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Factors affecting foal birth weight in Thoroughbred horses

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Abstract

Foaling data from 348 Thoroughbred foals born on a commercial stud were analysed to investigate interrelationships among mare age, parity, gestation length, foal sex, placental weight, and foal birth weight. Placental weight was positively correlated with foal birth weight up to a threshold of 6.5 kg; above this, placental weight was not significantly associated with foal birth weight. Placental weight was assessed, including the amniotic membranes and umbilical cord as well as the allantochorion. Using path analysis, parity was positively associated with foal birth weight both directly and through increased placental weights, but age was not directly related to foal birth weight. Over the range of gestation lengths observed, gestation length was not significantly associated with foal birth weight. We conclude that, in populations represented by this study population, either placental weights up to 6.5 kg are rate-limiting for foal birth weight or placental weight increases with foal birth weight up to this threshold. However, further increases in placental weight are not associated with additional increases in foal birth weight. The positive association between parity and foal birth weight is mediated through increased placental weight as well as other pathways. Age is not directly related to foal birth weight and gestation length is not strongly associated with foal birth weight.

Keywords: Foal; Birth weight; Mare parity; Gestation; Placenta

1. Introduction

Foal birth weights are perceived to be important within the commercial Thoroughbred industry of Australia, as foal birth weight is commonly thought to be positively associated with size as yearlings. Although the relationship between foal birth weight and birth height has not been described, Reed and Dunn [1] reported a significant positive correlation between birth height and mature height and concluded that birth height could be used as an accurate predictor of mature height. The general industry perception is that larger yearlings usually sell for higher prices than smaller yearlings, because of expected superior racing performance. Withers height and hip height of yearlings are positively correlated with lifetime earnings, Standard Starts Index and winning percentage [2] and body length and heart girth of yearlings are positively correlated with Standard Starts Index and winning percentage [2].

Placental and foal birth weights are routinely recorded on many stud farms. However, the relationship between these two measurements has not been investigated in Australian Thoroughbred horses. Positive linear relationships between placental weight and foal birth weight have been reported in horse populations from the United Kingdom and the USA [3–6]. Both age and parity have been positively correlated with both foal birth weight and

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placental weight [3–8]. However, the effects of gestation length on foal birth weight and placental weight have received little attention. In a study conducted in southern Brazil, there was no relationship between gestation length and foal birth weight [9]. Other than this report, all other studies were conducted in the northern hemisphere. Due to differences in climate, rainfall, seasonality and management procedures, the applicability of these relationships to Australian Thoroughbreds requires investigation.

Most studies assessing placental and birth weights have used univariable analyses [3–12]. Results of univariable analyses can be biased due to confounding. Multivariable techniques, such as stratification and multivariable regression, can be used to control for confounding [13]. Control of confounding is essential for correct understanding of determinants of placental weight and foal birth weight. Path analysis, an extension of multivariable regression, could also result in better understanding of the likely complex interrelationships between mare age, parity, gestation length, foal sex and placental weight and foal birth weight. This technique has not been previously applied in this area but has proven useful for understanding causation of multi-factorial conditions such as lameness [14] and reproductive events [15] in dairy herds.

The most widely used method for determining placental weight within the Australian Thoroughbred industry involves weighing the entire placenta, along with the amnion and umbilical cord. This differs from the accepted research method of removing the amnion and umbilical cord prior to weighing, i.e. only weighing the allantochorion. Most studies assessing placental weight have used the latter method [3–6,11,12]. The nature of the association between placental weight and birth weight may differ between the two methods of assessing placental weight. If the relationship between placental weight and birth weight was described using the standard industry method of weighing placentas, stud veterinarians may be better able to relate the results of research studies to field observations.

The aims of the current study were to investigate the interrelationship between placental weight and foal birth weight, and to investigate interrelationships among mare age, parity, gestation length, foal sex and placental weight and foal birth weight in horses at a commercial Thoroughbred stud in Australia.

2. Materials and methods

A retrospective cohort study was conducted on one large Thoroughbred stud located in the Hunter Valley of New South Wales, Australia (32°30′ latitude; 150°50′ longitude approximately) during the 2006 breeding season (August–December). All foals that were born alive and did not die within 48 h after birth during the 2006 breeding season were enrolled. This resulted in a total of 348 foals and their respective mares being included in the study. Long-term average annual rainfall for this region of Australia was 639.4 mm, with monthly averages for the breeding season ranging from 36.6 mm in August to 67.5 mm in December. Average maximum daily temperatures for the breeding season ranged from 19.4 °C in August to 31.4 °C in December. Average minimum daily temperatures for the breeding season ranged from 4.4 °C in August to 15.7 °C in December. Photoperiod for the breeding season ranged from an average of 7.3 h of sunshine daily in August, to an average of 8.7 h of sunshine daily in December [16].

