A National Census of Birth Weight in Purebred Dogs in Italy

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Academic Editor: Clive J. C. Phillips
Received: 23 March 2017; Accepted: 27 May 2017; Published: 30 May 2017

Simple Summary: Birth weight is a key factor for neonatal mortality and morbidity in most mammalian species. The great morphological variability in size, body weight and breed, as well as in skeletal and cranial conformation makes it challenging to define birth weight standards in dogs. A total of 3293 purebred pups were surveyed to study which maternal aspects can determine birth weight considering head and body shape, size, body weight and breed in bitches, as well as litter size and sex in pups. In our sample, multivariate analysis outcomes suggested that birth weight and litter size were directly proportional to maternal size. The maternal body shape influenced both birth weight and litter size, whereas the maternal head shape had impact only on birth weight. Sex differences in birth weight were found. Birth weight and litter size also varied among breeds. The results of the present study could have practical implications allowing one to identify pups in need of admission to intensive nursing care, as occurs in humans. A deeper knowledge of the factors that significantly influence birth weight could positively affect the canine breeding management helping to prevent and reduce neonatal mortality.

Abstract: Despite increasing professionalism in dog breeding, the physiological range of birth weight in this species remains unclear. Low birth weight can predispose to neonatal mortality and growth deficiencies in humans. To date, the influence of the morphotype on birth weight has never been studied in dogs. For this purpose, an Italian census of birth weight was collected from 3293 purebred pups based on maternal morphotype, size, body weight and breed, as well as on litter size and sex of pups. Multivariate analysis outcomes showed that birth weight ($p < 0.001$) and litter size ($p < 0.05$) increased with maternal size and body weight. Birth weight was also influenced by the maternal head and body shape, with brachycephalic and brachymorph dogs showing the heaviest and the lightest pups, respectively ($p < 0.001$). Birth weight decreased with litter size ($p < 0.001$), and male pups were heavier than females ($p < 0.001$). These results suggest that canine morphotype, not only maternal size and body weight, can affect birth weight and litter size with possible practical implications in neonatal assistance.

Keywords: birth weight; dog; morphometry

1. Introduction

Birth weight has an important effect on fetal and neonatal health in humans. Due to their immature development and adaptive postnatal failure, underweight babies are prone to potential
complications, especially impaired thermoregulation and hypoglycemia [1]. Therefore, they are susceptible to mortality and morbidity, developing cerebral palsy, hyaline membrane disease, apnea, intracranial hemorrhage, sepsis, retrolental fibroplasia, growth and neurocognitive deficiencies [2]. Low birth weight can result from either a short gestation period or retarded intrauterine growth (or a combination of both) [2] as reported for humans and animals of many polytocous species, including dogs [3]. Based on evidence of embryo transfer studies in the human, horse and sheep, the intrauterine environment in which the fetus develops seems to exert a profound effect on birth weight, suggesting a central maternal role in determining the birth weight [4]. Anthropometric parameters, mainly head circumference, provide an indirect measure of low birth weight in babies and may thus be of prognostic significance [5,6]. Moreover, maternal factors such as height and weight of the woman are positively related with term fetal weight [2,7,8]. The same implication could be assumed in the canine species.

Due to the wide phenotypic variability among breeds, dogs offer a unique opportunity to study correlations between morphology and birth weight. In fact, there are 337 breeds of domestic dogs (Canis familiaris) recognized by the Fédération Cynologique Internationale (FCI). Bench standard defines the ideal characteristics for each breed including size (height at withers), body weight and morphometry of the adult dogs, while no specific information on the birth weight is provided. To date, despite a large number of studies on the puppy growth chart [9], the influence of the morphotype on birth weight has never been studied in dogs. The cephalic index or cranial index is the ratio between maximum width and length of the skull of an organism (human or animal). This index is used to classify animals into three groups: brachycephalic, mesocephalic and dolichocephalic [10]. Similarly, the relationship between height at withers and thoracic conformation determines the division of dog breeds into brachymorph, mesomorph, dolichomorph and anachlicomorph type [11,12].

The pursuit of an optimal model to classify the purebred dog still represents an important goal for scientific purposes. This study for the first time correlates birth weight with phenotypic aspects in purebred dogs, namely considering the impact of different morphometric characteristics. The objective of the study was to detect which parameters can influence the birth weight of pups and the litter size among maternal morphotype (head and body shape), size (height at withers) and body weight (BW). An exploratory investigation of the influence of breed on birth weight was conducted in selected groups of dogs with the same morphotype.

2. Materials and Methods

This study is based on data collected through an on-line questionnaire administered to Italian dog breeders from February 2014–September 2015 in the context of a national census promoted by the Università degli Studi di Milano in collaboration with the Ente Nazionale della Cinofilia Italiana (ENCI) to register the birth weight in the Italian purebred dog population. Participation in the questionnaire was freely decided by the breeders. In this case, the approval of the Ethics Committee does not apply.

A large-scale prospective study to survey the birth weight (body weight of pups at birth (bBW)) of 3293 pups from a sample population of 588 purebred bitches of 99 breeds from a population of 154,195 dogs in Italy (see Appendix A) was performed (Table 1). Litter size, breed, as well as birth weight and sex of pups were recorded by the census. Maternal data, such as head shape (cranial index), body shape, size (height at withers) and body weight, were taken from FCI, ENCI and kennel clubs.
Table 1. Distribution of the bitches based on their breed, morphotype, size, body weight and the corresponding number of litters and pup birth weight.

| Breed                          | Head Shape | Body Shape | Size | BW | Np | Nk | Np | Nk | Np | Nk | Np | Nk | bBW |
|-------------------------------|------------|------------|------|----|----|----|----|----|----|----|----|----|-----|
| Afghan Hound                  | D          | D          | 4    | 3  | 2  | 12 | 2  | 6  | 5.5| 6.5| 500| 480| 562.5|
| Akita Inu                     | M          | M          | 3    | 4  | 9  | 57 | 4  | 6  | 5  | 8  | 401| 367| 420 |
| Alaskan Malamute              | M          | M          | 3    | 4  | 2  | 15 | 2  | 7.5| 7.25| 7.75| 468| 429| 695 |
| American Akita                | M          | M          | 4    | 4  | 2  | 14 | 2  | 7  | 7  | 7  | 576| 494.5| 695 |
| American Cocker               | M          | M          | 2    | 3  | 3  | 17 | 2  | 6  | 5.5| 6  | 200| 160| 220 |
| American Staffordshire T.     | M          | M          | 3    | 4  | 1  | 1  | 1  | 1  | 1  | 1  | 500| 500| 500 |
| Appenzeller Mountain dog      | M          | M          | 3    | 3  | 4  | 22 | 2  | 5.5| 4.5| 6.5| 357| 321.2| 424.5|
| Australian Shepherd           | M          | M          | 3    | 3  | 7  | 50  | 6  | 7  | 6.5| 8  | 350| 320| 390 |
| Basset Hound                  | M          | A          | 2    | 3  | 7  | 51  | 3  | 7  | 5.5| 9  | 448| 350| 510 |
| Beagle                        | M          | M          | 2    | 3  | 4  | 28  | 4  | 7.5| 6.5| 8  | 303.5| 278.8| 352.8|
| Bearded Collie                | M          | M          | 3    | 3  | 1  | 6  | 1  | 6  | 6  | 6  | 395| 371.8| 403.2|
| Beauceron                     | D          | M          | 4    | 4  | 1  | 6  | 1  | 6  | 6  | 6  | 535| 523.8| 542.5|
| Belgian Shepherd dog          | M          | M          | 3    | 4  | 5  | 31  | 2  | 7  | 5  | 8  | 425| 387.5| 460 |
| Bernese Mountain dog          | M          | M          | 3    | 3  | 7  | 50  | 6  | 7  | 6.5| 8  | 350| 320| 390 |
| Bichon Havanais               | M          | M          | 2    | 1  | 8  | 37  | 3  | 4.5| 3.75| 6  | 195| 165| 215.5|
| Black Russian Terrier         | M          | M          | 4    | 5  | 1  | 8  | 1  | 8  | 8  | 8  | 475| 457.5| 491.2|
| Bolognese                     | M          | M          | 2    | 1  | 3  | 10  | 3  | 3  | 2.5| 4  | 137.5| 130| 145.5|
| Border Collie                 | M          | M          | 3    | 3  | 13 | 83  | 10 | 7  | 5  | 7  | 350| 300| 378 |
| Border Terrier                | M          | M          | 2    | 2  | 1  | 5  | 1  | 5  | 5  | 5  | 193| 190| 200 |
| Borzoi                        | D          | D          | 4    | 4  | 1  | 11 | 1  | 11 | 11 | 11 | 446| 390.5| 480.5|
| Boston Terrier                | B          | M          | 2    | 2  | 8  | 20  | 3  | 3  | 1.75| 3  | 200| 178| 226 |
| Bouledogue                    | B          | B          | 2    | 3  | 9  | 46  | 4  | 5  | 4  | 6  | 184| 150.2| 235.8|
| Bouvier des Flandres          | M          | M          | 3    | 4  | 2  | 16  | 1  | 8  | 8  | 8  | 463.5| 438.5| 500 |
| Boxer                         | B          | M          | 3    | 4  | 12 | 82  | 10 | 8  | 4.75| 9  | 449.5| 400| 410 |
| Bracco Italiano               | M          | M          | 3    | 4  | 1  | 10 | 1  | 10 | 10 | 10 | 405| 400| 410 |
| Brussel Griffon               | B          | M          | 2    | 1  | 2  | 11  | 2  | 7  | 7  | 7  | 120| 106.5| 135 |
| Bulldog                       | B          | B          | 2    | 3  | 9  | 32  | 6  | 3  | 2  | 4  | 316| 280| 368.8|
| Bullmastiff                   | B          | M          | 4    | 5  | 3  | 22  | 3  | 7  | 6  | 8.5| 597.5| 579.2| 630 |
| Bull Terrier                  | M          | M          | 2    | 3  | 4  | 25  | 4  | 7  | 4.25| 9  | 330| 273.0| 350 |
| Cane Corso                    | B          | M          | 3    | 4  | 4  | 30  | 4  | 6.5| 6  | 8  | 494| 437| 682.5|
| Caucasian Shepherd Dog        | M          | M          | 4    | 5  | 1  | 5  | 1  | 5  | 5  | 5  | 720| 680| 730 |
| Cavalier King Charles Spaniel | B          | M          | 2    | 2  | 10 | 46  | 8  | 4.5| 3.25| 5.75| 230| 216| 252 |
| Chihuahua                     | B          | M          | 1    | 1  | 19 | 57  | 12 | 3  | 2  | 4  | 140| 111.5| 160 |
| Chinese Crested Dog           | M          | M          | 2    | 1  | 10 | 31  | 3  | 2.25| 3.75| 3.55| 155| 118.8| 176.2|
Table 1. Cont.

