time spent on a grazing system after weaning and before going into a feedlot (Rickey and Prichard 1988).

Although these practices are commonly used around the world including in South Africa, the response of preconditioned animals to future stressors and the potential effects on improvements in health, production, welfare and responsible antibiotic stewardship has not been reported widely before (Avent *et al*. 2002).

The objectives of the present study were therefore to determine whether preconditioning can reduce the incidence of BRD and associated antibiotic use and improve production of calves in a feedlot.

## Materials and methods

This project was approved by the Animal Ethics Committee of the University of Pretoria (project number V092-16).

### Animal population

The study population consisted of 633 bovine animals of both genders, which were born on different commercial farms and were sold to a feedlot via an auction after weaning. These were therefore all highly stressed calves due to co-mingling. They were of various beef breeds commonly found in feedlots in South Africa. The exact ages were not known, but were typical of calves at marketing age, being between 7 and 10 months of age. The study group were a group that represents a common sourcing practice for feedlots in SA (from an auction) and were considered to be at a high risk to contract BRD. The study was done during the autumn and early winter, a time of the year when a high incidence of BRD is expected.

### Study design and procedures

The model system was a prospective cohort study, with one cohort of calves (PC group) being exposed to common existing preconditioning practice, and the control cohort (C group) being transported directly from the auction to the feedlot. In the design of the study, which tested the effects of a 45-day preconditioning practice, the researchers chose to assume that environmental factors during the feedlot phase of the experiment were more likely to bias the results of the study, compared with bias caused by animal selection at the time of purchasing. It was therefore elected to have the feedlot phase of the experiment synchronised, rather than the purchasing of the calves from the auction. The risks associated with sample selection were mitigated by appointing the same animal buyers to buy calves from the same auction, with the same instruction regarding quality, breed type, conformation, health status, and price range of the calves. Furthermore, the animal buyers were not informed that they were purchasing calves for an experiment.

The PC group ($n$ = 301) were transported by road from the auction to the preconditioning site which was ~80 km away. Upon arrival they were vaccinated against BRD using a combination modified live vaccine (MLV) including IBR, PI3, BRSV and BVD, and a bacterial vaccine (*Mannheimia*), and treated against internal and external parasites. At the preconditioning site the calves were kept in extensive grazing camps for a period of 45 days. Calves were fed out of a trough on a daily basis with a typical lick supplement designed to support better utilisation of natural veld grazing. After the preconditioning period the animals were transported to the feedlot, ~580 km away.

The C group ($n$ = 332) were sourced at the same auction by the same agent and the same buyer, 45 days after sourcing the PC group, and originated from the same area as the preconditioned group. The animals were of similar weight, age and breed composition, and were shipped directly to the feedlot, ~620 km away, using the same transport company that transported the PC group.

Both groups arrived at the feedlot on the same afternoon: the PC group from the site of preconditioning and the C group from the auction. The two groups were offloaded into similar adjacent receiving pens and were processed in the standard way within 24 h of arrival. In the receiving pens both groups had access to fresh water, good quality hay, and a receiving ration topped onto grass hay in the bunk, as routinely done in the feedlot. Processing included unique individual identification of each calf, MLV vaccination, a bacterial vaccine (*Mannheimia*), an inactivated vaccine containing seven different clostridial antigens, anthrax bacterin, injectable ivermectin (1% solution) and a trenbolone acetate impregnated ear implant. As they left the processing chute they were sorted into waiting pens according to bodyweight (≤200 kg; 201–230 kg; >231 kg) and gender. In the waiting pens co-mingling of the PC and C groups occurred. From here they were placed into production pens ('home pens') of ~120 calves per pen with a density of 12–14 $m^2$ per calf.

Feedlot staff were blinded to study group and standard operating procedures were followed. This was to ensure that calves originating from the PC and Control groups were exposed to the same feedlot environment including the ration.

Sick animals were identified and pulled for treatment, as it is the practice in South African feedlots. All the calves were observed for any of the following signs of disease, these being depression, loss of or decreased appetite, increased breathing rate and/or abnormal breathing pattern. Once pulled, rectal temperature was measured and considered to be another sign of disease if it exceeded 39.5°C. If one or more of the above signs were recorded, the animal was removed from its home pen, recorded as a BRD case, weighed and treated using the standard protocol including systemic antibiotic treatment. All treatments, drugs, volume and route were recorded. When animals had recovered sufficiently they were taken back to their original home pen.