Each foaling was supervised by an experienced attendant. Foals were allowed to suckle and to remain with their dam for at least 2 h to allow bonding and were weighed when between 2 and 12 h of age. The foal was held by the foaling attendant whilst standing on a set of scales (Tru-Test scales, Model 702, Tru-Test Limited, Auckland, New Zealand). This gave a combined weight, from which the attendant's weight was subtracted giving the actual foal birth weight, which was recorded to the nearest kilogram. All placentas were retrieved by the foaling attendant at the completion of Stage 3 of labour. The entire placenta including the umbilical cord and amnion was placed into a bucket and weighed to the nearest half kilogram. The placental weight was then calculated by subtracting the weight of the bucket.

Data collected about each mare included service date, foaling date, mare age at foaling and parity at foaling (when mares produced their first foal during the study period, this was recorded as Parity 1). Gestation length for each foaling was calculated in days as foaling date minus the last recorded service date. Service dates were confirmed against the official records of the Australian Stud book, as were mare age and parity.

Descriptive statistics were calculated using Microsoft Excel 2003 Office edition (Microsoft Corporation, Redmond, WA, USA). Putative associations were then assessed using univariable and multivariable linear regression using Stata version 9.2 (StataCorp, College Station, TX, USA). For path analysis, a null hypothesis model was developed (Fig. 1) based on previous research results [3–12] and plausible temporal sequences of events. Foal sex was not included in the null model, as sex was not significantly associated with either foal birth weight or placental weight in the univariable analyses. Each variable in the null hypothesis model was, in turn,

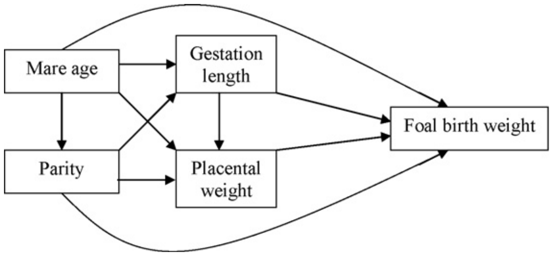

Fig. 1. Null hypothesis of path model for interrelationships among mare age, parity, gestation length, placental weight, and foal birth weight in Thoroughbred horses.

regressed on all directly preceding variables under the null hypothesis path model, using a series of linear regression models. Where more than one directly preceding variable was fitted, these linear regression models were built using backwards elimination, until all remaining preceding variables were significantly ($P \leq 0.05$) associated with the dependent variable. Postulated paths that were not significant ($P > 0.05$) in these linear regression models were removed from the path model. The relationship between placental weight and foal birth weight was modelled using piecewise nonlinear regression, with slopes for both 'pieces' and the second intercept variable in the model [17]. The placental weight at the threshold point for the piecewise regression was estimated using nonlinear least squares regression with Stata's *nl* command. From this model, the estimated placental weight at the threshold point was 6.43 kg (95% confidence interval (CI) 5.91, 6.95). The exposure variables age, parity and gestation length were categorised for descriptive purposes, but were treated as continuous variables in regression analyses.

3. Results

3.1. Study population

In total, 348 foals were born live on the farm during the 2006 breeding season and all were enrolled in the study. A further eight foals were stillborn or died shortly after birth and thus were ineligible for enrollment in the study. Placentas were collected and weighed for all study births.

The mean birth weight of study foals was 55.2 kg (S.D. 7.1 kg; range 29.0–75.0 kg). Of the 348 study foals, 170 were colts and 178 were fillies. Mean and standard deviation of birth weights for colts and fillies were 55.8 ± 7.2 kg and 54.7 ± 7.0 kg, respectively. Mean ($\pm$S.D.) weight for all placentas was 6.4 ± 1.4 kg (range 3.0–14.0), with 6.38 ± 1.39 and 6.37 ± 1.49 kg for male and female foals, respectively. Neither foal birth weight nor placental weight were significantly associated with foal sex on univariable analysis ($P = 0.166$ and 0.559, respectively).

3.2. Univariable relationship between placental weight and foal birth weight

The relationship between placental weight and foal birth weight is shown (Fig. 2). There was a strong positive relationship ($P < 0.001$) between the two variables, up to approximately 6.5 kg of placental weight. For every 1 kg increase in placental weight, there was a 4.5 kg increase in foal birth weight (95% CI 3.2–5.9; $P < 0.001$). At higher placental weights, the relationship reached a plateau, with negligible change in foal weight with increasing placental weights (estimated change −0.04; 95% CI −1.04 to 0.96; $P = 0.936$).

