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Radiographic evaluation of congenital vertebral anomalies in Korean raccoon dogs (*Nyctereutes procyonoides koreensis*)

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ABSTRACT

Background: The normal vertebral anatomy of Korean raccoon dogs and their variants require research attention as a prerequisite for identifying pathologies and anomalies.
Objectives: This retrospective study aimed at describing the vertebral formula and congenital vertebral anomalies in Korean raccoon dogs (*Nyctereutes procyonoides koreensis*).
Methods: Radiographs of 82 raccoon dogs (42 males, 40 females) acquired from May 2013 to June 2020 in the Gangwon Wildlife Medical Rescue Center were reviewed to evaluate the cervical, thoracic, and lumbar vertebrae of the spine.
Results: Normal morphology of all vertebrae was observed in 50 of the 82 raccoon dogs, and the vertebral formula was cervical 7, thoracic 13, and lumbar 7. Congenital vertebral anomalies were found in 32 raccoon dogs: transitional vertebrae (TV) in 31 and block vertebrae in 2. Two raccoon dogs had 2 types of vertebral anomalies: one had TV and block vertebra, and the other had 2 types of TV. Twenty-nine raccoon dogs had thoracolumbar TV (TTV) and 3 had lumbosacral TV. TTV was morphologically classified into 4 different types: unilateral extra-rib in 5 raccoon dogs, bilateral extra-ribs in 14, bilateral elongated transverse processes in 4, and an asymmetric mixed formation of extra-rib with elongated transverse process in 6.
Conclusions: This study showed that TTV is common in Korean raccoon dogs, and that the vertebral formula is relatively diverse. The bilateral extra-ribs type TTV is the most common variant, which is almost similar to normal rib to be confused the radiographic evaluation.

Keywords: Congenital anomaly; *Nyctereutes procyonoides*; raccoon dogs; spine; vertebrae

INTRODUCTION

The raccoon dog (*Nyctereutes procyonoides*) belongs to the order Carnivora, family Canidae. *N. procyonoides*, inhabits East Asia, and is classified into 6 subspecies [1]. *N. procyonoides ussuriensis* inhabits Russia, north-eastern China, and Eurasia; *N. procyonoides procyonides*, Vietnam and southern China; *N. procyonoides albus*, Hokkaido, Japan; *N. procyonoides viverrinus*, Japan, except Hokkaido; *N. procyonoides orestes*, Yunnan, China; and *N. procyonoides koreensis*, the Korean peninsula [2]. *N. procyonoides koreensis* is a subspecies native to Korea and the second-most rescued animal in the Gangwon Wildlife Medical Rescue Center (WMRC) [3].

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Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization: Park I, Choi S; Data curation: Lee EG, Park SY, Kim JT; Formal analysis: Lee EG; Funding acquisition: Choi S; Investigation: Lee EG, Park SY, Lee K, Jang M; Project administration: Choi S; Writing - original draft: Lee EG, Choi S; Writing - review & editing: Lee K, Jang M, Park I, Choi S.

Approximately 47.4% of the rescued animals at the WMRC were injured because of trauma, such as that caused by vehicle collision or poaching tools [3]. In the evaluation of trauma patients, imaging modalities such as radiography and computed tomography (CT) are the basic tools for diagnosing musculoskeletal injury, thoracic, and abdominal trauma [4-6]. Particularly for musculoskeletal injuries, these imaging modalities provide critical information regarding the location, type, complexity, and potential complications associated with fractures, which aids in assessing and planning surgery [4-6]. For such frequent cases, knowledge of normal anatomy or of normal variations and aberrant anatomic changes is key for the accurate interpretation of radiological images [6].