After 59 days on feed (DOF) the calves were individually sorted for market readiness based on a subjective visual observation. After determining market readiness, they were put into two groups: the market ready group were fed for another 30 days on a ration containing a $\beta_2$-agonist growth stimulant followed by a 5-day withdrawal period and were then transported to the abattoir (35 km away) for slaughter. These calves were fed for a total of 94 days. Calves in the non-market ready group were maintained for an additional 21 days on a finisher ration after which they were again individually sorted according to market readiness. Those that were now market ready were fed for another 30 days on the $\beta_2$-agonist ration followed by a 5-day withdrawal period before slaughter, totalling 115 DOF. The third group consisted of those that were still not market ready; they were maintained for another 18 days on the finisher ration before being moved to the $\beta_2$-agonist ration and slaughtered after a total of 133 DOF.

At the abattoir each animal's lungs were scored for lung lesions in the cranioventral lobe, and for adhesions, as described by Bryant *et al*. (1999). Lesions observed for lung scoring were the following: collapse/consolidation, diffuse or marginal pleuritis, lobe to lobe adhesion, lobe to thoracic adhesion, missing lobes, abscesses, fibrosis, emphysema and disseminated lesions. Adhesion scores were based on severity of the adhesions. Both scores were recorded on a scale of 0–5 with '0' being normal and '5' being severe pathology. In the case of lung lesions severity is categorised as '1' if lesions were mild and affected <5% of lung tissue and '2' if moderate and affected 5–14% of lung tissue.

**Calculation of carcass weight at processing**

According to Fox *et al*. (1976), the relationship between carcass weight (CW) and empty bodyweight (EBW, liveweight minus weight of ingesta) is:

$$\text{EBW} = 1.40 \times \text{CW} + 40.2\,\text{kg}. \tag{1}$$

The relationship between live bodyweight (BW) and EBW is somewhat variable, depending on degree of shrinkage and nature of the ingesta, and several equations have been described for it. A relatively conservative estimate of EBW was given by Owens *et al*. (1995) in the formula:

$$\text{EBW} = 0.917 \times \text{SBW} - 11.39\,\text{kg}, \tag{2}$$

where SBW is shrunk bodyweight (bodyweight after an overnight fast). Jesse *et al*. (1976) provided a more liberal estimate of EBW in the formula:

$$\text{EBW} = 0.972 \times \text{SBW} - 13.6\,\text{kg}. \tag{3}$$

Combining Eqns (1) and (2), the relationship between CW and SBW is:

$$\text{CW} = 0.655 \times \text{SBW} - 36.85\,\text{kg}. \tag{4}$$

Combining Eqns (1) and (3), the relationship between CW and SBW is:

$$\text{CW} = 0.694 \times \text{SBW} - 38.43\,\text{kg}. \tag{5}$$

It was assumed that the calves' live mass at the time of processing was SBW, as some degree of fasting would have occurred before processing. The CW of each animal at the time of processing was then calculated from its SBW using both Eqns (4) and (5), and the average of the two weights was used. Carcass gain (kg) and average daily gain (ADG) (kg/day) was then calculated for the interval from processing to slaughter.

**Statistical analyses**

All data were entered into a spreadsheet (Excel, Microsoft Corp., Sacramento, CA, USA) and analysed using NCSS 2004 (NCSS, Kaysville, UT, USA). Proportions and means were compared using the Fisher exact test and Student's *t*-test respectively. Medians were compared using the Wilcoxon rank-sum test and were reported for variables that were not normally distributed based on the kurtosis normality test ($P < 0.05$). Multivariable linear and logistic regression models were used to determine the effects of preconditioning on continuous (ADG and carcass gain) and binary (pulling for BRD) outcomes, respectively. A multivariable Cox regression model was used to determine the effect of preconditioning on DOF. Covariates that were included in the models were gender, mass on the day of processing ('in mass'), DOF, pulling, lung scores at different threshold levels and carcass ADG. After univariable screening, all potential predictor variables that were associated with the outcome with $P \leq 0.20$ were initially included in the multivariable models, thereafter variables were removed one by one based on the highest Wald P-value in the model. When only variables with $P_{\text{Wald}} \leq 0.10$ remained, previously excluded variables were included into the model again one by one to test for confounding. Confounding was considered to occur if a variable changed the coefficient, odds ratio or hazard ratio of another variable by ≥15%, in which case the confounder was retained in the model.