3.3. Mare age

Descriptive statistics to explore the univariable associations between mare age at foaling and both foal birth weight and placental weight are shown (Table 1). On univariable analysis, both foal birth weight and placental weight were associated with age ($P < 0.001$ and $P = 0.044$, respectively). For every extra year of age, foal birth weight increased by 0.5 kg (95% CI 0.3–0.7) and placental weight increased by 0.04 kg (95% CI 0.00–0.08).

3.4. Mare parity

Descriptive statistics to explore the univariable associations between mare parity at foaling and both

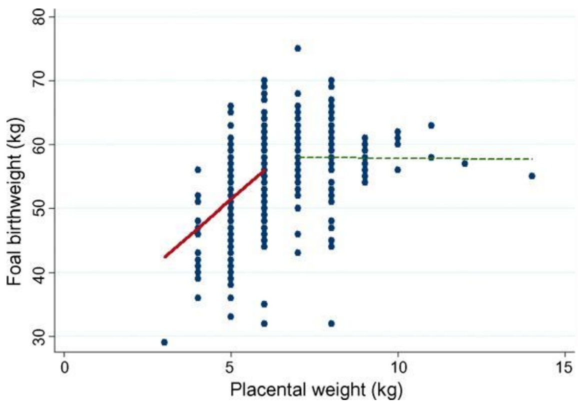

Fig. 2. Univariable relationship between placental weight and foal birth weight for 348 Thoroughbred foalings on a commercial Australian stud.

Table 1
Univariable associations between mare age and both foal birth weight and placental weight for 348 Thoroughbred foalings from a commercial Australian stud (mean ± S.D.).

	Mare age (years)				
	4–6	7–9	10–12	>12	All ages
No. foals	79	110	84	75	348
Foal weight (kg)	51.6 ± 6.4	54.3 ± 6.4	57.4 ± 5.9	57.8 ± 7.3	55.2 ± 7.1
Placental weight (kg)	6.2 ± 1.5	6.2 ± 1.4	6.6 ± 1.4	6.6 ± 1.4	6.4 ± 1.4

Table 2
Univariable associations between mare parity and both foal birth weight and placental weight for 348 Thoroughbred foalings from a commercial Australian stud (mean ± S.D.).

	Mare parity				
	1 (maiden)	2–4	5–7	>7	All parities
No. foals	74	143	82	49	348
Foal weight (kg)	49.6 ± 6.6	55.8 ± 6.0	58.1 ± 6.6	57.3 ± 7.2	55.2 ± 7.1
Placental weight (kg)	5.7 ± 1.3	6.5 ± 1.4	6.7 ± 1.6	6.4 ± 1.2	6.4 ± 1.4

foal birth weight and placental weight are shown (Table 2). On univariable analysis, both foal birth weight and placental weight were associated with parity ($P < 0.001$ and $P = 0.012$, respectively). For every extra foaling, foal birth weight increased by 0.8 kg (95% CI 0.5–1.0) and placental weight increased by 0.06 kg (95% CI 0.01–0.12).

3.5. *Mare age and parity combined*

Because mare age and parity were associated, to further explore the effects of mare age independently of parity and vice versa, mare age was also analysed within parity group using stratification (Table 3). There was a large increase in mean foal birth weight from maidens

Table 3
Associations between mare parity, mare age and foal birth weight in 348 Thoroughbred foalings from a commercial Australian stud (mean ± S.D.).

Parity	Mare age (years)				
	4–6	7–9	10–12	>12	All ages
1 (maiden)					
No. foals	48	22	3	1	74
Foal birth weight (kg)	49.4 ± 6.3	48.4 ± 6.5	59.0 ± 5.1	57.0 ± n/a	49.6 ± 6.6
2–4					
No. foals	31	82	24	6	143
Foal birth weight (kg)	55.0 ± 5.1	55.5 ± 6.3	57.6 ± 5.8	55.2 ± 7.7	55.8 ± 6.0
5–7					
No. foals		6	53	23	82
Foal birth weight (kg)		60.7 ± 5.2	57.1 ± 6.3	59.7 ± 7.1	58.1 ± 6.6
>7					
No. foals			4	45	49
Foal birth weight (kg)			58.5 ± 2.3	57.2 ± 7.4	57.3 ± 7.2
All parities					
No. foals	79	110	84	75	348
Foal birth weight (kg)	51.6 ± 6.4	54.3 ± 6.4	57.4 ± 5.9	57.8 ± 7.3	55.2 ± 7.1

n/a: not applicable.

to 2–4th parity mares within the age groups of 4–6- and 7–9-year-mares, but within parity categories, mean foal birth weights were similar across different age categories.

