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Hair Whorls in the Dog (*Canis familiaris*), Part II: Asymmetries

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ABSTRACT

In horses and cattle, hair whorls have been shown to act as a structural marker of reactivity and behavioral lateralization. Few studies on canine whorls have been reported and none have assessed whorl position or direction of flow. This study describes the distribution and characteristics of whorl in each of 10 regions in which whorls are typically located in dogs. Hair whorls were assessed in dogs (n = 120) and were recorded as clockwise or counterclockwise in the cephalic, cervical (dorsal, lateral, ventral), thoracic and brachial axillary, chest, shoulders, elbows, abdominal, and ischiatic regions. Bilateral whorls, including brachial axillary, elbow, abdominal and ischiatic whorls, rotated in opposing directions, allowing the dog's overall hair coat to be symmetrical. Cephalic, brachial axillary, and ischiatic whorls were consistent in their direction; cephalic and ischiatic whorls were clockwise on the right side of the body, and counterclockwise on the left, whereas right brachial axillary whorls were counterclockwise and left were clockwise. The central chest whorl was predominantly counterclockwise (91.21%). Direction of whorls was associated with several factors, including coat length, coat thickness, sex and source of the dog. Anat Rec, 293:513–518, 2010. © 2009 Wiley-Liss, Inc.

Key words: hair whorl; whorl direction; hair coat; trichoglyphs; dog

Hair whorls are anatomical features of the hair coat that can show left-right asymmetry (Murphy and Arkins, 2005, 2008; Jansen et al., 2007). It is recognized that the direction of simple (divergent) whorls gives rise to hair patterning across the dogs' body. However, as with whorl occurrence *per se*, the exact mechanism that controls whorl direction is unknown and could be influenced by the same factors. Whorl direction is of interest as it is not influenced by culture and, hence, is a structural marker of lateralization and could potentially provide a visual indicator of functional brain lateralization. The relationship between hair whorls and brain development can be attributed to the nervous system and integument sharing a common ectodermal embryonic origin (Smith and Gong, 1974). This relationship has been investigated mainly in humans, with a significant association between hand preference and hair whorl direction having been reported, where an excess of clockwise whorls were observed in right-handed subjects (Klar, 2003; Beaton and Mellor, 2007). Numerous studies have reported a predominance of clockwise hair whorls in humans, with less than 10% of the general population pertaining counterclockwise whorls (Wunderlich and Heerema, 1975; Klar, 2003; Ziering and Krenitsky, 2003).

Related studies in non-human animals have largely focused on relationships between forehead (cephalic) whorl position and temperament (Grandin et al., 1995; Randle, 1998; Lanier et al., 2001; Górecka et al., 2006), but have not assessed whorl direction. More recently, Murphy and Arkins (2008) reported an association between cephalic hair whorl direction and reported motor laterality in horses, with counterclockwise whorls occurring in 52% of horses and being significantly linked

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Fig. 1. Photographs of hair whorls demonstrating directionality: (**A**) a clockwise (right) simple whorl; (**B**) a counterclockwise (left) simple whorl.

with a left-motor bias during ridden work. Hair whorl characteristics in *Canidae* have not widely been assessed prior to this two-part study (see Tomkins and McGreevy, in press). Evans and Christensen (1979) made brief reference to hair whorls being located in different regions of the body. Similarly, Pullig (1950) reported different locations in which whorls occurred on related Cocker Spaniels, but to date, there are no known studies investigating canine whorl direction. Therefore, the aim of the current study was to, first, assess the direction of whorls in each of the 11 different regions in which they are found and, second, describe the distribution of whorl directionality in the sample domestic dog population.

MATERIALS AND METHODS

Animals

Dogs (n = 120) were sourced across New South Wales, Australia, from both an animal shelter (shelter dogs; n = 60) and the University of Sydney Veterinary Teaching Hospital (nonshelter dogs; n = 60). Dogs available at both sites were assessed on days when the operator was visiting and were not subjected to selection by the operator. The group comprised breeds and crossbreeds and both males (n = 63; of which 18 were castrated) and females (n = 57; of which 20 were spayed and 23 were unspecified).