## Results

A total of 301 and 332 animals were included in the PC and C groups respectively. The gender ratio of the two study groups differed (Table 1). The mean in weights and mean calculated initial carcass weights did not differ between the two groups; however, the in-weight data of the preconditioned calves were not normally distributed ($P < 0.01$), and the median weights and initial carcass weights of the preconditioned calves were 10 kg and 6.7 kg less than that of the control calves respectively (Table 1). In contrast, there were no calves in the PC group that weighed <180 kg, whereas 12.7% of the calves in the C group weighed <180 kg ($P < 0.01$). The proportion of calves that were pulled and the proportion of pulled calves that were re-pulled within 21 days of the initial pulling were lower in the PC group than in the C group. The proportion of calves in the C group that had in weights <180 kg and that were pulled for BRD tended to be more than the proportion in the same group with in weights ≥180 kg (10/42 vs 48/290, $P = 0.06$). In the logistic regression model of pulling, treatment group and calves with in weight <150 kg were independent predictors of pulling. The odds of a calf from the control group being pulled was 2.2 times that of a preconditioned calf (95%CI 1.34–3.65, $P < 0.01$) and the odds of being pulled for a calf with in weight <150 kg was five times more than that of a heavier calf (95%CI 1.21–20.61, $P = 0.03$). Calf in weight was not a confounder of the effect of preconditioning on pulling in this model.

**Table 1. Descriptive statistics per study cohort**

Means, medians and proportions with different lowercase letters within rows differ significantly ($P < 0.05$)

| | Preconditioned group | Control group |
|---|---|---|
| *Feedlot data* | | |
| *n* | 301 | 332 |
| Proportion male calves (*n*) | 0.399a (120) | 0.627b (208) |
| In weight (kg)[A] | 230a (215; 245) | 240b (205; 270) |
| Calculated initial carcass weight (kg)[A] | 117.5a (107.4; 127.6) | 124.2b (100.6; 144.5) |
| Proportion within weight <180 kg | 0.000a (0) | 0.127b (42) |
| Proportion pulled for treatment (*n*) | 0.083a (25) | 0.175b (58) |
| Proportion re-pulled within 21d (*n*) | 0.080a (2) | 0.172b (10) |
| Days to first pulling[A] | 6a (5; 8) | 11b (7;14) |
| Weight at first pull[B] (kg) | 232.5a (219.4; 245.7) | 211.2a (197.9; 224.3) |
| Mass gained from processing until first pull[B] (kg) | 1.12a (–10.33; 12.57) | –17.90b (–26.28; –9.51 |
| Out weight (kg) | 334.4a (328.0;340.8) | 329.0a (323.9;335.2) |
| *Carcass data* | | |
| *n* | 173 | 248 |
| Proportion slaughtered by 90 days on feed (*n*) | 0.890a (154) | 0.673b (167) |
| Proportion slaughtered after 133 days on feed (*n*) | 0.017a (3) | 0.101b (25) |
| Carcass weight[A] (kg) | 218.6a (214.8; 222.3) | 209.7b (205.5; 213.9) |
| Carcass gain[A] (kg) | 99.7a (96.9; 102.5) | 88.2b (84.9; 91.5) |
| Carcass average daily gain (kg/day) | 1.10a (1.06; 1.11) | 0.89b (0.86; 0.92) |
| *Lung data* | | |
| *n* | 169 | 223 |
| Proportion carcasses with any lung scores (*n*) | 0.556a (94) | 0.610a (136) |
| Proportion carcasses with lung score >2 (*n*) | 0.036a (6) | 0.027a (6) |
| Proportion carcasses with any lung adhesion scores (*n*) | 0.509a (86) | 0.315b (70) |
| Proportion carcasses with lung adhesion scores >2 (*n*) | 0.124a (21) | 0.068a (15) |

[A]Median (inter quartile range).
[B]Mean (95% CI).