With multivariable modelling, after adjusting for parity, mare age was no longer significantly associated with foal birth weight ($P = 0.628$; β-coefficient 0.1; 95% CI −0.3 to 0.5). Parity, however, remained significantly associated with foal birth weight ($P = 0.007$). After adjusting for age, every extra foaling was associated with an increase of 0.7 kg in foal birth weight (95% CI 0.2–1.1). After fitting mare age and parity, neither mare age nor parity were significantly associated with placental weight ($P = 0.829$; β-coefficient −0.01; 95% CI −0.08 to 0.07 and $P = 0.132$; β-coefficient 0.08; 95% CI −0.02 to 0.18, respectively).

3.6. Gestation length

Descriptive statistics to explore the univariable association between gestation length and both foal birth weight and placental weight are summarised (Table 4). There was little difference in both foal birth weights and placental weights between gestation length categories. On univariable analyses, there was no significant association between gestation length and foal birth weight ($P = 0.781$; estimated change for every extra 10 d of gestation −0.1; 95% CI −0.7 to 0.5). There was also no significant univariable association between gestation length and placental weight ($P = 0.133$; estimated change for every extra 10 d of gestation −0.09; 95% CI −0.22 to 0.03). Estimated effects of gestation length on both foal birth weight and placental weight were similar after adjusting for mare age and parity simultaneously. Adjusted estimates for the effects of every extra 10 d of gestation on foal birth weight and placental weight were −0.3 (95% CI −0.9 to 0.3; $P = 0.310$) and −0.12 (95% CI −0.24 to 0.01; $P = 0.076$), respectively.

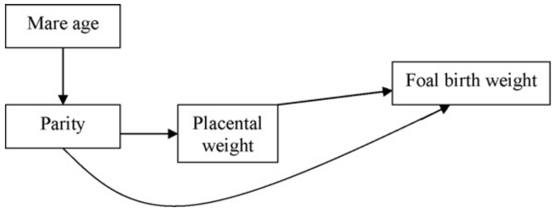

Fig. 3. Final path model of interrelationships among mare age, parity, placental weight and foal birth weight for Thoroughbred foals.

3.7. Path model

The final path model is shown (Fig. 3) and β-coefficients, associated 95% CIs and P-values for associations in the final model are shown (Table 5).

Parity increased significantly with age and age explained 72.1% of the variation in parity. Gestation length did not change significantly with parity after adjusting for age ($P = 0.109$), but increased with age on univariable analysis ($P = 0.001$; estimated increase for each additional year of age 0.6 d; 95% CI 0.2–0.9).

Table 4
Univariable associations between gestation length and both foal birth weight and placental weight for 348 Thoroughbred foalings from a commercial Australian stud (mean ± S.D.).

	Gestation length (d)						
	≤320	321–330	331–340	341–350	351–360	>360	All gestation lengths
No. foals	6	28	113	145	42	14	348
Foal weight (kg)	50.0 ± 12.1	52.2 ± 8.1	56.0 ± 6.3	55.6 ± 6.7	55.45 ± 7.7	52.28 ± 9.3	55.2 ± 7.1
Placental weight (kg)	6.5 ± 1.5	6.3 ± 1.4	6.4 ± 1.4	6.5 ± 1.5	6.1 ± 1.2	5.9 ± 1.1	6.4 ± 1.4

Table 5
β-coefficients and associated 95% CIs and P-values for associations in a final path model of mare age, parity, placental weight and foal birth weight assessed using data from 348 Thoroughbred foalings in a commercial Australian stud.

Dependent variable	Exposure variable	Adjusted for	β-coefficient (95% CI)	P
Parity	Mare age	No other variables	1.1 (1.0 to 1.2)	<0.001
Placental weight	Parity	No other variables	0.07 (0.01 to 0.12)	0.012
Foal birth weight	Parity	Placental weight	0.6 (0.3 to 0.8)	<0.001
Foal birth weight	Placental weight	Parity	Placental weight	
			≤6.5 kg: 4.0 (2.6–5.3)	<0.001
			>6.5 kg: 0.0 (−0.9 to 1.0)	0.956

When modelling effects of age, parity and gestation length on placental weight, mare age then gestation length were removed from that linear regression model, as these were not significantly associated with placental weight ($P > 0.05$). On univariable analysis, placental weight increased with parity (estimated increase with every extra foaling 0.07 kg).