| Breed                                      | Head Shape | Body Shape | Size | BW  | Nb | Np  | Ng  | bBW  |
|--------------------------------------------|------------|------------|------|-----|----|-----|-----|------|
| Chow Chow                                  | M          | M          | 3    | 4   | 17 | 71  | 3   | 4    |
| Cirneco dell’Etna                         | M          | M          | 3    | 2   | 2  | 12  | 2   | 6    |
| Epagneul Nain Continental Papillon         | M          | M          | 2    | 1   | 5  | 18  | 5   | 7    |
| Czechoslovakian Wolfdog                    | M          | M          | 3    | 4   | 3  | 20  | 3   | 7    |
| Dalmatian                                  | M          | M          | 3    | 3   | 4  | 36  | 3   | 9    |
| Deerhound                                  | M          | M          | 4    | 4   | 1  | 6   | 1   | 6    |
| Doberman                                   | D          | M          | 4    | 4   | 7  | 56  | 6   | 9    |
| Dogue de Bordeaux                          | B          | M          | 3    | 5   | 1  | 8   | 1   | 8    |
| Drahthaar                                  | M          | M          | 3    | 4   | 1  | 9   | 1   | 9    |
| Dachshund                                  | M          | A          | 1/2  | 2   | 14 | 59  | 11  | 4    |
| English Cocker Spaniel                     | M          | M          | 2    | 3   | 17 | 96  | 5   | 5    |
| English Pointer                            | M          | M          | 3    | 3   | 2  | 7   | 2   | 3.5  |
| English Setter                             | M          | M          | 3    | 3   | 5  | 32  | 2   | 6    |
| Entlebucsher Mountain Dog                 | M          | M          | 3    | 3   | 1  | 7   | 1   | 7    |
| Epagneul Breton                            | M          | M          | 3    | 3   | 7  | 43  | 5   | 7    |
| Fox Terrier Wire                           | M          | M          | 2    | 2   | 2  | 6   | 2   | 3    |
| German Shepherd dog                        | M          | M          | 3    | 4   | 35 | 232 | 18  | 7    |
| German Spitz Klein                         | M          | M          | 2    | 1   | 1  | 2   | 2   | 3    |
| German Spitz Zwerg-Pomeranian              | M          | M          | 2    | 1   | 3  | 11  | 1   | 4    |
| Giant Schnauzer                            | M          | M          | 3    | 4   | 1  | 10  | 1   | 10   |
| Golden Retriever                           | M          | M          | 3    | 4   | 19 | 148 | 10  | 8    |
| Gordon Setter                              | M          | M          | 3    | 4   | 2  | 16  | 2   | 8    |
| Great Dane                                 | M          | M          | 4    | 5   | 5  | 44  | 5   | 10   |
| Hovawart                                   | M          | M          | 3    | 4   | 8  | 68  | 3   | 9    |
| Italian Greyhound                          | D          | D          | 2    | 1   | 18 | 59  | 5   | 3    |
| Italian Spinone                            | D          | M          | 3    | 4   | 2  | 16  | 2   | 8    |
| Jack Russell Terrier                       | M          | M          | 2    | 2   | 15 | 57  | 8   | 5    |
| Labrador Retriever                         | M          | M          | 3    | 4   | 44 | 264 | 26  | 6    |
| Lagotto                                    | M          | M          | 3    | 3   | 2  | 17  | 2   | 8.5  |
| Lakeland Terrier                           | M          | M          | 2    | 2   | 1  | 5   | 1   | 5    |
| Leonberger                                 | M          | M          | 4    | 5   | 2  | 12  | 2   | 6    |
| Little Lion Dog                            | M          | M          | 2    | 2   | 1  | 4   | 1   | 4    |
| Maltese                                    | M          | M          | 2    | 2   | 1  | 6   | 1   | 3    |
| Maremma Sheepdog                           | M          | M          | 4    | 4   | 3  | 23  | 2   | 7    |
| Mastino Napoletano                         | B          | M          | 4    | 5   | 3  | 21  | 2   | 8    |
| Newfoundland                               | M          | M          | 4    | 5   | 4  | 21  | 2   | 6    |
Table 1. Cont.