The median DOF at first pulling was lower in the PC group compared with the C group, and pulling in the C group was spread more evenly throughout the feeding period, compared with the PC group (Table 1). In the logistic regression model of pulling for BRD, treatment group was the only independent predictor with the odds of control calves being 2.3 times that of preconditioned calves to be pulled for BRD ($P < 0.01$).

Although the bodyweight at first pulling did not differ, the bodyweight gained from processing until first pulling in the C group was significantly less than in the PC group. The bodyweights of calves in the two groups at the end of their feeding periods were similar (Table 1).

At the abattoir, carcass data of 173 and 248 animals were collected in the PC and C groups respectively. Carcass weight, carcass gain and carcass ADG were significantly higher in the PC group when compared with the C group. A significantly higher proportion of preconditioned calves were slaughtered by 90 DOF, whereas a significantly lower proportion of preconditioned calves were slaughtered after 133 DOF when compared with the C group (Table 1).

Lung scoring data were available for 169 of the original 301, and 223 of the original 332 animals in the PC and C groups respectively. The proportion of carcasses with any lung score as well as the median lung score did not differ between the two groups, whereas the proportion of carcasses with any lung adhesion score as well as the median lung adhesion score were significantly higher in the PC group compared with the C group (Table 1). The proportion of carcasses with lung adhesion scores >2 tended to be higher in the PC group compared with the C group ($P = 0.07$, Table 1).

In the multiple regression model of carcass ADG (kg/day), preconditioning was independently associated with 197 g higher carcass average daily gain and carcasses of male calves independently gained 130 g of CW more per day than those of female calves (Table 2). Carcasses of calves that were pulled for BRD treatment gained 60 g/day less than those of calves that were not pulled for treatment, after adjusting for the effects of preconditioning, gender and in weight (Table 2).

**Table 2. Multiple regression model of carcass average daily gain (kg/day)**

| Predictor | Level | Coefficient | 95% CI | | *P*-valu |
|---|---|---|---|---|---|
| Cohort | Control | 0.00 | – | – | – |
| | Precondition | 0.20 | 0.16 | 0.23 | <0.01 |
| In weight (kg) | | $-6 \times 10^{-4}$ | $-11 \times 10^{-4}$ | $-1 \times 10^{-4}$ | 0.02 |
| Gender | Female | 0.00 | – | – | – |
| | Male | 0.13 | 0.09 | 0.17 | <0.01 |
| Pulling | Not pulled for treatment | 0.00 | – | – | – |
| | Pulled for treatment | –0.06 | –0.12 | –0.01 | 0.02 |

In the Cox regression model of DOF, preconditioning was independently associated with lower DOF (increased hazard of being removed for slaughter, HR = 1.38, 95% CI: 1.11–1.71, $P < 0.01$) (Table 3). DOF was lower in calves with higher carcass ADG and in female calves. Lung score ≥ 3 was retained in the Cox regression model of DOF because it was a confounding factor based on the fact that removing it from the model changed the hazard ratios of the experimental cohort and gender by 29 and 67% respectively.

**Table 3. Cox regression model of days on feed**

| Predictor | Level | Hazard Ratio | 95% CI | | *P*-value |
|---|---|---|---|---|---|
| Cohort | Control | 1.00 | – | – | – |
| | Precondition | 1.38 | 1.11 | 1.71 | <0.01 |
| In weight (kg) | | 1.00 | 1.00 | 1.01 | <0.01 |
| Gender | Female | 1.00 | – | – | – |
| | Male | 0.21 | 0.16 | 0.26 | <0.01 |
| Lung score | ≤2 | 1.00 | – | – | – |
| | ≥3 | 0.80 | 0.44 | 1.46 | 0.47 |
| Carcass average daily gain (kg/day) | | 1.90 | 1.25 | 2.88 | <0.01 |

Preconditioning was associated with a 17.7 kg increase in carcass gain after adjusting for the effects of DOF and gender (Table 4). Male calves gained 16.4 kg more CW after adjusting for the effects of preconditioning and DOF, whereas calves slaughtered at the second and third slaughtering opportunities gained an additional 15.4 and 44.0 kg respectively (Table 4). Gender was not an independent predictor, whilst for every 1 kg/dat increased carcass ADG, the overall carcass gain was 100 kg (95% CI 99–102, $P < 0.01$).