Congenital vertebral anomalies include transitional vertebrae (TV), block, hemi-, and wedge vertebrae. TV are characterized by features retained from adjacent regions in the vertebral column, and found at the junction between 2 divisions of the vertebral column—cervicothoracic, thoracolumbar, lumbosacral, or sacrocaudal, and the resultant number of vertebrae found within a division may vary accordingly [7,8]. Based on a comprehensive comparative study, the number of thoracolumbar vertebrae tends to be 19 in many groups of mammals and 20 in most Carnivora species, while cervical vertebrae are almost always 7 in mammals [9]. According to a 1983 necropsy study that investigated vertebral variations in *N. procyonoides viverrinus*, the vertebral column of raccoon dogs consists of 7 cervical, 13 thoracic, and 7 lumbar vertebrae (C7-Th13-L7), which is almost invariably the normal formula [10]. However, from our radiographic experiences at the Gangwon WMRC, TV of extra-rib has frequently been detected in the Korean raccoon dog. Therefore, congenital vertebral variation could be assumed to be considerably high in this subspecies.

We conducted a retrospective radiographic study on rescued Korean raccoon dogs in the Gangwon WMRC to evaluate the overall vertebral congenital anomalies and to identify variations in radiographic vertebral morphology and formula in Korean raccoon dogs.

MATERIALS AND METHODS

The study included rescued raccoon dogs that had undergone radiographic evaluation including that of the entire cervical, thoracic, and lumbar sections of the vertebral column as part of their diagnostic evaluation at the Gangwon WMRC between 2013 and 2020. The sex of all the raccoon dogs was recorded. All radiographs were acquired using the digital radiography system (VXR-9M; DRGEM, Republic of Korea). Radiographic images acquired from May 2013 to September 2016 were stored as jpg files and those acquired from October 2016 to June 2020 were stored as DICOM files in the communication system (ViewRex; TechHeim, Republic of Korea).

All radiographic images were reviewed by an experienced veterinarian and the vertebrae were classified as follows: vertebrae with normal morphology and vertebrae with congenital anomalies of TV, block, hemi-, and wedge vertebrae. The formula and total count from the cervical to lumbar vertebrae and the location of TV were also recorded. Thoracolumbar TV (TTV) was classified according to the morphology of its rib or transverse process, and divided into those with and without the shape of a rib. If the morphology of the rib resembled the shape of a rib, had orientation in the same direction, and a width similar to the rib on the adjacent thoracic vertebra [11,12], then it was designated as extra-rib. Others, having a broad base of rib or a length of less than half that of the adjacent rib, were designated as