| Breed                        | Head Shape | Body Shape | Size | BW | Nt | Np | Nk | bBW |
|------------------------------|------------|------------|------|----|----|----|----|-----|
|                              |            |            |      |    |    |    |    |     |
| Poodle (miniature and toy)   | M          | M          | 2    | 1  | 6  | 12 | 5  | 2   | 1.25 | 2   | 116.5 | 99   | 155.5 |
| Pug                          | B          | B          | 2    | 2  | 8  | 32 | 4  | 3.5 | 2.75 | 5.5  | 164.5 | 135.5 | 192.8 |
| Pumi                         | M          | M          | 3    | 3  | 1  | 7  | 1  | 7   | 7    | 7   | 232   | 222   | 238   |
| Rhodesian Ridgeback          | M          | M          | 4    | 4  | 7  | 76 | 3  | 12  | 8.5  | 12.5 | 390   | 358.5 | 420   |
| Rottweiler                   | B          | M          | 3    | 5  | 4  | 30 | 4  | 6.5 | 5.5  | 8.5  | 360   | 322.5 | 399.5 |
| Saint Bernard dog            | B          | M          | 4    | 5  | 1  | 12 | 2  | 12  | 12   | 12.5 | 370   | 355   | 375   |
| Samoyedo                     | M          | M          | 3    | 3  | 1  | 7  | 1  | 7   | 7    | 7    | 229   | 218.8 | 248   |
| Schapendoes                  | M          | M          | 3    | 3  | 1  | 8  | 1  | 8   | 8    | 8    | 229   | 218.8 | 248   |
| Rough Collie                 | M          | M          | 3    | 3  | 1  | 1  | 1  | 1   | 1    | 1    | 155   | 155   | 155   |
| Scottish Terrier             | M          | M          | 3    | 3  | 1  | 3  | 1  | 3   | 3    | 3    | 210   | 205   | 210   |
| Segugio dell’Appennino       | M          | M          | 3    | 3  | 1  | 6  | 1  | 6   | 6    | 6    | 337   | 326   | 365.2 |
| Shar Pei                     | M          | M          | 3    | 3  | 3  | 11 | 3  | 3   | 2    | 5    | 450   | 425   | 475   |
| Shetland Sheepdog            | M          | M          | 2    | 2  | 1  | 5  | 1  | 5   | 5    | 5    | 150   | 143   | 150   |
| Shiba Inu                    | M          | M          | 2    | 2  | 2  | 6  | 1  | 3   | 3    | 3    | 241   | 223.5 | 282.5 |
| Shih Tzu                     | B          | M          | 2    | 2  | 2  | 8  | 1  | 4   | 3.5  | 4.5  | 155   | 145   | 178   |
| Siberian Husky               | M          | M          | 3    | 3  | 3  | 15 | 3  | 5   | 4.5  | 5.5  | 556   | 497.5 | 593.5 |
| Staffordshire Bull Terrier   | B          | M          | 2    | 3  | 10 | 50 | 6  | 5   | 4    | 6    | 319.5 | 297.2 | 463.5 |
| Standard Schnauzer           | M          | M          | 3    | 3  | 3  | 30 | 2  | 11  | 9.5  | 11   | 280   | 262.5 | 297.5 |
| Tibetan Mastiff              | M          | M          | 3    | 5  | 15 | 107 | 2 | 7   | 6    | 8    | 450   | 385   | 490   |
| Tibetan Terrier              | M          | M          | 2    | 2  | 1  | 2  | 1  | 2   | 2    | 2    | 217   | 215.5 | 218.5 |
| Vizsla                       | M          | M          | 3    | 3  | 1  | 6  | 1  | 6   | 6    | 6    | 400   | 4000  | 437.5 |
| Volpino Italiano             | M          | M          | 2    | 1  | 6  | 22 | 4  | 4   | 3.25 | 4    | 132.5 | 85    | 173.8 |
| Weimaraner                   | M          | M          | 3    | 4  | 4  | 25 | 3  | 6.5 | 3.75 | 9    | 450   | 410   | 495   |
| West Highland White T.       | M          | M          | 2    | 2  | 16 | 68 | 7  | 4   | 3    | 5.25 | 180   | 150   | 200   |
| Whippet                      | D          | D          | 3    | 3  | 2  | 13 | 2  | 6.5 | 6.25 | 6.75 | 352   | 332   | 380   |
| White Swiss Shepherd dog     | M          | M          | 3    | 4  | 3  | 22 | 2  | 8   | 7    | 8    | 352   | 323.5 | 460   |
| Yorkshire Terrier            | M          | M          | 1    | 1  | 5  | 14 | 3  | 3   | 2    | 4    | 120   | 106.2 | 128.8 |
| Zwergpinscher                | M          | M          | 2    | 1  | 6  | 24 | 4  | 4   | 3    | 5.75 | 145   | 123   | 176.8 |
| Zwergschnauzer               | M          | M          | 2    | 2  | 10 | 40 | 6  | 4   | 3.25 | 4    | 184.5 | 165.5 | 193.5 |

*a* Head shape: B = brachycephalic; M = mesocephalic; D = dolichocephalic; *b* body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; *c* size: 1 = toy; 2 = small; 3 = medium; 4 = large; *d* BW means maternal body weight: 1 = <5 kg; 2 = 5 ≤ BW ≤ 10 kg; 3 = 10 < BW ≤ 25 kg; 4 = 25 < BW ≤ 45 kg; 5 = >45 kg; *e* Nt means number of litters; *f* Np means number of pups; *g* Nk means number of kennels; *h* bBW means body weight of pups at birth (grams); *i* Q1 means first quartile; *l* Q3 means third quartile.
2.1. Definitions

The Total Cephalic Index (TCI) is the ratio between the cranium width and the head length (tip of the nose-tip of the occiput). Based on their head shape, dogs were classified as brachycephalic (TCI > 50), mesocephalic (TCI = 50) and dolichocephalic (TCI < 50) [11]. The Corporal Index (CI) is the ratio between the length of the body (point of shoulder-ischiatic tuberosity) and the thoracic girth. According to their body shape, dogs were divided into: brachymorph (CI = 60–70), mesomorph (CI = 71–84), dolichomorph (CI = 85–100) and anacholicomorph [11,12]. Anacholicomorph, a term derived from Greek, means short legged: basset-like proportion [11]. Dogs were also categorized into groups according to maternal size, i.e., height at withers (<20 cm: toy; 20 cm ≤ small ≤ 40 cm; 40 cm < medium ≤ 65 cm; >65 cm: large) [13] and maternal body weight (<5 kg; 5 kg ≤ BW ≤ 10 kg; 10 kg < BW ≤ 25 kg; 25 kg < BW ≤ 45 kg; >45 kg) [14]. The sex of pups was recorded at birth and stated as undefined when it was ambiguous or pups were malformed. We included both live and stillborn pups in the database.

2.2. Statistical Analysis

The distribution of birth weight and number of pups according to the maternal characteristics mentioned above was synthesized by the following indices: minimum, first quartile (1st Q), median, mean, third quartile (3rd Q) and maximum.

The relationship between birth weight of the pups (response variable) and litter size, maternal characteristics and sex of pups (explicative variables) was evaluated by linear mixed regression model. Litter size, maternal characteristics and sex of pups were considered as fixed effects. The correlation among pups from the same litter was accounted for including in the model the mother’s identification code as a random effect. The categorical maternal characteristics and sex of pups were included in the regression model as dummy variables. For a categorical variable with k categories, one of the categories is considered as the “reference”, and k-1 dummy variables are generated to compare the mean of the response variable in each category with the mean of the response variable in the reference category. The number of pups per litter was included in the regression model in its original measurement scale. Residual analysis suggested the use of the logarithmic transformation of the birth weight. After logarithmic transformation, the regression coefficients can be related to the geometric mean of the response variable (i.e., the mean of the logarithm of birth weight is the geometric mean of birth weight rather than the usual arithmetic mean of the birth weight). For categorical variables, the exponent of the regression coefficient of each dummy variable was the estimate of the ratio between the geometric mean of birth weight of the category represented by the dummy variable and the geometric mean of the birth weight of the reference category. For litter size, the exponent of the regression coefficient was the estimate of the ratio between the geometric mean of the birth weight for each of two consecutive litter size values.

The null hypothesis of the regression coefficient equal to 0 for fixed effects was tested by the t statistic. To perform adequate inference procedures, Satterthwaite’s approximation of the degree of freedom of the t statistic was applied. The relationship between the litter size (response variable) and the maternal characteristics (explicative variables) was evaluated by a generalized linear model with Poisson error. As the considered maternal characteristics are categorical, each characteristic dummy variable was generated as previously described. In this generalized linear model, the exponent of the regression coefficient of each dummy variable was the estimate of the ratio between the geometric mean of the category represented by the dummy variable and the geometric mean of the birth weight of the reference category. For litter size, the exponent of the regression coefficient was the estimate of the ratio between the geometric mean of the birth weight for each of two consecutive litter size values.

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for the lowest value of the explicative variable and the increase of the mean of the response variable for a one-unit increase of the explicative variable. For both the Poisson and linear mixed model, the effect of each explicative variable was evaluated firstly by univariate analysis, then a multivariable regression model was used to evaluate the joint role of all of the explicative variables. The authors consider the maternal body weight and size as correlated, so two alternative multivariable regression models were performed including weight and size, respectively. A parsimonious final model was obtained by the stepwise selection procedure.

An exploratory analysis was performed to evaluate the association between breeds and birth weight and between breeds and litter size in dogs sharing the same morphotype. To obtain reliable results, only breeds represented by at least 15 litters were considered.

Statistical significance was accepted at \( p < 0.05 \).

The analysis was performed by the R Core Team (2016) software; R: A language and environment for statistical computing; R: Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0 [15]; package lme4 for bBW [16]; and the glm function for the number of pups.

3. Results

The distribution of pup number and birth weight according to combinations of maternal morphotype, size and body weight of dogs in the study is summarized in Table 2.

3.1. Birth Weight

The birth weight ranged from 40–1250 g. The lightest pup was a German Spitz (Pomeranian-Zwergspitz) that died within 24 h after birth; its surviving littermate weighed 124 g. The heaviest pup was from a Mastino Napoletano dog that delivered eight healthy pups.