**Table 4. Multiple regression model of carcass gain (kg) from the calculated initial carcass weight to the carcass weight at slaughter**

| Predictor | Level | Coefficient | 95% CI | | *P*-value |
|---|---|---|---|---|---|
| Cohort | Control | 0.00 | – | – | – |
| | Precondition | 17.71 | 13.75 | 21.66 | <0.01 |
| In weight (kg) | | –0.08 | –0.13 | –0.02 | <0.01 |
| Gender | Female | 0.00 | – | – | – |
| | Male | 16.42 | 12.01 | 20.83 | <0.01 |
| Days on feed | 88 or 89 | 0.00 | – | – | – |
| | 115 | 15.37 | 9.85 | 20.90 | <0.01 |
| | >133 | 44.03 | 35.51 | 52.54 | <0.01 |

The final CW of preconditioned calves was on average 8.9 kg higher than that of control calves ($P < 0.01$, Table 1).

## Discussion

The objectives of the present study were to determine if preconditioning affects the health and production of weaned calves in the feedlot. Our data show that both health and production were improved in the preconditioned calves (Table 1). Although production improvement is the economically more important effect of preconditioning, health plays a significant role in the improvement of production and can be seen as a primary benefit of preconditioning.

The study design used whereby the two cohorts of calves were bought on different dates, ensured the same feedlot environment for both the preconditioned and control calves. The alternative option would have been to purchase all calves at the same time in order to ensure that the two cohorts were similar in composition. However, this would have resulted in different feedlot environments. The present study was executed in such a way that all possible measures were taken to ensure that the two cohorts were as similar as possible in composition. Gender proportion differed significantly for the two cohorts, and therefore gender was always included in multivariable models to rule out confounding. The fact that the preconditioned and control groups were co-mingled ensured that the same disease dynamics and other environmental factors existed for both groups, including any possible errors in feeding practices, management changes, lack of water or weather changes which might have occurred.

### Effects of preconditioning on health

Calves in the PC group each received two vaccinations against BRD (MLV and bacterial vaccine) before entering the feedlot phase, compared with only one similar vaccination in the case of the C group. This represents an inherent advantage of the preconditioning practice. Calves in the C group never received a follow-up (booster) vaccination against BRD due to the comingling that took place after processing.

This study showed that the biggest effect seen of preconditioning is the significant protective effect on BRD morbidity: the pulling rate of preconditioned calves was more than 50% less than that of the control calves (8.3 vs 17.5%, Table 1). Additional to this, preconditioned calves that were pulled for BRD had a significantly better treatment response as seen by the lower 21 days re-pulling rate of preconditioned calves (8.0 vs 17.2%, Table 1). It is known that the more an animal is pulled the lesser the chances of it recovering. With a second occurrence of BRD additional production is lost due to lesser feed intake and poorer feed conversion (Smith 2000).

The study was done in a commercial feedlot and the researcher did not influence the slaughter dates of animals resulting in 241 animals that were enrolled into the study not being followed to slaughter. The time of marketing for these missing animals is not known, but occurred between the three recorded slaughter events or after the last event. It can be reasonably assumed that the subset of carcasses for which data were available was a representative sample of the total study group.

When pulling and re-pulling data are combined, it is evident that the number of antibiotic treatment doses given to the preconditioned calves was less than 50% of the number of antibiotic treatment doses given to the control calves (27/301 vs 68/332, $P < 0.01$). This suggests that preconditioning may allow the production veterinarian to decrease the use of antibiotics for BRD whilst improving health. This reduced usage of antibiotics decreases the risk for AMR developing within the feedlot (Blondeau 2000). The reduction in antibiotic usage also decreases the risk of antibiotics finding their way into the food chain and the environment, mitigating the risk of AMR in other species including humans. Other recent strategies to reduce the use of antibiotics in feedlots have focused mostly on improving the accuracy of pulling (Apley 2017), whereas preconditioning addresses the underlying causes of BRD, namely stress, immature immune systems, poor adaptation to a feedlot environment and high pathogen challenge (Smith 2000).