Whorl Direction

Whorl direction was determined according to the swirling direction of the hair: clockwise (hair growth radiating from the centre over to the right) or counterclockwise (hair growth radiating from the centre over to the left; Fig. 1).

The direction of a simple (divergent) whorl, where hairs diverge in a flattened swirling pattern, can be determined visually by the way in which the hairs radiate from the centre of the whorl. Determining direction in a tufted whorl, where hairs converge from different directions to a central point, requires palpation. In the current study, manipulation of the hair tuft was used to identify the way in which the majority of local hair shafts settled. The point at which the hair converged over the centre of the whorl was located, and the tuft of hair was then held between the index finger and thumb to rotate the hair in a given direction. The centre of the rotated tuft was then pushed down with the index finger, and if the flattened hair revealed a whorl formation, then the direction of the whorl could be identified. When hair is rotated against the natural direction of the hair shafts, it will not flatten to reveal the direction of the whorl but instead remains tufted without the appearance of any slightly flattened centre. Where this was the case, the hair tuft was rotated in the opposite direction to ensure that a clear distinction could be verified. Whorl direction was measured by a single operator.

Whorl Location

Whorls were assessed in 11 different regions of the body for each dog as described in Tomkins and McGreevy (in press). Briefly, these regions included the head (cephalic), neck (cervical and dorsal, lateral, and ventral mandibular), thorax (chest and thoracic axillary), thoracic limbs (brachial axillary, shoulder, and elbow), abdomen and caudal thighs (ischiatic). Where whorls were present bilaterally, such as in the brachial axillary, elbow, and ischiatic regions, they were recorded as right or left whorls for each region.

Coat Length and Thickness

Coat length and density were categorized using the methodology described previously in Tomkins and McGreevy (in press).

Interobserver Reliability

A group of randomly selected dogs (n = 10) was reviewed by two observers to determine interobserver reliability of assessing hair whorl characteristics. Both classification (simple or tuft) and direction (clockwise or

TABLE 1. Presence and direction of whorls occurring bilaterally

	Right Side			Left Side		
		Direction (%)			Direction (%)	
Position	Presence (%)	C	CC	Presence (%)	C	CC
Cephalic	5.00	100.00	0.00	5.00	0.00	100.00
Cervical—dorsal	–	–	–	–	–	–
Cervical—lateral[a]	8.40	0.00	100.00	7.56	77.78	22.22
Brachial axillae[a]	88.24	0.00	100.00	87.39	100.00	0.00
Thoracic axillae[b]	14.41	47.06	52.94	15.25	66.67	33.33
Shoulder	1.67	0.00	100.00	2.50	66.67	33.33
Elbow	81.67	15.31	84.69	82.50	82.83	17.17
Abdominal	2.50	33.33	66.67	2.50	66.67	33.33
Ischiatic	80.00	100.00	0.00	80.00	0.00	100.00

The percentage of dogs with whorls present in each region are based on n =120, with the exception of [a]n = 119, [b]n = 118.

counterclockwise) of hair whorls were assessed in each of the 10 regions assessed on each dog for whorls. Dogs were assessed individually by observers at separate sessions, and no discussions about observations took place. Interobserver reliability was also determined for characterizing coat characteristics in the sampled dog population. A second observer characterized both coat length and coat thickness of a subsample of randomly selected dogs (n = 30) based on the criteria outlined in the above methodology.

TABLE 2. Presence and direction of whorls occurring centrally

		Direction (%)	
Position	Presence (%)	C	CC
Cervical—ventral mandibular[a]	19.47	53.33	46.67
Chest	75.83	8.79	91.21

The percentage of dogs with whorls present in each region are based on n = 120, with the exception of [a]n = 113.