For statistical purposes, 45 pups whose data were incomplete were excluded from our investigation, thus including a total of 3248 pups.

In univariate analysis, maternal head shape significantly influenced the mean birth weight of brachycephalic dogs when compared to mesocephalic dogs (Table 3). Similarly, in brachymorph dogs, birth weight was related to maternal body shape when compared to mesomorph dogs. In the remaining morphological categories, no statistical differences in bBW were observed with respect to brachymorph.

The mother’s size was directly related to the bBW. Similar results were obtained considering the mother’s body weight. Concerning the relationship between the logarithm of the bBW and the litter size, no evidence for a non-linear effect was found. The estimated bBW increased with the increase of the number of pups per litter. To clarify this result, the effect of litter size on birth weight was adjusted for mother’s size. In this case, the impact of litter size was not statistically significant and inversely proportional to birth weight (mean ratio 0.99, \( p > 0.3 \)).

When maternal head shape, body shape, body weight, number of pups per litter and the sex of pups were jointly considered, the mother’s head shape did not contribute significantly to the bBW (\( p = 0.0558 \)) and was excluded from the final regression model by the stepwise procedure. Concerning the body shape, the mean bBW of brachymorph dogs was significantly lower than that of all other categories. As already mentioned, the average bBW increased with the decreasing of the litter size. Results of the final regression model are reported in Table 4.

When the mother’s size was considered instead of the mother’s weight, all variables showed a significant contribution (Table 5). The mean bBW of brachycephalic dogs was significantly greater than that of mesocephalic and dolichocephalic dogs. Concerning maternal body shape, the mean bBW of anacholicomorph dogs was significantly greater than that of brachymorph dogs, and no significant differences were found among the other maternal body shape categories. The results for litter size were similar to those reported above.

The contribution of maternal body weight and size to the model was \( F = 341.32, p < 0.0001 \) and \( F = 273.47, p < 0.0001 \), respectively.
Table 2. Combinations of maternal morphotype, size and body weight and the corresponding pup number and birth weight in our canine sample.

| Head Shape
a  | Body Shape
b  | Size
C | BW
D | Nl
E | Np
f | Np
Min | Q1
h | Median | Mean | Q3
i | Max | Min | Q1
h | Median | Mean | Q3
i | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B  | B  | 2 | 2 | 8 | 32 | 1 | 2.75 | 3.5 | 4 | 5.5 | 7 | 86 | 135.5 | 164.5 | 161.5 | 192.8 | 230 |
| B  | B  | 2 | 3 | 18 | 76 | 1 | 3 | 4 | 4.33 | 6 | 7 | 55 | 176 | 241.5 | 243.9 | 288.2 | 510 |
| B  | M  | 1 | 1 | 19 | 56 | 1 | 2 | 3 | 3 | 4 | 5 | 60 | 111.5 | 140 | 134.8 | 160 | 207 |
| B  | M  | 2 | 1 | 2 | 11 | 4 | 4.75 | 5.5 | 5.5 | 6.25 | 7 | 85 | 117 | 136 | 163 | 227.5 | 260 |
| B  | M  | 2 | 2 | 20 | 74 | 1 | 2.75 | 3 | 3.7 | 5 | 8 | 120 | 176.5 | 220 | 211.3 | 245 | 306 |
| B  | M  | 2 | 3 | 10 | 50 | 3 | 4 | 5 | 5 | 6 | 7 | 234 | 297.2 | 319.5 | 394.9 | 463.5 | 766 |
| B  | M  | 3 | 4 | 16 | 108 | 2 | 5 | 7.5 | 7 | 9 | 11 | 315 | 409 | 455.5 | 493.3 | 554 | 900 |
| B  | M  | 3 | 5 | 5 | 38 | 4 | 6 | 7 | 7.6 | 8 | 13 | 248 | 333.8 | 375 | 396.8 | 436.2 | 620 |
| B  | M  | 4 | 5 | 7 | 55 | 3 | 6 | 8 | 7.86 | 10 | 12 | 500 | 580 | 620 | 677.1 | 692 | 1250 |
| M  | 1 | 5 | 14 | 1 | 2 | 3 | 2.8 | 4 | 4 | 90 | 106.2 | 120 | 129.6 | 128.8 | 202 |
| M  | 2 | 5 | 182 | 1 | 2 | 3 | 3.51 | 5 | 7 | 44 | 114 | 142 | 147.8 | 179 | 266 |
| M  | 2 | 2 | 3 | 50 | 2 | 3 | 4 | 4.16 | 5 | 7 | 90 | 167.8 | 190 | 189.6 | 214.2 | 350 |
| M  | 3 | 2 | 2 | 166 | 2 | 5 | 6 | 5.93 | 7 | 9 | 130 | 247.8 | 286 | 287.5 | 330 | 500 |
| M  | 3 | 2 | 2 | 12 | 5 | 5.5 | 6 | 6 | 6.5 | 7 | 235 | 273.8 | 290 | 289.2 | 308.8 | 335 |
| M  | 3 | 3 | 60 | 392 | 1 | 5 | 7 | 6.55 | 8 | 11 | 148 | 280 | 344.5 | 341.1 | 392 | 650 |
| M  | 3 | 4 | 190 | 1203 | 1 | 4 | 7 | 6.37 | 8 | 13 | 57 | 400 | 450 | 464.3 | 530 | 900 |
| M  | 3 | 5 | 15 | 105 | 4 | 6 | 7 | 7.13 | 8 | 10 | 220 | 390 | 450 | 443 | 490 | 650 |
| M  | 4 | 4 | 13 | 117 | 5 | 7 | 8 | 9.15 | 12 | 15 | 220 | 370 | 420 | 459.5 | 530 | 770 |
| M  | 4 | 5 | 8 | 84 | 1 | 4 | 8 | 6.92 | 9 | 11 | 200 | 507.5 | 612.5 | 594 | 690 | 900 |
| M  | 5 | 12 | 47 | 1 | 2.75 | 4 | 3.92 | 5 | 7 | 116 | 144.5 | 160 | 170.6 | 187.5 | 250 |
| M  | A  | 2 | 2 | 3 | 15 | 3 | 3.5 | 4 | 5 | 6 | 8 | 200 | 210 | 230 | 237.1 | 258 | 305 |
| M  | A  | 3 | 7 | 51 | 4 | 5.5 | 7 | 7.29 | 9 | 11 | 40 | 350 | 443 | 413.8 | 501 | 580 |
| D  | M  | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 155 | 155 | 155 | 155 | 155 |
| D  | M  | 3 | 4 | 2 | 16 | 7 | 7.5 | 8 | 8 | 8.5 | 9 | 400 | 415 | 450 | 511.2 | 600 | 700 |
| D  | M  | 4 | 4 | 8 | 59 | 3 | 6 | 8 | 7.75 | 9 | 13 | 60 | 340 | 471 | 434.1 | 530.5 | 780 |
| D  | D  | 2 | 18 | 59 | 2 | 2 | 3 | 3.28 | 4 | 7 | 116 | 167.5 | 185 | 188.8 | 208 | 281 |
| D  | D  | 2 | 3 | 2 | 13 | 6 | 6.25 | 6.5 | 6.5 | 6.75 | 7 | 205 | 332 | 352 | 347.4 | 380 | 417 |
| D  | D  | 4 | 3 | 2 | 11 | 5 | 5.5 | 6 | 6 | 6 | 7 | 420 | 480 | 500 | 516.4 | 562.5 | 600 |

a Head shape: B = brachycephalic; M = mesocephalic; D = dolichocephalic; A = anacholicomphalic; b body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; C: size: 1 = toy; 2 = small; 3 = medium; 4 = large; D BW means maternal body weight: 1 = <5 kg; 2 = 5 ≤ BW ≤ 10 kg; 3 = 10 < BW ≤ 25 kg; 4 = 25 < BW ≤ 45 kg; 5 = >45 kg; E Nl means number of litters; f Np means number of pups; g bBW means body weight of pups at birth (grams); h Q1 means first quartile; i Q3 means third quartile.
Table 3. Birth weight of pups and maternal characteristics: results of linear mixed regression model univariate analysis.