The preconditioned calves were not only pulled less frequently, but were pulled for BRD earlier than the calves that were placed directly in the feedlot (Table 1). Calves in the control group that were pulled lost significantly more liveweight from processing until they were pulled for the first time compared with the preconditioned calves (Table 1). It is possible that the preconditioned calves arrived with a subclinical, incubating infection at the feedlot and with the additional stress of loading, transport and co-mingling at the feedlot resulted in the manifestation of clinical BRD earlier, but of lower severity. The overall effect of preconditioning, lower stress and more robustly prepared calves (including their immune systems) may have resulted in the lower BRD incidence and BRD of lesser consequence when compared with the control calves. It has to be considered that the co-mingling of calves at the beginning of the study period in this case may have diluted the beneficial effect of preconditioning on health, due to the higher level of herd immunity in the preconditioned calves resulting in a decrease in the pathogen challenge to both groups (John *et al*. 2000). Further studies could investigate the effect of preconditioning on health where the disadvantage of higher challenge due to no co-mingling at feedlot entry (thus higher pathogen challenge) could be included in the study design. In other words, where the control calves are maintained in the same group throughout the feeding period.

In the authors' experience, the overall BRD incidence of 13% indicates that the BRD challenge was not high compared with industry standards over the winter period in South Africa. It is not known whether preconditioning will have the same proportionate effect on BRD incidence in a high morbidity setting; this requires repetition of the study under different conditions.

It has been shown that the way cattle are currently pulled in a feedlot is not adequate. A significant proportion of cattle ends up at the abattoir with lung lesions, but they have not been pulled in the feedlot (Thompson *et al*. 2006). In contrast, some calves that have been pulled have shown little or no lung pathology when slaughtered on the day of pulling (Apley 2017). The feedlot industry internationally is continuously looking at improving this, using methods such as intake and movement behaviour studies using electronic tags. They are all focused on the improvement of efficiency of pulling and improve animal welfare by reducing the time and degree of discomfort, but preconditioning is likely to addresses the most important stressors (weaning, co-mingling and nutrition) which are the major initial causative factors in developing BRD.

Preconditioning showed little effect on lung pathology and adhesions, possibly a result of the low overall BRD morbidity. Only a small proportion of carcasses had severe lung lesions, with the majority of lung lesions being scored 1 or 2. Although the presence of severe lung lesions (score >2) had an independent effect on DOF, as previously described in South Africa (Thompson *et al*. 2006), in the present study lung lesions were not associated with growth rate. Based on the lungs evaluated, the preconditioned calves had more mild lung adhesions than the control calves (Table 1), which is in contrast with the BRD incidence as defined by the pulling of sick calves in those groups. The higher observed proportion of mild lung adhesions in the preconditioned calves was likely a result of the earlier pulling of preconditioned calves as seen in the temporal distribution of clinical disease (Table 1).

Although the present study was not designed to measure the effects of preconditioning on welfare, it is evident that preconditioning improved the welfare of calves entering the feedlot due to the reduction in BRD incidence and retreatments. Freedom of disease, being one of the measures of welfare (https://www-avma-org.uplib.idm.oclc.org/KB/Resources/Reference/AnimalWelfare/Pages/what-is-animal-welfare.aspx, accessed 24 July 2017), was improved by preconditioning independently of the effects of gender and in weight, as shown in the logistic regression model of pulling. Although stress of the calves was not measured directly in this study, it can be assumed that reduced stress in the preconditioned calves was at least partly responsible for the reduction in BRD incidence.

The negative economic impact BRD has on production is well described (Speer *et al*. 2001). The reduction in the incidence and degree of BRD has an economic advantage. With less cattle needing pulling, less labour hours are necessary to pull, treat and manage sick cattle which decreases the health associated expenses to the feedlot. Apart from this, the economic advantage lies in lower medicine inventory of antibiotics and possible ancillary treatments, interest on loaned facilities (if applicable), reduced DOF and indirectly through improved growth rate due to the energy draining effects of BRD (Gifford *et al*. 2012). This was demonstrated very clearly in the present study, where preconditioning was associated with lower BRD incidence, shorter DOF and higher final carcass weights.