Statistical Analysis

Logistic regression from the statistical package GenStat tenth edition (VSN International; Hemel Hempstead, United Kingdom) was used for all whorl direction analyses. Four predictor variables (sex, source, coat length, and coat thickness) were used in the regression model. Statistical significances were established using likelihood ratio χ^2 test. Following the precedent reported in horse (Murphy and Arkins, 2004; Górecka et al., 2006) and cattle (Evans et al., 2005) studies, dogs that had multiple hair whorls in a single region and on a single side were recorded, but excluded from the analysis. This protocol caused the exclusion of dogs from the ventral mandibular (n = 7), thoracic axillary (n = 2), and brachial axillary (n = 1) whorl analyses. A kappa test from the statistical package Minitab fifteenth edition (Minitab, Pennsylvania, PA) was used to assess interobserver reliabilities for both whorl and coat characteristics.

RESULTS

Hair whorls were identified in 10 locations in domestic dogs (Tables 1, 2), with no whorls being observed on the dorsal surface of the cervical region. This region was checked, because it is known to bear whorls in at least two breeds of dog: the Rhodesian ridgeback and the Thai ridgeback. Although whorls were identified in each of these 10 regions, not all dogs had whorls present in every region. Therefore hair whorl direction data were based on a different number of dogs for each region as outlined for bilateral and centrally located whorls in Tables 1 and 2, respectively.

When whorls were found in a specific region in less than 10% of dogs (cephalic, cervical [lateral], shoulder, and abdominal regions), there were not enough data available to determine whether factors such as coat length and thickness, source, and sex of the dog were associated with whorl direction, and hence, these regions were excluded from the analysis.

Cephalic Whorls

Whorls were bilateral, and there was consistency in the direction of the whorls on each side of the head. Whorls on the dog's left were counterclockwise, whereas those on the right were clockwise.

Cervical Whorls

Whorls were not observed on the dorsal surface of the cervical region. Lateral cervical whorls were present, and there was consistency in whorl direction on the right side of the neck, with 100% of whorls being counterclockwise. Whorls on the left side of the neck were not consistent in direction: 77.78% of whorls being clockwise and 22.22% being counterclockwise.

Ventral Mandibular Whorls

Asymmetry was observed in the ventral mandibular region in that 86.67% of dogs with only a single whorl present had it on the left side of the body. Ventral mandibular whorls were clockwise in direction in 53.33% of dogs. Whorl direction was not affected by coat length ($\chi^2 = 2.56$, df = 1, $P = 0.110$), coat thickness ($\chi^2 = 0.82$, df = 2, $P = 0.664$), or source ($\chi^2 = 0.37$, df = 1, $P = 0.545$).

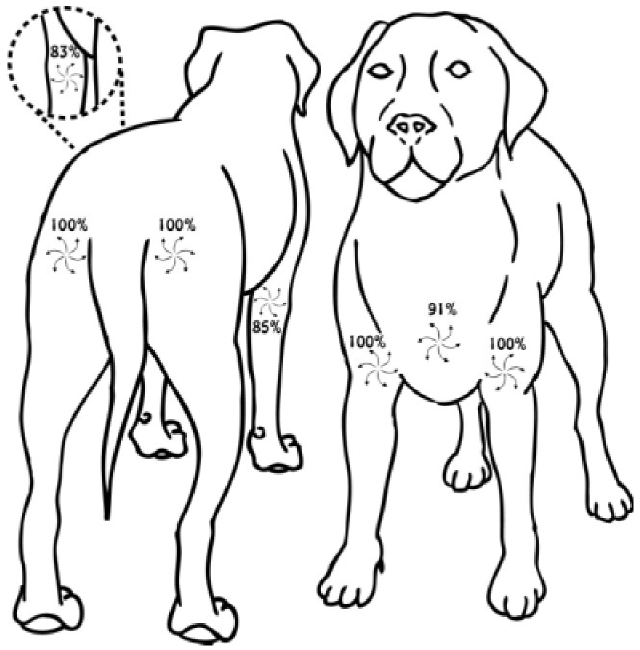

Fig. 2. The most common directions of hair whorls in the brachial axillary, elbow, chest, and ischiatic regions (i.e., whorls for which there was more than 80% concurrence on direction in the current dog population).