| Variable          | Mean | Contrast | Mean Ratio | 95% Lower Limit | 95% Upper Limit | t    | p-Value |
|-------------------|------|----------|------------|-----------------|-----------------|------|---------|
| Head shape a       |      |          |            |                 |                 |      |         |
|                   | 264.36| reference |            |                 |                 |      |         |
|                   | 323.37| M/B      | 1.22       | 1.10            | 1.37            | 3.57 | <0.001  |
|                   | 269.81| D/B      | 1.02       | 0.83            | 1.25            | 0.20 | 0.8425  |
| Body shape b       |      |          |            |                 |                 |      |         |
|                   | 221.32| reference |            |                 |                 |      |         |
|                   | 322.08| M/B      | 1.46       | 1.19            | 1.78            | 3.62 | <0.001  |
|                   | 222.16| D/B      | 1.00       | 0.75            | 1.34            | 0.03 | 0.9794  |
|                   | 238.34| A/B      | 1.08       | 0.80            | 1.44            | 0.50 | 0.6197  |
| Size c             |      |          |            |                 |                 |      |         |
|                   | 146.1 | reference |            |                 |                 |      |         |
|                   | 203.22| 2/1      | 1.39       | 1.24            | 1.56            | 5.52 | <0.001  |
|                   | 423.99| 3/1      | 2.90       | 2.59            | 3.26            | 18.17| <0.001  |
|                   | 519.26| 4/1      | 3.55       | 3.07            | 4.11            | 17.31| <0.001  |
| BW d              |      |          |            |                 |                 |      |         |
|                   | 147.39| reference |            |                 |                 |      |         |
|                   | 192.46| 2/1      | 1.31       | 1.21            | 1.41            | 6.58 | <0.001  |
|                   | 317.54| 3/1      | 2.15       | 2.00            | 2.32            | 20.38| <0.001  |
|                   | 455.82| 4/1      | 3.09       | 2.89            | 3.31            | 33.22| <0.001  |
|                   | 512.14| 5/1      | 3.47       | 3.14            | 3.85            | 23.96| <0.001  |
| Litter size e      | 221.91| reference | one-pup    | 1.07            | 1.06            | 1.09 | 9.39   | <0.001  |
| Sex of pups f      | 303.14| reference |            |                 |                 |      |         |
|                   | 314.91| 1/0      | 1.04       | 1.03            | 1.05            | 7.30 | <0.001  |
|                   | 260.66| 2/0      | 0.86       | 0.80            | 0.92            | −4.31| <0.001  |

* When the number of pups is adjusted for maternal size, the estimates for a one-pup increase per litter are: mean ratio = 0.99 (95% confidence limits: 0.98–1.01) t = −1.03 p value = 0.3024; a head shape: B = brachycephalic; M = mesocephalic; D = dolichocephalic; b Body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; c size: 1 = toy; 2 = small; 3 = medium; 4 = large; d BW means maternal body weight: 1 = <5 kg; 2 = 5 kg ≤ BW ≤ 10 kg; 3 = 10 kg < BW ≤ 25 kg; 4 = 25 kg < BW ≤ 45 kg; 5 = >45 kg; the category coded 1 is the reference; e sex of pups: 0 = female; 1 = male; 2 = unidentified; the category coded 0 is the reference; f mean (grams) is the estimated geometric mean of the weight distribution.

Table 4. Birth weight of pups and maternal characteristics: results of final linear mixed regression model multivariable analysis (step-wise selection procedure); body shape and weight, number of newborns, sex of pups.

| Variable          | Contrast | Mean Ratio d | 95% Lower Limit | 95% Upper Limit | t    | p-Value |
|-------------------|----------|--------------|-----------------|-----------------|------|---------|
| Body shape a       |          |              |                 |                 |      |         |
|                   | M/B      | 1.29         | 1.16            | 1.45            | 4.57 | <0.001  |
|                   | D/B      | 1.69         | 1.44            | 1.98            | 6.41 | <0.001  |
|                   | A/B      | 1.36         | 1.16            | 1.58            | 3.88 | <0.001  |
| BW b              |          |              |                 |                 |      |         |
|                   | 2/1      | 1.41         | 1.3             | 1.54            | 8.23 | <0.001  |
|                   | 3/1      | 2.45         | 2.26            | 2.65            | 22.1 | <0.001  |
|                   | 4/1      | 3.48         | 3.23            | 3.75            | 32.82| <0.001  |
|                   | 5/1      | 3.98         | 3.58            | 4.43            | 25.36| <0.001  |
| Litter size       |          |              |                 |                 |      |         |
|                   | one-pup  | 0.98         | 0.97            | 0.99            | −4.36| <0.001  |
| Sex of pups c      |          |              |                 |                 |      |         |
|                   | 1/0      | 1.04         | 1.03            | 1.05            | 7.13 | <0.001  |
|                   | 2/0      | 0.85         | 0.80            | 0.91            | −4.6 | <0.001  |

* Body shape: B = brachycephalic; M = mesomorph; D = dolichomorph; A = anacholicomorph; b BW means maternal body weight: 1 = <5 kg; 2 = 5 kg ≤ BW ≤ 10 kg; 3 = 10 kg < BW ≤ 25 kg; 4 = 25 kg < BW ≤ 45 kg; 5 = >45 kg; the category coded 1 is the reference; e sex of pups: 0 = female; 1 = male; 2 = unidentified; the category coded 0 is the reference; f mean ratio means model estimated ratio between geometric means.
Table 5. Birth weight of pups and maternal characteristics: results of final linear mixed regression model multivariable analysis (step-wise selection procedure); head and body shape, size, number of newborns, sex of pups.

| Variable          | Contrast | Mean Ratio | 95% Lower Limit | 95% Upper Limit | t     | p-Value |
|-------------------|----------|------------|-----------------|-----------------|-------|---------|
| Head shape a      | M/B      | 0.8        | 0.74            | 0.87            | –5.42 | <0.001  |
|                   | D/B      | 0.66       | 0.53            | 0.81            | –3.95 | <0.001  |
| Body shape b      | M/B      | 1.07       | 0.93            | 1.24            | 0.96  | 0.3377  |
|                   | D/B      | 1.24       | 0.95            | 1.63            | 1.57  | 0.1163  |
|                   | A/B      | 1.87       | 1.51            | 2.32            | 5.68  | <0.001  |
| Size c            | 2/1      | 1.78       | 1.56            | 2.02            | 8.83  | <0.001  |
|                   | 3/1      | 4.04       | 3.52            | 4.63            | 20.03 | <0.001  |
|                   | 4/1      | 5.15       | 4.36            | 6.09            | 19.22 | <0.001  |
| Litter size d     | one-pup increase | 0.99 | 0.98 | 1 | –2.21 | 0.0275 |
| Sex of pups e     | 1/0      | 1.04       | 1.03            | 1.05            | 7.08  | <0.001  |
|                   | 2/0      | 0.85       | 0.80            | 0.91            | –4.57 | <0.001  |

- Head shape: B = brachycephalic; M = mesocephalic; D = dolichocephalic; Body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; Size: 1 = toy; 2 = small; 3 = medium; 4 = large. The category coded 1 is the reference; Sex of pups: 0 = female; 1 = male; 2 = unidentified; the category coded 0 is the reference; Mean ratio means model estimated ratio between geometric means.

3.2. Litter Size

Litter size ranged from 1–14 pups with the largest litter delivered by a Rhodesian ridgeback dog. In univariate analysis, the mother’s head shape was related to litter size with mesocephalic dogs delivering litters at a mean 1.2-times more numerous than brachycephalic ones (Table 6). Similarly, mesomorph dogs had litters at a mean more numerous than brachymorph dogs. Litter size was directly proportional to maternal size. Likewise, the litter size increased proportionally to the maternal body weight.