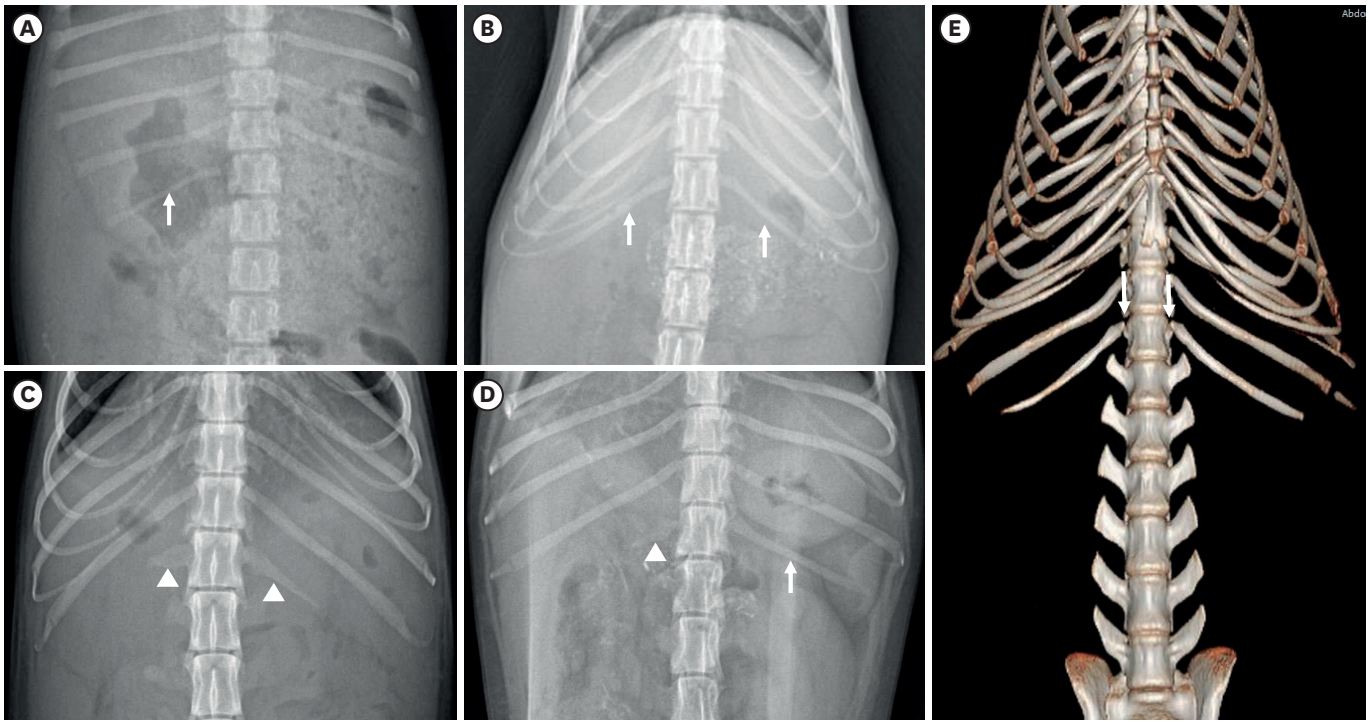

Fig. 1. Ventrodorsal radiographic view of raccoon dogs with thoracolumbar transitional vertebrae. (A) Unilateral extra-rib (white arrow) is detected, classified as type 1. (B) Supernumerary ribs (white arrows) are detected, classified as type 2. (C) Bilateral elongated transverse processes (white arrow heads) are detected, classified as type 3. (D) Asymmetric mixed formation of extra-rib (white arrow) and elongated transverse process (white arrow head) are detected, classified as type 4. (E) Three-dimensional computed tomography image clearly shows the costovertebral joints (white arrows).

elongated transverse process [12,13]. As a result, TTV was classified into 4 different types (**Fig. 1A-D**): unilateral extra-rib and normal transverse process (type 1), bilateral extra-ribs (supernumerary ribs) similar to normal morphology (type 2), bilateral elongated transverse processes (type 3), and mixed formation of extra-rib and elongated transverse process (type 4). Lumbosacral TV (LTV) was divided into 3 types based on the morphological characteristics of the transverse process [14]. The sacrum was identified as a single segment, and the number of sacral segments was not evaluated.

The number of congenital anomalies and total vertebral count were statistically analyzed for the frequency of occurrence, stratified by sex, by the Fisher's exact test using the commercial software SPSS 25.0 (IBM SPSS statistics, USA). The level of statistical significance was set at $p < 0.05$.

RESULTS

A total of 144 rescued Korean raccoon dogs' radiographs were reviewed, and the entire vertebral columns were identified in the radiographs of 82 (42 male, 40 female). Of the 82 raccoon dogs, 50 (60.9%) had normal morphology in all vertebrae. Abnormal vertebral morphology was identified in 32 raccoon dogs (35 vertebral anomalies). Twenty-nine raccoon dogs had single vertebral anomalies and 3 of them had 2 vertebral anomalies (**Table 1**). Thirty-two TV were found in 31 raccoon dogs, of which 29 were TTV and 3 were LTV. One raccoon dog had both TTV and LTV. When classified according to the morphology of TTV, the most common type was type 2 in 14 raccoon dogs, followed by type 4 in 6, type 1 in 5, and type 3 in 4 (**Fig. 1**). There was an ambiguity in one case, where the right side of this raccoon dog's TTV