However, the sex of the dog did affect the direction of the whorl ($\chi^2 = 5.59$, df = 1, $P = 0.018$) in the ventral mandibular region. Clockwise whorls were observed in different frequencies between males (63.64%) and females (25.00%), whereas counterclockwise whorls occurring in 36.36% of males and 75.00% in females.

Chest Whorls

The direction of chest whorls was predominantly counterclockwise (91.21%) and was not influenced by coat length ($\chi^2 = 0.77$, df = 1, $P = 0.381$), coat thickness ($\chi^2 = 1.78$, df = 2, $P = 0.410$), sex ($\chi^2 = 0.33$, df = 1, $P = 0.568$), or source ($\chi^2 = 0.62$, df = 1, $P = 0.433$) of the dog.

Thoracic Axillary Whorls

There was a difference in the direction of whorls depending on the side of the thorax in which they were located. The majority of whorls on the left were clockwise (66.67%), and on the right, were counterclockwise (52.94%). The direction of whorls on the left or right side of the thoracic region was not affected by coat length (right [R], $\chi^2 = 2.36$, df = 1, $P = 0.124$; left [L], $\chi^2 = 1.12$, df = 1, $P = 0.291$), coat thickness (R, $\chi^2 = 3.06$, df = 2, $P = 0.217$; L, $\chi^2 = 2.12$, df = 2, $P = 0.346$), or source (R, $\chi^2 = 0.13$, df = 1, $P = 0.719$; L, $\chi^2 = 0.18$, df = 1, $P = 0.674$) of the dog. Direction of whorls situated on the left side of this region was influenced by the dog's sex ($\chi^2 = 4.46$, df = 1, $P = 0.035$), but that of those on the right side was not ($\chi^2 = 0.21$, df = 1, $P = 0.644$).

Brachial Axillary Whorls

There was consistency in the direction of left and right brachial axillary whorls: whorls on the right were counterclockwise and those on the left were clockwise. Because there was no variability in the data, statistical analysis could not be performed as direction of the whorl occurred independently of any association with factors such as coat length and thickness, and sex and source of the dog.

Shoulder Whorls

Whorls on the right shoulder were all counterclockwise in direction, whilst those on the left shoulder were only counterclockwise in 33.33% of the dogs where a whorl was present.

Elbow Whorls

The direction of elbow hair whorls differed greatly, depending on the forearm on which it was located. Right elbow whorls were primarily counterclockwise in direction (84.69%) and were influenced by coat length ($\chi^2 = 11.06$, df = 1, $P < 0.001$), coat thickness ($\chi^2 = 6.78$, df = 2, $P = 0.034$), and source ($\chi^2 = 8.23$, df = 1, $P = 0.004$), but not sex ($\chi^2 = 1.19$, df = 1, $P = 0.275$) of the dog. In contrast to this, left elbow whorls were primarily clockwise in direction (82.83%) and were influenced by coat length ($\chi^2 = 11.89$, df = 1, $p < 0.001$) and thickness ($\chi^2 = 6.27$, df = 2, $P = 0.044$), but not by source ($\chi^2 = 0.17$, df = 1, $P = 0.684$) or sex ($\chi^2 = 0.07$, df = 1, $P = 0.797$) of the dog.

Abdominal Whorls

Whorls were found in only 2.50% of the sample population and had little consistency in their direction. Whorls on the right side of the abdomen were clockwise in 33.33% of dogs, while those on the left were clockwise in 66.67% of the dogs.

Ischiatic Whorls

There was consistency in the direction of the whorls on each side of the caudal thighs. Whorls on the left side were counterclockwise, whereas those on the right side were clockwise.

Hair whorls were identified in more than 75% of the sample dog population on the chest, brachial axillary, elbow, and ischiatic regions. Within these regions, more than 80% of whorls were of the same directionality (Fig. 2).