When modelling effects of placental weight, mare age, parity and gestation length on foal birth weight, gestation length then mare age were removed from that linear regression model. As there was then no direct or indirect path from gestation length to foal birth weight, gestation length was removed from the path model. After adjusting for placental weight, foal birth weight increased with parity (estimated increase for each additional foaling 0.6 kg). After adjusting for parity, foal birth weight increased with placental weight with similar estimates to those observed on univariable analysis. Parity and placental weight explained 24.2% of the variation in foal birth weight.

4. Discussion

We infer that, in populations similar to the study population, placental weight may be rate-limiting for foetal growth up to a threshold of approximately 6.5 kg. Alternatively, placental weight increases with fetal size up to this threshold. At higher placental weights, placental weight does not appear to be rate-limiting for fetal growth, with further increases in placental weight not associated with commensurate increases in fetal size. Several previous studies have reported a positive linear association between placental weight and foal birth weight [3–6]. These studies assumed a linear relationship across all placental weights, whereas results of the present study suggested a threshold point, above which placental weight no longer influenced foal birth weight. Placental weight was measured in the current study using the usual commercial method of weighing the entire placenta along with the amnion and umbilical cord, rather than the usual research method of weighing only the allantochorion. Future studies are required to analyse the relationship between combined allantochorion, amnion and umbilical cord weight and allantochorion weight alone. If these are closely correlated, this would indicate that the observed nonlinear relationship between placental weight and birth weight is similar, regardless of which method of assessing placental weight is used.

Age and parity in commercial mares are closely related, as these mares are usually managed with the objective of producing one foal every year. Numerous studies, including the current study, found both age and parity to be significantly associated with foal birth weight when using univariable analysis [3–8]. However, due to the close relationship between age and parity, observed associations with age may be confounded by effects of parity. In the current study, we eliminated this bias using both stratification and multivariable regression. Based on these analyses, we conclude that parity rather than age influences foal birth weight and placental weight. The largest effect of parity on foal birth weight was between maiden mares' foals and second parity mares' foals. Perhaps the equine uterus needs to be in some way ''primed'' by a first pregnancy before it can achieve its full potential in terms of facilitating foetal growth [6,12]. The conclusion that parity has more influence than age on foal birth weight was alluded to by Wilsher and Allen [4]. These workers proposed that parity was more important in determining foal birth weight than maternal age, due to primiparous placentas having reduced microcotyledon surface densities, coupled with reduced chorionic volumes, resulting in less total available area for haemotrophic exchange of nutrients and gases. In a study of 84 commercial Thoroughbred foals, primiparous mares had significantly smaller foals than multiparous mares [6]. Primiparous mares also had significantly lower allantochorion mass than multiparous mares, with placental weight tending to increase with parity and then reaching a plateau in multiparous mares aged 10–15 years. Interestingly, placental weight did not significantly increase between first and second parities in the same mare [6].

The negligible effect of gestation length on foal birth weight is in agreement with the only other study that we aware are of that has investigated this relationship [9]. The current study also demonstrated that gestation length has no substantial effect on placental weight. To our knowledge, this is the first time that the relationship between gestation length and placental weight has been investigated.

These findings clearly demonstrate an important relationship between placental weight and foal birth weight, but neither age nor gestation length appear to have strong effects on placental weight. Placental weight increased with parity, but further studies are required to identify additional determinants of placental weight.

With 348 foals enrolled, this study was relatively large. Although large numbers of horses were enrolled in studies by Kurtz Filho et al. [9] and Hintz et al. [10] (who studied 390 and 1992 foals, respectively), most studies in this area have enrolled less than 110 foals [3–8,11,12]. However, the current study was conducted in a single breeding season on one stud farm. This design had the advantage of minimising or eliminating variation in climatic conditions, management practices and data recording over time, all of which may potentially cause confounding and/or affect data quality, particularly in studies conducted over many years. Notwithstanding, because this study was conducted on only one commercial Thoroughbred stud, confidence in extrapolating these results to other populations is reduced. A follow-up study, using the same population of mares comparing consecutive foalings, would improve confidence when extrapolating these results. So too would further studies using this design conducted on different farms both in Australia and in the northern hemisphere.

We conclude that, in populations represented by this study population, either placental weights up to 6.5 kg are rate-limiting for foal birth weight or placental weight increases with foal birth weight up to this threshold, but further increases in placental weight are not associated with additional increases in foal birth weight. The positive association between parity and foal birth weight is mediated through increased placental weight, as well as other pathways. Neither mare age nor gestation length are strongly associated with foal birth weight.

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