Iranian Veterinary Surgery Association

Iranian Journal of Veterinary Surgery

Journal homepage: www.ivsajournals.com

Original Article

Computed Tomographic and Morphometric Study of Lumbosacral and Coccygeal Vertebrae in Healthy White New Zealand Rabbit (*Oryctolagus Cuniculus*)

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ARTICLE INFO

Article History:

Received 22 December 2021
Revised 10 February 2022
Accepted 5 March 2022
Online 5 March 2022

Keywords:

Morphometry
Lumbar vertebrae
Sacrum
Coccygeal vertebrae
Rabbit

ABSTRACT

Rabbits are commonly used in researches but despite their wide usage, knowledge of normal structure of various parts of lumbosacral and coccygeal vertebrae with computed tomography (SC) is obscure. On the other hand, scrutinizing of structures in these regions in their natural status can bring about more accurate diagnostic and therapeutic approaches for clinicians and surgeons. The goal of this study was to provide an exhaustive descriptive and morphometric assessment of lumbosacral and coccygeal vertebrae in rabbits with computed tomography. In this article morphometric parameters in 2D CT images of 10 healthy, mature, white New Zealand rabbits were measured. End plate height (EPH) had no significant difference through lumbosacral and coccygeal vertebrae but other parameters such as vertebral body height (VBH), spinous process height (SPH), transverse process length (TPL), transverse process width (TPW), spinous process angle (SPA), transverse process angle (TPA) and vertebral body length (VBL) had significant differences. Spinal canal depth (SCD) had an invariable measure from the first lumbar vertebra up to the third sacral vertebra and decreased at the location of the fourth sacral vertebra and was invariable up to the second coccygeal vertebra. Pedicle width (PDW) had an invariable measure from the first cervical vertebra up to the second coccygeal vertebra. In conclusion computed tomographic anatomy of lumbosacral and coccygeal vertebrae in white New Zealand rabbits were evaluated and different parts of vertebrae were described.

Introduction

It should be noted that studies on the morphometry of rabbit cervical vertebrae have been performed by computed tomography (CT) scan.[1] Of course, cases such as vertebral formula and congenital abnormalities of

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https://doi.org/10.30500/IVSA.2022.321066.1288

the vertebral column in rabbits have also been considered in studies.[2] Studies have also been performed on Functional Neuroanatomy of the Domestic Rabbit.[3] Alfraihat *et al*. in 2022 studied thoracic vertebral morphology in normal and scoliosis deformity in skeletally immature rabbits. They examined changes in the vertebral body height (VBH).[4] Tan and colleague in 2004 details the quantitative three-dimensional anatomy of cervical, thoracic and lumbar vertebrae (C3–T12) of Chinese Singaporean subjects based on 220 vertebrae from 10 cadavers. In their study the linear dimensions, angulations and areas of individual vertebra were measured and data were compared with similar studies performed on Caucasian specimens.[1] Ohlerth *et al*. in 2005 introduced CT scan as one of the most practical diagnostic methods for small animal orthopedics purposes,[5] and in current examination CT provided precise series of measurements of selected parameters. Zotti *et al*. in 2009 evaluated anatomy of neck, thorax and abdomen of healthy rabbits by computed tomography and explained the morphologic appearances of each anatomical region.[6] Van Caelenberg *et al*. in 2010 evaluated the normal anatomy of the rabbit's head and the soft tissues around it.[7]. Da Costa *et al*. in 2010 represented computed tomography as a fast and exact method for evaluation of vertebral column in small animals,[8] which current examination declare that CT can be used in exotic and lab animals such as rabbits. Rong-Ring *et al*. in 2013 evaluated vertebral degenerative diseases in rabbits by computed tomography.[9] Axlund *et al*. in 2003 evaluated the lumbar and sacral vertebrae in 22 dogs.[10] Ren Sheng *et al*. in 2009 evaluated vertebral column in large animals and compared them with human.[11]. Jeffcott *et al*. in 1979 evaluated anatomy radiography of thoracic and lumbar vertebra in horses.[12] Cotterill *et al*. in 1986 compared thoracic-lumbar vertebrae in cows with humans. Current study is based on measurements of vertebrae and evaluation done on radiography, 2D and 3D computed tomography.[13]

Comparative studies between rabbit vertebrae and other animals have also been performed.[14] Of course, different parameters have been examined with our study. There are similar cases that we compared with our study. Shateri *et al*. in 2020 studied morphometry of cervical vertebrae in healthy rabbits.[15]

Computed tomography is a nonaggressive modality which provides detailed information about the vertebral column.[16] Therefore, this modality is considered as a valuable method for detection of bony changes of vertebrae in medicines and veterinary medicines.[10]

Despite the wide usage of rabbit in researches, knowledge of normal structure of various parts of lumbosacral and coccygeal vertebrae with computed tomography is obscure. On the other hand, scrutinizing of structures in these regions in their natural status can bring about more accurate diagnosis and therapeutic approaches for clinicians and surgeons. The goal of this study was to provide an exhaustive descriptive and morphometric assessment of lumbosacral and coccygeal vertebrae in rabbits with computed tomography. In this article, several parameters of lumbosacral and coccygeal vertebrae were measured with computed tomography.