Table 1. Congenital vertebral anomalies and vertebral formulas in Korean raccoon dogs (n = 82)

Morphology	Type of anomaly	Vertebral formula	Male/female	Total
Normal		C7-Th13-L7	27/23	50
Abnormal	TTV	C7-Th13-TTV-L6	12/14	26
	TTV	C7-Th13-TTV-L7	0/1	1
	LTV	C7-Th13-L6-LTV	0/1	1
	LTV	C7-Th13-L7-LTV	1/0	1
	TTV, LTV	C7-Th13-TTV-L6-LTV	1/0	1
	Block vertebra (Th1-3, Th4-5)	C7-Th13-L7	0/1	1
	TTV, Block vertebra (C6-7)	C7-Th13-TTV-L6	0/1	1

TTV, thoracolumbar transitional vertebra; LTV, lumbosacral transitional vertebra; C, cervical; L, lumbar; Th, thoracic.

was the direction and length of a rib, but with a broad base. This vertebra was classified as type 3; however, if the right side of TTV was categorized as an extra-rib, it would be classified as type 4. All LTVs articulated symmetrically with the wings of the ilium and were classified as symmetric type 3/3 (**Fig. 2A**). Block vertebrae were identified at 3 locations (C6-7, Th1-3, and Th4-5) in 2 raccoon dogs (**Fig. 2B and C**), and the other anomalies (hemi- and wedge vertebra) were not identified in any raccoon dogs.

Seven vertebral formulas were identified. C7-Th13-L7 was the most common vertebral formula (62.2%), followed by C7-Th13-TTV-L6 (32.9%). The total vertebral count was 27 in most raccoon dogs, except in 3 that had 28 vertebrae, with the following vertebral formulas: C7-Th13-TTV-L7, C7-Th13-TTV-L6-LTV, and C7-Th13-L7-LTV. In 29 raccoon dogs with TTV, the most common vertebral formula was C7-Th13-TTV-L6 (27/29), while 2 had the formulas C7-Th13-TTV-L7 and C7-Th13-TTV-L6-LTV. Raccoon dogs with LTV had 3 different types of formulas: C7-T13-L6-LTV, C7-Th13-L7-LTV, and C7-Th13-TTV-L6-LTV. There was no statistical difference in occurrence of vertebral anomalies ($p = 0.20$) and TTV ($p = 0.27$), and vertebral total count ($p = 0.52$) by sex.

Although CT image was not involved in this study design, there was a series of CT images in a raccoon dog with type 2, and the 3-dimensional CT image clearly showed costovertebral joints of the extra-ribs (**Fig. 1E**).