Table 6. Number of pups and maternal characteristics: results of Poisson’s regression model univariate analysis.

| Variable          | Mean a | Contrast | Mean Ratio | 95% Lower Limit | 95% Upper Limit | Wald Statistics | p-Value |
|-------------------|--------|----------|------------|-----------------|-----------------|-----------------|---------|
| Head shape a      | 4.829  | M/B      | 1.205      | 1.095           | 1.325           | 3.839           | <0.0001 |
|                   | 5.118  | D/B      | 1.060      | 0.892           | 1.259           | 0.662           | 0.5080  |
| Body shape b      | 4.231  | M/B      | 1.360      | 1.124           | 1.645           | 3.168           | 0.0015  |
|                   | 5.754  | D/B      | 0.976      | 0.742           | 1.285           | –0.171          | 0.8642  |
|                   | 4.130  | A/B      | 1.214      | 0.934           | 1.579           | 1.448           | 0.1476  |
| Size c            | 3.278  | 2/1      | 1.310      | 1.081           | 1.586           | 2.76            | 0.00578 |
|                   | 4.293  | 3/1      | 1.981      | 1.645           | 2.386           | 7.208           | <0.0001 |
|                   | 7.932  | 4/1      | 2.420      | 1.964           | 2.982           | 8.299           | <0.0001 |
| BW d              | 3.368  | reference| 1.212      | 1.046           | 1.406           | 2.552           | 0.0107  |
|                   | 5.969  | 2/1      | 1.772      | 1.555           | 2.019           | 8.592           | <0.0001 |
|                   | 6.657  | 3/1      | 1.976      | 1.752           | 2.229           | 11.082          | <0.0001 |
|                   | 7.250  | 4/1      | 2.152      | 1.836           | 2.523           | 9.435           | <0.0001 |

- Head shape: B = brachycephalic; M = mesocephalic; D = dolichocephalic; Body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; Size: 1 = toy; 2 = small; 3 = medium; 4 = large; BW means maternal body weight: 1 = <5 kg; 2 = 5 kg ≤ BW ≤ 10 kg; 3 = 10 kg < BW ≤ 25 kg; 4 = 25 kg < BW ≤ 45 kg; 5 = >45 kg; the category coded 1 is the reference; Mean is expressed in grams.

When maternal head shape, body shape and body weight were jointly considered, the contribution of head shape was not statistically significant, and the final model excluded this variable (Table 7). The maternal body shape influenced litter size with brachymorph dogs delivering the lowest number of pups. The mean number of pups increased with the increase of the maternal BW. Similarly,
when maternal size was considered in the model instead of BW, the head shape did not contribute significantly to litter size and was not included in the final model (Table 8). However, the impact of maternal body shape on the number of pups showed a minor contribution with a difference in litter size only emerging between brachymorph and anacholicomorph dogs. The mean number of pups increased with the increasing of the maternal size.

### Table 7. Litter size and maternal characteristics: results of final Poisson regression model multivariable analysis (step-wise selection procedure); body shape and weight.

| Variable       | Contrast | Mean Ratio | 95% Lower Limit | 95% Upper Limit | Wald Statistic | p-Value |
|----------------|----------|------------|-----------------|-----------------|----------------|---------|
| Body shape     | M/B      | 1.303      | 1.069           | 1.588           | 2.619          | 0.0088  |
|                | D/B      | 1.355      | 1.015           | 1.808           | 2.061          | 0.0393  |
|                | A/B      | 1.407      | 1.078           | 1.837           | 2.514          | 0.0119  |
|                | BW       | 2/1        | 1.23            | 1.05            | 1.441          | 2.567   | 0.0103  |
|                |          | 3/1        | 1.835           | 1.599           | 2.105          | 8.66    | <0.001  |
|                |          | 4/1        | 1.991           | 1.753           | 2.261          | 10.593  | <0.001  |
|                |          | 5/1        | 2.169           | 1.84            | 2.556          | 9.225   | <0.001  |

* Body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; BW means maternal body weight: 1 = <5 kg; 2 = 5 kg ≤ BW ≤ 10 kg; 3 = 10 kg < BW ≤ 25 kg; 4 = 25 kg < BW ≤ 45 kg; 5 = >45 kg; the category coded 1 is the reference.

### Table 8. Litter size and maternal characteristics: results of final Poisson regression model multivariable analysis (step-wise selection procedure); body shape and size.

| Variable       | Contrast | Mean Ratio | 95% Lower Limit | 95% Upper Limit | Wald Statistic | p-Value |
|----------------|----------|------------|-----------------|-----------------|----------------|---------|
| Body shape     | M/B      | 1.007      | 0.824           | 1.231           | 0.07           | 0.9442  |
|                | D/B      | 0.841      | 0.638           | 1.109           | –1.228         | 0.2194  |
|                | A/B      | 1.487      | 1.126           | 1.963           | 2.795          | 0.0052  |
| Size           | 2/1      | 1.506      | 1.225           | 1.852           | 3.883          | <0.001  |
|                | 3/1      | 2.298      | 1.87            | 2.825           | 7.906          | <0.001  |
|                | 4/1      | 2.836      | 2.26            | 3.559           | 8.995          | <0.001  |

* Body shape: B = brachymorph; M = mesomorph; D = dolichomorph; A = anacholicomorph; Size: 1 = toy; 2 = small; 3 = medium; 4 = large; the category coded 1 is the reference.

### 3.3. Breed

According to our inclusion criteria, five breeds were considered for exploratory analysis: German shepherd, golden retriever, Jack Russel terrier, Labrador retriever and West Highland white terrier (WHWT) (Table 9). German shepherd, golden retriever and Labrador retriever belong to mesocephalic, mesomorph, medium sized, 25–45-kg weighing dogs. Jack Russel terrier and WHWT belong to mesocephalic, mesomorph, small-sized, 5–10-kg weighing dogs.

### Table 9. Number and birth weight of pups per litter in five breeds.

| Breed          | Nl | Np | Np | bBW |
|----------------|----|----|----|-----|
|                | Min| Q1 | Median| Mean| Q3 | Max| Min| Q1 | Median| Mean| Q3 | Max|
| German Shepherd| 35 | 232| 2   | 4.5 | 7  | 6.629 | 8.5 | 12  | 57    | 435 | 503 | 510.5 | 600 | 900 |
| Golden Retriever| 19 | 148| 3   | 5.5 | 8  | 7.789 | 10  | 13  | 280   | 426.2 | 461.5 | 475.1 | 527.5 | 750 |
| Labrador Retriever| 44 | 264| 1   | 5   | 6  | 6.725 | 7.25 | 10  | 188   | 369.5 | 405.5 | 412.1 | 450 | 624 |
| Jack Russel Terrier| 15 | 67 | 2   | 3.5 | 5  | 4.467 | 5   | 7   | 122   | 180  | 200 | 201.3 | 220 | 320 |
| WHWT            | 16 | 68 | 2   | 3   | 4  | 4.25  | 5.25 | 6   | 90    | 150  | 180 | 175 | 200 | 280 |

* Nl = number of litters; Np = number of pups; bBW = birth weight of pups (grams); Q1 = first quartile; Q3 = third quartile; WHWT = West Highland White Terrier.

The bBW was lower in WHWT than in Jack Russel terrier (p < 0.05), while no significant differences were recorded among the other breeds. Few differences were found between mean bBW of German
shepherd, golden retriever and Labrador retriever (reference): the estimated mean ratio was 0.9 and 1.03, respectively.

The ratio between mean litter size of Labrador retriever and golden retriever was 0.77 ($p = 0.01$). The ratio between mean litter size of German shepherd and golden retriever was 0.85 ($p = 0.12$). Only the comparison between Labrador and golden retriever was statistically significant. No significant differences in mean litter size between Jack Russel terrier and WHWT were recorded (mean ratio = 0.951).

3.4. Sex of Pups

In our samples, 1559 pups were females and 1665 males. In the remaining 24 pups, the sex was not defined, as it was ambiguous or they were malformed. In univariate analysis, mean bBW of males was greater than mean bBW of females (mean ratio = 1.04, $p < 0.001$; Table 3). The mean bBW of pups with undefined sex was lower than mean bBW of females (mean ratio = 0.86, $p < 0.001$). These results were confirmed by multivariate analysis ($p < 0.001$; Tables 4 and 5).

4. Discussion

Despite its relevant impact on neonatal and adult health, deep knowledge of factors affecting birth weight in dogs is still lacking. As already noted, low birth weight in pups, as well as in babies, kittens and piglets, leads to higher risk of neonatal morbidity and mortality compared with normal weight littermates [17–19]. Mortality of pups attributed to low birth weight is reported from 1.4% [20] to 2.1% [21]. In large-sized breeds, birth weight in dogs dying during the first week after birth was 100 g lower than in surviving pups [22,23]. Moreover, pup weight at birth has a significant influence on the outcome of parturition [24], and being oversized in pups may be responsible for uterine inertia and consequent fetal distress [25,26]. Pups being oversized in the case of singleton pregnancy, as well as disproportion between maternal pelvic and pup head dimensions are known to be predisposing factors to dystocia since more uterine force is needed to expel these pups [25]. Namely, dystocia is reported to occur more likely in some canine breeds and morphotypes, with increasing cranial circumference of the pups, that is in brachycephalic dogs [24,26–30].