Materials and Methods

Animals

In this study 10 white and mature female New Zealand rabbits (*Oryctolagus cuniculus*) with average body weight of 1.95 ± 0.05 kg were evaluated. All of the rabbits were healthy physically. All the experimental procedures were in accordance with the ethical values of the NIH *Guide for the Care and Use of Laboratory Animals.*[17] It should be noted that none of the rabbits were euthanized for this study.

Computed Tomography

The rabbits were anesthetized for CT scan (ketamine and xylazine combination). Images were taken as transverse and perpendicular to vertebral column and in 2 mm slices. Images were constructed in ventral recumbency. Computed tomography technical factors were: rotation time 1 s; slice thickness 1 mm; reconstruction interval 0.5–1 mm; pitch 1; X-ray tube potential 120 kV; and X-ray tube current 130 mA. Several structures in vertebral column were evaluated in images and different parts were named. For the purpose of evaluating each part, proper window level (WL) and window width (WW) have been chosen for evaluation of bone window and thorax (chest) window.

Morphometric Study

Morphometric mensurement in CT images was done with Syngo MMWP VE40A software. The measured parameters are shown in Table 1. The results of mentioned parameters were analyzed by SPSS software version 16 and paired sample *t*-test. $p > 0.05$ was considered as the significant difference.

Results

Morphologic Results

The formula of the lumbar, sacral and coccygeal part of the vertebral column in rabbits was: L_7, S_4, Cd_{16}.

Lumbar vertebrae. There were seven lumbar vertebrae in white New Zealand rabbits. Transverse process in these vertebrae were very long and were located caudally, distally and laterally. Spinous process length increases from the first to sixth vertebra (Figures 1 and 2). Accessory processes were seen in the first to sixth lumbar vertebrae that were more prominent in the first to fifth ones. These processes were between transverse process and caudal articular process or were located on caudal articular process (Figures 1, 2, 3, and 4).

Sacral vertebrae. There were 4 sacral vertebrae. These vertebrae were completely separated and were not fused (Figures 2 and 3).

Coccygeal vertebrae. The main part of these vertebrae were consisted of body and arch. Process in these vertebrae were dwindled. Spinous process had mostly two parts. Cranial vertebrae were longer and caudal vertebrae were shorter (Figure 3 and 5).

Morphometric Results

The results of measurements and statistical analysis are shown in Tables 2 to 7.

Table 1. Morphometric parameters investigated in this study.

Parameter	Abbreviation	Description
Vertebral body height	VBH	Distance between the base of vertebra to vertebral canal in transverse view
Spinous process height	SPH	Distance between base of spinous process to apex of process in transverse view
Transverse process length	TPL	Distance between the base of transverse process to extremity of process in transverse view
Transverse process width	TPW	Distance between left extremity of process to right extremity in transverse view
Spinous process angle	SPA	The angle between spinous process with horizontal line in sagittal view
Transverse process angle	TPA	The angle between transverse process with horizontal line in transverse view
Spinal canal depth	SCD	Distance between proximal extremity of vertebral canal to distal extremity of vertebral canal in transverse view
Spinal canal width	SCW	Distance between left extremity of vertebral canal to right extremity of vertebral canal in transverse view
Pedicle length	PDL	Distance between proximal extremity of pedicle to distal extremity in transverse view
Pedicle width	PDW	The width of pedicle in transverse view
Vertebral body length	VBL	The length of vertebral body in sagittal view
Endplate width	EPW	The width of end plate in transverse view
Endplate height	EPH	The height of end plate in transverse view

Table 2. Morphometric measurements of lumbar vertebrae of 10 rabbits (mean ± standard deviation in cm and degree).

Lumbar vertebrae	TPA	SPA	TPW	TPL	SPH	VBH
L_1	49.5 ± 0.6a	101.3 ± 1.9a	1.5 ± 0.4a	0.9 ± 0.3a	0.8 ± 0.07a	**0.7 ± 0.1a**
L_2	50 ± 0.1a	102.6 ± 1.4a	2 ± 4.2b	1.2 ± 0.2a	0.8 ± 0.1a	**0.7 ± 0.1a**
L_3	45.4 ± 0.1b	109.6 ± 1.1b	2.5 ± 0.2c	1.7 ± 0.1b	0.8 ± 0.1a	**0.6 ± 0.1a**
L_4	45.8 ± 0.4b	113 ± 1.6b	2.9 ± 0.2d	1.8 ± 0.1b	0.8 ± 0.07a	**0.4 ± 0.09a**
L_5	42.7 ± 0.5b	112.5 ± 1.2b	3 ± 0.2d	1.8 ± 0.08b	0.8 ± 0.1a	**0.4 ± 0.03a**
L_6	43.1 ± 0.8b	113.5 ± 1.1b	3 ± 0.4d	1.7 ± 0.4b	0.9 ± 0.09a	**0.5 ± 0.03a**
L_7	43.4 ± 0.1b	112.5 ± 1.1b	2.1 ± 0.5b	1.7 ± 0.2b	0.9 ± 0.1a	**0.5 ± 0.05a**

The different letters (a, b) in each column represent significant different between vertebrae (n = 10, $p < 0.05$).