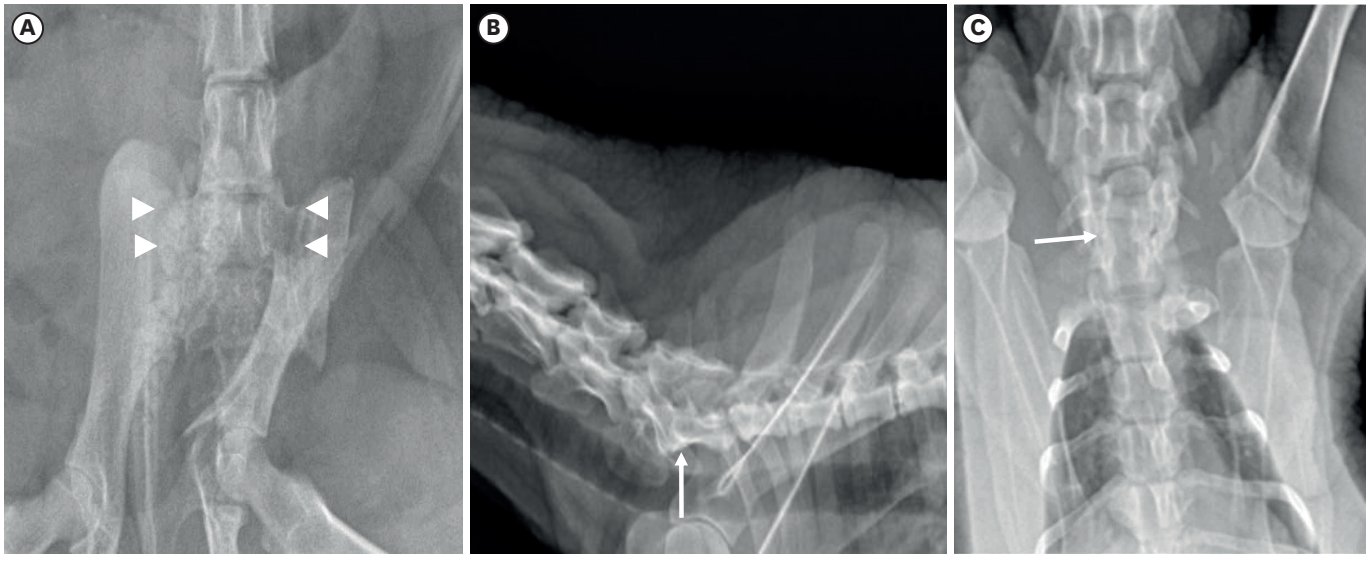

Fig. 2. Raccoon dogs with various vertebral morphologic anomalies. (A) Ventrodorsal radiographic view in a raccoon dog with lumbosacral transitional vertebrae (white arrow heads). Pelvic fracture is also seen in this raccoon dog. (B, C) Lateral and ventrodorsal view of a raccoon dog with block vertebra. Incomplete fusion of the vertebral body C6-7 seen (white arrows). No angular deformity noted.

DISCUSSION

In our study, the most common vertebral formula was the same as other Canidae family members, and the percentage of this formula was noticeably low (60.9%). Dogs and red foxes have the vertebral formula C7-Th13-L7, which is almost constant (dogs, 93.0%; red fox 100%) [10,15]. In Japanese raccoon dogs, vertebral formula is almost constant as well [10]. TV is one of the most common anomalies observed in veterinary medicine, and TTVs are commonly identified among the TVs [8]. Previous studies in dogs found TTV in 7.0% and LTV in 3.5% [14,15]. The percentages of TTV and LTV demonstrated are 14.0% and 2.5% in cats [11], 10.6% and 1.8% in rabbits [12], and 7.6% and 5.8% in ferrets [13], respectively. In Japanese raccoon dogs, TTV was identified in 6.2% and LTV in 2.0% [10]. In our study, the most commonly identified vertebral anomaly was TV, especially TTV, which is typically identified more frequently in Korean raccoon dogs than in other species.

Although the exact cause of TV is not known, it is considered to be due to a shift in the boundary of the somites during the vertebral developmental period [8]. At this time, a cranial shift occurs, resulting in the 1st lumbar thoracicization; if a partial cranial shift occurs, partial or incomplete rib formation also occurs [16]. *Hox* genes are regulators of development of the vertebrae, spinal nerves, and their interactions [17]. Mutations in *Hox* genes have been reported to play a critical role in the formation of TV in human, mice, and dogs [18-20]. No research has been done on raccoon dogs yet, but based on these studies, it may be assumed that the diversity of the thoracic vertebrae is genetic. Although sexual dimorphism was found in some characteristics of the spinal cord in previous studies [21], sex was not related to the occurrence of vertebral anomalies, TTV, and total vertebral count in our study.