Interobserver Reliability

Results demonstrated 100% interobserver reliability for both the classification ($\kappa = 1.000$) and direction ($\kappa = 1.000$) of hair whorls at all regions where a whorl was present in the dogs. Interobserver reliability for coat characteristics was 93.33% for both coat length ($\kappa = 0.857$) and coat thickness ($\kappa = 0.891$).

DISCUSSION

Typical whorls, such as those located on the chest, ischiatic, and brachial axillary regions and the elbows were present in the majority of dogs. Whorls that were a feature of fewer than 20% of the population were considered atypical, so represent a variation from normal hair patterning. Whorls present on the head, cervical regions (dorsal, ventral, and lateral), shoulders, thoracic axillary region, and ventral abdominal region were atypical.

In some regions, such as the cephalic, brachial axillary, and ischiatic regions, direction was consistent between all dogs. Only a small number of dogs had cephalic whorls (5.00%), but it could be assumed with some confidence that directionality of whorls in the brachial axillary and ischiatic regions is likely to persist in dogs and be independent of the presence of atypical whorls.

Whorls that were bilateral generally exhibited rotation in opposite directions. This can be attributed to the overall tendency for the dog's hair coat to be symmetrical. To enable this to occur, the simple whorls (such as brachial axillary and ischiatic whorls) that initiate the direction of hair growth over the body need to be opposing. The hair then moves in symmetrical streams over the body, meeting at lines or at tuft whorls where opposing symmetry is also achieved. This patterning is supported by the findings of brachial axillary and elbow whorl directions. The left and right brachial axillary whorls are in opposing directions, and the corresponding tufted whorl at the elbows were also in opposing directions to each other, but were in the same direction as the proximal brachial axillary whorl.

In contrast to the bilateral whorls on the left and right side of the body, which were largely consistent in the proportions of whorls in opposing directions, the two centrally located whorl regions had proportions of clockwise and counterclockwise whorls that were vastly different from each other. Whorls in the ventral mandibular region were roughly equal in their clockwise (53.33%) and counterclockwise (46.67%) direction. In contrast, the direction of the chest whorl differed greatly to that expected by chance (50.00% counterclockwise) under the assumption of independence. Counterclockwise whorls were reported in 91.21% of dogs with chest whorls. Numerous studies have shown the number of counterclockwise hair whorls in humans to be less than 10% in the general population (Wunderlich and Heerema, 1975; Klar, 2003; Ziering and Krenitsky, 2003), which compares with the 8.79% of clockwise chest whorls observed in the current canine sample. Although the primary direction of whorls differed, the similarity between the distribution of human scalp whorls and canine chest whorls may suggest that, like the relationship between scalp whorls and handedness where an excess of clockwise whorls were observed in right-handed subjects, the chest whorl may be the key whorl to examine when exploring potential associations between hair whorls and behavioral asymmetries, such as pawedness, in dogs.

Some factors were identified as affecting whorl direction. Sex was one of these: males had a predominance of clockwise whorls and females counterclockwise whorls in the ventral mandibular region. The opposite was true for the left thoracic whorl, where males predominately had counterclockwise whorls and females clockwise. Differences in whorl direction attributed to sex could be associated with different hormone concentrations *in utero* between male and female fetuses, given that previous studies have indicated that sex hormones *in utero* can influence the development of asymmetries (Schwarz and Rogers, 1992; Rogers and Rajendra, 1993; Scheirs and Vingerhoets, 1995). However, the only significant sex differences in this study were for whorls that were atypical. This sex difference may be anomalous as a result of the low number of whorls observed in the atypical regions. The relationship was not observed in any of the typical whorls. Therefore, to truly ascertain the relationship, if any, between sex and whorl direction, more dogs with atypical ventral mandibular and thoracic axillary whorls need to be identified and assessed.

The direction of elbow whorls was influenced by coat length and thickness, and on the right elbow, by source. On the right elbow, dogs with medium coat thickness had the highest percentage of counterclockwise whorls, whereas dense-coated dogs had the lowest. It was interesting to note that the association between coat thickness and direction corresponded to the same order for clockwise whorls on the left elbow, where medium-coated dogs had the highest percentage of clockwise whorls and dense-coated dogs had the least.