Theoretically, in all mammalian species, there is an ideal range of birth weight associated with eutocic parturition and neonatal well-being [4]. To date, due to a wide morphological and morphometric variability within canine breeds, no criteria are available to recognize which range of birth weight is to be considered physiological. Even the present study has no claim to provide a birth weight cut-off for each breed, rather to investigate associations among birth weight, litter size and morphology by an original canine classification. Although the effect of maternal phenotype on birth weight was investigated by a multivariate regression model, our result cannot be used for predictive aims. Indeed, a suitable predictive model would require a very large population with independent case series for model validation. To the authors’ knowledge, this is the first study evaluating the influence of maternal morphotype, namely head and body shape and not only size and weight, on pup birth weight and number. Given that studies on the average weight of purebred pups at birth are few and based on a small scale, a thorough comparison with the available literature is not possible. However, the birth weights of the German shepherd, Labrador retriever and Rottweiler pups in our sample were similar to those previously described [31].

The body weight was reported to vary up to 40-times among adult dogs from different sizes and breeds, while it was only 10-times different at most among pups at birth [32]. Our results showed a greater range of birth weight than those reported by Fiszdon et al. (2009) with the thinnest pup about 31-times lighter than the heaviest one [32]. This aspect can be justified by both a different sample size of our study ($n = 501$ versus $n = 3293$ pups) and our inclusion of either live or stillborn pups. Severely underweight pups are not likely to survive. However, the relation between birth weight and neonatal mortality has not been investigated, beyond the aim of the present study.

Data shown in this study are from a census, so they do not represent the registered database of ENCI during the same period (see Appendix A). Being that participation in the census was based on
the voluntary participation of breeders, a potential bias of our sample in relation to the distribution of the whole canine Italian population is possible. Moreover, a possible ‘kennel effect’ on birth weight and litter size of dogs from the same breeder (Table 1) should not be neglected, as well as the involvement of the bloodlines.

In our canine population, the maternal head shape had a significant impact on birth weight of pups when morphotype, litter size and sex of pups were considered together with maternal size. Brachycephalic dogs had the heaviest pups. These data are consistent with studies reporting an association between low birth weight and small head circumference at birth in babies [6,33]. However, the head shape contribution was not significant when the same variables (morphotype, litter size and sex of pups) were considered together with maternal body weight. We speculate that maternal body weight may have a more powerful impact on birth weight than size. Conversely, litter size was not affected by the head shape.

The maternal body shape influenced significantly both birth weight and litter size with brachymorph dogs delivering the lightest pups and a lower number of pups than anacholicomorph ones. Studies in humans highlighted the importance of maternal phenotype influence on birth weight, indicating that weight at birth is attributable to maternal anthropometry differences and not to maternal size variability alone [34].

Maternal size and body weight were directly proportional to both birth weight and litter size in our sample. The same observation was reported in cats with birth weight increasing as maternal weight and height increased [35]. Similarly, observational epidemiological studies have revealed that both maternal height and weight are associated with birth weight in babies [7]. These associations have been interpreted based on a mechanistic assumption that maternal dimension sets a physical constraint on the intrauterine environment that affects fetal growth [7].

A limit of the present study is the lack of data on the real maternal body weight, body condition score, gestational weight gain and caloric intake of the dogs included in the census. Therefore, we cannot exclude that the nutritional status of bitches may also affect the birth weight of pups as described in humans [36,37]. Moreover, maternal size and weight were taken from FCI, ENCI and kennel clubs and not directly recorded by the questionnaire. Although the used classifications are reliable [13,17], a partial loss of information on the relationship between these two variables and bBW or litter size could be possible. Finally, a possible bias on birth weight recording is intrinsic in a study based on data directly collected by the owner.

As expected on the basis of the literature, litter size was inversely proportional to birth weight, with weight reduction for each additional pup per litter [26,35]. A significant sex difference in birth weight was recorded, with male pups being the heaviest. Data reported in literature on this topic are conflicting. Some authors have found no difference on birth weight between male and female pups [23,26]. On the contrary, other studies have shown an increased birth weight in male compared with female pups [38,39], as described in humans and sheep [2,4]. These heterogeneous results could be due to different sample sizes and different distributions of dog’s morphologic characteristics in case series. A comparison of results should be performed after taking into account litter size, maternal weight and morphotype in a multivariate analysis.

As previously observed, ambiguous or malformed pups resulted in lighter birth weight than healthy ones [40]. In humans, congenital malformations seem to be the most important factor that determines low birth weight [41]. Heritability for body weight at birth has been demonstrated in boxers [42]. A significant breed-dependent difference in birth weight and litter size among breeds of the same size and weight was recorded in our sample, even though only five breeds have been compared. These data suggest a non-negligible role of the breed, not only size, weight and morphotype, in determining birth weight. However, the breed influence should be further investigated to be verified in very large datasets.
5. Conclusions

There is strong evidence that birth weight results from a complex interaction between genetic and environmental factors of parental, placental and fetal origin in humans [43]. Due to some above-mentioned limitations, besides the lack of paternal information, the outcomes of this survey should be generalized with caution, as it represents a definite sample of pedigree dog population in Italy. Studies in human reported that paternal birth weight and height are significant and independent predictors of birth weight in offspring [44,45], although maternal factors make bigger contributions to babies’ birth weight [46]. This large-scale study provides evidence that canine morphotype, not only maternal size and body weight, together with breed are involved in determining birth weight and litter size. Results of the present study have concrete implications in canine neonatal practice allowing one to deepen the knowledge of factors that significantly influence variation in birth weight and to identify pups in need of admission to intensive nursing care.

Acknowledgments: The authors are grateful to ENCI for contributing to the census questionnaire distribution among Italian canine breeders.

Author Contributions: Conceived of and designed the study: Debora Groppetti, Alessandro Pecile; Collected data: Clara Palestrini, Stefano P. Marelli. Performed the statistical analysis: Patrizia Boracchi. Wrote the paper: Debora Groppetti, Alessandro Pecile, Patrizia Boracchi. All of the authors participated in the drafting and critical reading of the manuscript.

Conflicts of Interest: There is no conflict of interest that could be declared.

Appendix

Table A1. Number of Dogs Registered in the Genealogical Book ENCI from 1 January 2015–31 December 2015.

| Breed                                    | Number |
|------------------------------------------|--------|
| Affenpinscher                            | 13     |
| Afghan Hound                             | 81     |
| Airedale Terrier                         | 63     |
| Akita Inu                                | 1283   |
| Alaskan Malamute                         | 562    |
| Alpenlaendische Dachsbracke              | 536    |
| American Akita                           | 461    |
| American Cocker                         | 87     |
| American Staffordshire T.                | 4484   |
| Anatolian Shepherd                       | 26     |
| Anglo Francais De Petite Venerie         | 66     |
| Appenzeller Mountain dog                 | 48     |
| Argentine Dogo                           | 1124   |
| Ariegeois                                | 663    |
| Australian Cattle Dog                    | 396    |
| Australian Kelpie                        | 39     |
| Australian Shepherd                      | 1567   |
| Australian Silky Terrier                 | 7      |
| Azawakh                                  | 8      |
| Basenji                                  | 60     |
| Basset Fauve De Bretagne                 | 16     |
| Basset hound                             | 338    |
| Beagle                                   | 1402   |
| Beagle Harrier                           | 79     |
| Bearded Collie                           | 49     |
| Beauceron                                | 132    |
| Bedlington Terrier                       | 15     |
| Breed                                      | Number |
|-------------------------------------------|--------|
| Belgian Shepherd Dog                       | 886    |
| Bergamasco Shepherd Dog                    | 63     |
| Bernese Mountain Dog                       | 1554   |
| Bichon A Poil Frise                        | 232    |
| Bichon Havanais                            | 75     |
| Black Russian Terrier                      | 41     |
| Bloodhound                                | 86     |
| Bobtail                                   | 28     |
| Bolognese                                 | 358    |
| Border Collie                              | 3135   |
| Border Terrier                             | 13     |
| Borzoi                                    | 89     |
| Boston Terrier                             | 338    |
| Bouledog                                  | 1822   |
| Bouvier des Flandres                       | 22     |
| Boxer                                     | 3682   |
| Bracco Italiano                            | 694    |
| Braque d’Auvergne                          | 1      |
| Braque français                            | 172    |
| Brazilian Mastiff                          | 35     |
| Briard                                    | 58     |
| Briquet Griffon Vendeen                    | 654    |
| Broholmer                                  | 4      |
| Brussel Griffon                            | 31     |
| Bull Terrier                               | 516    |
| Bulldog                                   | 2153   |
| Bullmastiff                                | 346    |
| Byerischer gebirgsschweisshund             | 179    |
| Cairn Terrier                              | 39     |
| Canaan Dog                                 | 14     |
| Cane Corso                                 | 3957   |
| Cao De Agua                                | 32     |
| Cao De Castro Laboreiro                    | 3      |
| Catalan Shepherd Dog                       | 10     |
| Caucasian Shepherd Dog                     | 418    |
| Cavalier King Charles Spaniel             | 1313   |
| Central Asian Shepherd Dog                 | 394    |
| Chesapeake Bay Retriever                   | 10     |
| Chihuahua                                  | 5794   |
| Chin                                      | 58     |
| Chinese Crested Dog                        | 74     |
| Chow Chow                                  | 179    |
| Cirneco dell’Etna                          | 105    |
| Clumber Spaniel                            | 59     |
| Coton De Tulear                            | 99     |
| Czechoslovakian Wolfdog                    | 1362   |
| Dachshund                                  | 2904   |
| Dalmatian                                  | 146    |
| Deerhound                                  | 9      |
| Dobermann                                  | 1693   |
| Doogo Canario                              | 73     |
| Dogue De Bordeaux                          | 801    |
| Dutch Shepherd Dog                         | 33     |
Table A1. Cont.