**Effects of preconditioning on production**

Production in a feedlot is traditionally measured as the rate of gain (ADG) based on liveweight (Owen *et al*. 1995). Owen (1995) indicated that there is a difference in liveweight gain and gain based on carcass. Since it is the carcass that is sold in the South African feedlot industry and production economics are measured ideally through carcass weights and quality, this study measured the production effect of preconditioning on a carcass basis. In order to obtain a CW at processing a formula was developed to calculate CW in kg based on the shrunk liveweight. Our method of calculation has not been described before and made production measurements on carcass basis possible.

Carcass growth rate in the PC group was 23% higher than in the C group (Table 1) and this effect of preconditioning on carcass growth rate was independent of the effects of gender, initial weight and pulling for BRD (Table 2). This indicates that preconditioning in our study resulted in improved carcass growth rate due to the effects on health, but also for reasons other than the effects on health. These reasons most likely include higher feed intake due to reduced stressors (weaning and co-mingling), and faster adaptation to the feed bunks (Hutcheson and Cole 1986). However, it may be that the additional increased growth rate seen in the PC group in this study (not explained by pulling for BRD) was due to compensatory growth if growth during the preconditioning period was regulated. Unfortunately, the data to rule out compensatory growth as mechanism was not available.

When cattle selected by market readiness, as it was done in this study, preconditioned calves were market ready at an earlier time than the control group (Tables 1, 3). Of the calves that were followed to slaughter, 89% of the PC group and only 67% of the C group were slaughtered at the first event (before 90 DOF), whereas 2% of preconditioned calves and 10% of control calves were slaughtered at the last event ($P < 0.01$, Table 1). Cattle that were preconditioned were therefore market ready earlier, which means they could be replaced by other calves for fattening. Based on this study, the inventory in the feedlot can potentially be turned 4 times per year (90 DOF) versus three times (120 DOF) as is commonly the case in the South African feedlot industry. This increased turnover (due to shorter DOF) potentially has a beneficial effect on the contribution towards overheads by each marketable carcass.

Preconditioning increases carcass gain via its positive effect on the rate of gain (ADG). Preconditioning was not positively associated with carcass gain independent of its effect on growth rate, indicating that increased growth rate was the mechanism through which preconditioning resulted in increased carcass gain. This was shown when ADG was added in the multiple regression model of carcass gain (Table 4) resulting in a significant change in the coefficient for preconditioning which means that the effect of preconditioning on carcass gain was confounded by ADG. In the current study the effect of preconditioning on carcass gain resulted in 17.7 kg more sellable meat after adjusting for gender and DOF (Table 4).

DOF was the independent predictor that had the biggest effect on carcass gain (Table 4), whereas preconditioning and growth rate were independently associated with a reduced DOF. Preconditioning however increased carcass gain in spite of its negative effect on DOF.

This implies a 3-fold economic advantage of preconditioning: in the first and second instances the economic impact of reduced BRD incidence and reduced DOF potentially results in a significant decrease in cost; and in the third instance increased carcass gain and heavier sellable carcass was achieved in preconditioned calves which will increase the income of the feedlot.

Although the data of the present study did not allow us to determine if the independent effect of preconditioning on weight gain (not related to BRD incidence) was a result of better adaptation and better feed intake, or a result of compensatory growth, it is interesting to note that the effect of preconditioning on carcass growth rate (+200 g/day) as well as on CW gain (+17.7 kg) was bigger than the effect of gender (Table 4). Irrespective of the cause, the known negative correlation between ADG and feed conversion ratio (Nkrumah *et al*. 2004) can lead to the logical assumption that the beneficial effect of preconditioning may in fact be the result of improved efficiency of growth in the feedlot.

It is concluded that preconditioning of feedlot calves has the potential to reduce the use of antibiotics and also to economically benefit South African feedlots by decreasing losses associated with BRD, decreasing DOF and increasing carcass gain.

## Conflicts of interests

The authors declare no conflicts of interest.

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