Studies by Wang et al. (2006) showed that hair orientation occurred before follicles emerged through the surface of the skin in the fetus, which concurs with the findings of Curtiss et al. (2002) that gene expression and cell signaling play a role in determining hair whorl characteristics. The trend for dogs with fine-to-medium coats to be more consistent in the direction of their elbow whorls than dogs with dense coats may reflect less efficient cell signaling in regions with a higher concentration of follicles (i.e., in dense-coated dogs) than in those with fewer follicles (such as that occurs in finer-coated dogs). When the ratio of primary (guard) hairs to secondary (undercoat) hairs is reduced, as in the case of dense-coated dogs such as huskies, the strength of cell signaling to control whorl direction may be reduced, and hence, a difference in the percentage of dogs with whorls emerges. However, if this is the case, it is difficult to explain why it occurs only on the elbows. Alternatively, the absence of an association between coat thickness and whorl direction in other regions may indicate that this phenomenon is also linked to the classification of whorls and to whether or not they are simple or tufted. Along with the chest, the elbows were one of two regions that featured tufted and not simple whorls. Although some researchers (Guo et al., 2004; Wang et al., 2006) have shown that the Wnt-signaling pathway and Fz6 play a role in hair patterning, the exact mechanism that controls hair development remains the subject of speculation. If Colin's (1943) theory on metabolic activity controlling whorl characteristics holds, then the centre of the tufted (converging) whorl should represent regions of high activity. It is in these regions of high metabolic activity that the cell signaling may be altered, depending on the thickness of the dog's coat.

The relationship between coat length and elbow whorl direction is similar to that between coat thickness and elbow whorl direction. Dogs with short-haired coats had significantly more whorls in a given direction on each elbow. On the right elbow, 90.91% of short-haired dogs had counterclockwise whorls in comparison with only 71.88% in long-haired dogs. On the left elbow, 89.71% of short-haired dogs had clockwise whorls compared with 67.74% in long-haired dogs. Evans (1993) reported that dogs with longer hair coats have a tendency to have higher hair implantation angles than short-haired dogs, which suggests that the mechanism for controlling hair direction may interact with that controlling follicle angle.

The direction of a whorl on the right elbow was also affected by source. Nonshelter dogs had significantly more counterclockwise whorls than shelter dogs (95.24% vs. 76.79%; $P = 0.004$). The cadavers in this study were sourced from a shelter, and given that a study by Salman et al. (2000) found that behavioral problems are the leading cause of owners relinquishing dogs to shelters, it suggests that the direction of the elbow whorl could be of interest as a potential predictor of certain unfavorable behavioral attributes. By identifying potential predictors of unfavorable behavioral attributes, owners may be able to prevent adverse tendencies from developing or be better equipped for management strategies.

The relationship between whorl direction and behavioral characteristics has not widely been established in non-human animals, and even where studies have been conducted, such as that by Murphy and Arkins (2008) in the horse, only cephalic whorls were studied. By describing the distribution of whorl direction in the 10 different regions of the dog, a clearer understanding of whorls can be ascertained in the domestic dog, with the current data offering the potential to facilitate exploration of the relationship between laterality and hair whorl characteristics.

This study has demonstrated that the direction of hair whorls in a sample of the general dog population varies with each of the 10 different regions of the body in which they were located. Population consistency was observed for whorls in the cephalic, brachial axillary, and ischiatic regions. Bilateral whorls, such as brachial axillary, elbow, abdominal, and ischiatic whorls showed a trend for whorls to rotate in opposing directions, supporting the overall tendency for the dog's hair coat to be symmetrical. However, significant population biases occurred in the direction of whorls in the cephalic, cervical (lateral), chest, brachial axillary, shoulder (right), elbow, and ischiatic regions. Some of these were sex-related, while others were associated with coat qualities and the source of the dog. The last of these variables merits particular scrutiny in case it reflects behavioral tendencies.

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