TTV most commonly involves the presence or absence of a costa or transverse process. Characteristics of adjacent divisions are exhibited in a single vertebra, unilaterally or bilaterally [8]. A rib is defined as a separated bone that articulates with the costal foveae at the bodies or the pedicle of the vertebrae, and the morphologic characteristics and classification system for the ribs of TTV have been studied in humans [22]. Unlike humans, a clear morphologic classification for extra-ribs in animals is not yet available. In our study, we classified TTV morphologically as rib-like and non-rib-like. The resultant classification shows various morphologies of TTV, notably the bilateral extra-ribs (type 2), which was most common. Type 2 TTV is morphologically almost similar to a normal rib; hence, caution is advised when interpreting its radiographs. Furthermore, it is important to take a radiograph in which the entire vertebrae are visible to allow the surgeon to determine the surgical site of the spine and evaluate the number of thoracic vertebrae.

In one raccoon dog, there was an ambiguity regarding assignment to type 3 or type 4. For accurate identification, the joint with the vertebral body should have been evaluated, but the presence or absence of costovertebral joints is difficult to identify in radiographs [12]. In previous human studies, morphologic characteristics and variations in TTV were definitively determined using CT, which enabled the evaluation of the costovertebral joint [22], similar to the CT image presented in this study. A CT scan is recommended for more accurate and detailed classification of vertebral morphologies and anomalies.

LTV is commonly known to increase the incidence of lumbosacral disc disease and nerve root compression. Dogs with LTV have a predisposition to cauda equine syndrome [23,24]; asymmetrical LTV can result in femoral head subluxation, malformation of the hip joint,

and secondary osteoarthritis [25]. Mammals with LTV have decreased strength and flexibility in the lumbosacral joint; hence, they cannot survive for long [26]. Low variability in the lumbosacral junction may be a feature of fast and agile mammals [26]. The Castellvi classification, based on a human study, classifies LTV morphology into 4 different types [27]. In dogs 3 types are recognized [14]: type 1 as lumbar type, type 2 as intermediate type, and type 3 as sacral type. According to this classification, the raccoon dogs in this study had symmetric type 3 LTV. In the study on Japanese raccoon dogs in 1983, 63.2% had block vertebrae [10]. According to previous studies on other species, block vertebrae are seen in, 0.7%, 1.5%, 1.8%, and 1.2% of dogs, cats, rabbits, and ferrets, respectively, which similar to our findings in Korean raccoon dogs [11-13,15].

Our study had limitations associated with the population used. First, although this study was conducted on Korean raccoon dogs, only the raccoon dogs that were rescued at the Gangwon WMRC and underwent radiographic examination of the entire vertebral column were selected for analysis. In previous studies, raccoon dog populations of Gangwon and Seoul/Gyeonggi had similar genetic profiles, but both populations showed significant differences in genetic profiles when compared with those of Chungcheong, Jeolla, and Gyeongsang [2]. The population in our study might not be representative of all healthy Korean raccoon dogs. Moreover, there could have been a difference between the rescued raccoon dogs and the non-rescued ones. Even though TTV, which was most frequently identified in this study, has not been associated with any particular clinical symptoms [28], incomplete vertebral transformations impair axial mobility and thereby threaten survival [26]. It might be meaningful to confirm its link with clinical symptoms through further studies. Second, the morphological anomalies of the sacrum were not evaluated. The normal sacrum consisted of 3 fused vertebrae is fused spinous processes to form the medial sacral crest, and there are no intervertebral discs [14]. In most cases, when evaluating vertebra in our study, radiography was not suitable for evaluating the sacral crest; CT could enable evaluation of the number of spinous processes in the medial sacral crest. A form of lumbarization has been identified in TV of the sacrum [14]. A link may exist between the assessment of sacral lumbarization and the 3 raccoon dogs with total 28 vertebral count in our study.

In conclusion, this study showed that TTV is common in Korean raccoon dogs, that vertebral formula is relatively diverse, and that the bilateral extra-ribs type TTV is the most common type that is almost similar to normal rib. These factors may be confused during the radiographic evaluation of congenital vertebral anomalies. It is suggested that radiographs of the entire vertebrae must be obtained to prevent an error in interpretation when evaluating congenital vertebral anomalies.

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