| Breed                                      | Number |
|--------------------------------------------|--------|
| English Cocker Spaniel                     | 2084   |
| English Pointer                            | 2339   |
| English Setter                             | 13,702 |
| English Springer Spaniel                   | 1773   |
| Entlebucher Mountain Dog                   | 13     |
| Epagneul Breton                            | 3275   |
| Epagneul Nain Continental Papillon         | 108    |
| Erdélyi Kopó                               | 14     |
| Eurasier                                   | 25     |
| Flat Coated Retriever                      | 205    |
| Fox Terrier Wire                           | 181    |
| Galgo Espanol                              | 1      |
| Gascon Saintongeois                        | 194    |
| German Jagdterrier                         | 176    |
| German Shepherd                            | 14,369 |
| German Shorthaired Pointer                 | 2435   |
| German Spaniel                             | 59     |
| German Spitz                               | 905    |
| German Wirehaired Pointer                  | 763    |
| Giant Schnauzer                            | 339    |
| Golden Retriever                           | 5692   |
| Gordon Setter                              | 357    |
| Grand Griffon Vendeen                      | 2      |
| Great Dane                                 | 1075   |
| Greyhound                                  | 50     |
| Griffon Belge                              | 13     |
| Griffon Bleu De Gascogne                   | 319    |
| Griffon Nivernais                          | 42     |
| Hannoverischer Schweisshund                 | 83     |
| Hokkaido                                   | 5      |
| Hound of the Maremma                       | 2923   |
| Hovawart                                   | 232    |
| Hungarian Vizsla SH                        | 259    |
| Irish Soft-Coated Wheaten Terrier          | 43     |
| Irish Terrier                              | 31     |
| Irish Water Spaniel                        | 1      |
| Irish Wolfhound                            | 24     |
| Istrian Hound Rough Hair                   | 19     |
| Istrian Hound Short Hair                   | 212    |
| Italian Greyhound                          | 295    |
| Italian Hound Rough Haired                 | 1070   |
| Italian Hound Smooth Haired                | 3570   |
| Italian Spinone                            | 506    |
| Jack Russel Terrier                        | 5257   |
| Japanese Spitz                             | 26     |
| Karelian Bear Dog                          | 39     |
| Kerry Blue Terrier                         | 25     |
| King Charles Spaniel                       | 8      |
| Komondor                                   | 3      |
| Kooikerhondje                              | 5      |
| Labrador Retriever                         | 9414   |
| Lagotto Romagnolo                          | 2341   |
| Lakeland Terrier                           | 98     |
Table A1. Cont.

| Breed                                                        | Number |
|--------------------------------------------------------------|--------|
| Landseer                                                     | 14     |
| Lappinkoira                                                 | 16     |
| Leonberger                                                  | 161    |
| Lhasa Apso                                                  | 129    |
| Little Lion Dog                                             | 2      |
| Maltese                                                     | 1631   |
| Manchester Terrier                                          | 16     |
| Maremma and the Abruzzes Sheepdog                           | 993    |
| Mastiff                                                     | 32     |
| Miniature English Bull Terrier                              | 222    |
| Mudi                                                        | 7      |
| Neapolitan Mastiff                                          | 514    |
| Newfoundland                                               | 406    |
| Norfolk Terrier                                             | 30     |
| Norwich Terrier                                             | 20     |
| Nova Scotia Duck Tolling Retriever                          | 61     |
| Parson Russell Terrier                                      | 174    |
| Pekingese                                                   | 17     |
| Perdigueiro Português                                       | 1      |
| Petit Basset Griffon Vendeen                               | 56     |
| Petit Bleu De Gascogne                                      | 148    |
| Petit Brabançon                                             | 9      |
| Pharaoh Hound                                               | 1      |
| Picardy Shepherd                                            | 2      |
| Pinscher                                                    | 23     |
| Podenco Ibicenco                                            | 6      |
| Podengo Portugues                                           | 1      |
| Polish Greyhound                                            | 1      |
| Polish Lowland Sheepdog                                     | 5      |
| Poodle                                                      | 2072   |
| Porcelaine                                                  | 153    |
| Posavatz Hound                                              | 48     |
| Pug                                                         | 632    |
| Puli                                                        | 1      |
| Pumi                                                        | 2      |
| Pyrenean Mastiff                                            | 91     |
| Pyrenean Mountain Dog                                       | 115    |
| Pyrenean Shepherd                                           | 14     |
| Rhodesian Ridgeback                                         | 318    |
| Romanian Shepherd Bucovina                                  | 10     |
| Romanian Shepherd Dog Mioritic                              | 27     |
| Rottweiler                                                  | 4080   |
| Rough Collie                                                | 391    |
| Russian Toy                                                 | 16     |
| Saarloos Wolfdog                                            | 48     |
| Saint Bernard Dog                                           | 629    |
| Saluki                                                      | 34     |
| Samoiedo                                                    | 304    |
| Schapendoes                                                 | 16     |
| Schipperke                                                  | 13     |
| Scottish Terrier                                            | 113    |
| Sealyham Terrier                                            | 5      |
| Segugio dell’Appennino                                      | 197    |
| Segugio Maremmano                                           | 2923   |
### Table A1. Cont.

| Breed                        | Number |
|------------------------------|--------|
| Serbian Hound                | 1      |
| Serbian Tricolour hound      | 7      |
| Shar Pei                     | 551    |
| Shetland Sheepdog            | 168    |
| Shiba Inu                    | 701    |
| Shih Tzu                     | 604    |
| Shikoku                      | 9      |
| Siberian Husky               | 857    |
| Skye Terrier                 | 12     |
| Sloughi                      | 1      |
| Slovakian hound              | 103    |
| Smooth Collie                | 1      |
| Smooth Fox Terrier           | 80     |
| Spanish Mastiff              | 11     |
| Staffordshire Bull Terrier   | 1266   |
| Standard Schnauzer           | 208    |
| Swiss hound                  | 248    |
| Swiss Mountain Dog           | 86     |
| Tibetan Mastiff              | 124    |
| Tibetan Spaniel              | 5      |
| Tibetan Terrier              | 48     |
| Tosa                         | 2      |
| Volpino Italiano             | 130    |
| Weimaraner                   | 1158   |
| Welsh Corgi Cardigan         | 2      |
| Welsh Corgi Pembroke         | 195    |
| Welsh Springer Spaniel       | 3      |
| Welsh Terrier                | 36     |
| West Highland White T.       | 592    |
| Whippet                      | 489    |
| White Swiss Shepherd Dog     | 438    |
| Xoloitzcuintle               | 1      |
| Yorkshire Terrier            | 551    |
| Yugoslavian Shepherd Dog     | 25     |
| Zwergpinscher                | 454    |
| Zwergschnauzer               | 785    |
| **Total**                    | 154,195|

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