Table 3. Morphometric measurements of lumbar vertebrae of 10 rabbits (mean ± standard deviation in cm).

Lumbar vertebrae	EPH	EPW	VBL	PDW	PDL	SCW	SCD
L_1	0.4 ± 0.02a	0.8 ± 0.04a	1.4 ± 0.09a	0.2 ± 0.03a	0.5 ± 0.05a	0.4 ± 0.04b	**0.4 ± 0.02a**
L_2	0.4 ± 0.02a	0.9 ± 0.06a	1.5 ± 0.06a	0.2 ± 0.03a	0.5 ± 0.06a	0.4 ± 0.02b	**0.3 ± 0.03a**
L_3	0.4 ± 0.03a	0.9 ± 0.05a	1.6 ± 0.07a	0.2 ± 0.03a	0.5 ± 0.08a	0.5 ± 0.07b	**0.4 ± 0.03a**
L_4	0.4 ± 0.04a	1 ± 0.04a	1.6 ± 0.06a	0.2 ± 0.03a	0.5 ± 0.03a	0.4 ± 0.05b	**0.4 ± 0.04a**
L_5	0.4 ± 0.02a	1.07 ± 0.05a	1.6 ± 0.07a	0.2 ± 0.04a	0.5 ± 0.04a	0.5 ± 0.07b	**0.4 ± 0.03a**
L_6	0.4 ± 0.02a	1.1 ± 0.07a	1.5 ± 0.1a	0.2 ± 0.03a	0.4 ± 0.08a	0.3 ± 0.03b	**0.4 ± 0.04a**
L_7	0.4 ± 0.03a	0.9 ± 0.3a	1.3 ± 0.2a	0.4 ± 0.2a	0.4 ± 0.06a	0.6 ± 0.07b	**0.4 ± 0.07a**

The different letters (a, b) in each column represent significant different between vertebrae (n = 10, $p < 0.05$).

Table 4. Morphometric measurements of sacral vertebrae of 10 rabbits (mean ± standard deviation in cm and degree).

Sacral vertebrae	TPA*	SPA*	TPW	TPL	SPH	VBH
S_1	37.5 ± 0.7a	77 ± 1a	2 ± 0.3a	0.9 ± 0.07a	0.9 ± 0.1a	**0.5 ± 0.09a**
S_2	36 ± 1.4a	44.7 ± 1b	1.3 ± 0.5b	0.5 ± 0.2b	0.5 ± 0.1b	**0.4 ± 0.03a**
S_3	36.7 ± 0.8a	37.9 ± 1.6c	0.6 ± 0.1c	0.3 ± 0.09b	0.4 ± 0.04b	**0.1 ± 0.006b**
S_4	21.4 ± 0.7b	31.9 ± 0.8c	0.5 ± 0.1c	0.2 ± 0.06b	0.4 ± 0.02b	**0.1 ± 0.02b**

The different letters (a, b, c) in each column represent significant different between vertebrae (n = 10, $p < 0.05$).

Table 5. Morphometric measurements of sacral vertebrae of 10 rabbits (mean ± standard deviation in cm).

Sacral vertebrae	EPH	EPW	VBL	PDW	PDL	SCW	SCD
S_1	0.3 ± 0.02a	0.9 ± 0.2a	1.01 ± 0.1a	0.3 ± 0.2a	0.3 ± 0.05a	0.4 ± 0.1a	**0.4 ± 0.1a**
S_2	0.2 ± 0.06a	0.4 ± 0.07b	1 ± 1.1a	0.3 ± 0.1a	0.2 ± 0.07a	0.3 ± 0.1a	**0.3 ± 0.05a**
S_3	0.2 ± 0.03a	0.4 ± 0.08b	0.8 ± 0.1a	0.2 ± 0.006a	0.2 ± 0.04a	0.3 ± 0.07a	**0.3 ± 0.1a**
S_4	0.2 ± 0.03a	0.3 ± 0.01b	0.7 ± 0.1a	0.1 ± 0.02a	0.06 ± 0.02b	0.07 ± 0.03b	**0.05 ± 0.02b**

The different letters (a, b) in each column represent significant different between vertebrae (n = 10, $p < 0.05$).

Table 6. Morphometric measurements of coccygeal vertebrae of 10 rabbits (mean ± standard deviation in cm and degree).

Coccygeal vertebrae	TPA*	SPA*	TPW	TPL	SPH	VBH
Cd_1	23.6 ± 0.5a	31.8 ± 0.2a	0.6 ± 0.1a	0.3 ± 0.06a	0.3 ± 0.09a	**0.1 ± 0.02a**
Cd_2	22.6 ± 8.4a	26.8 ± 0.2b	0.7 ± 0.04a	0.3 ± 0.08a	0.2 ± 0.06a	**0.1 ± 0.04a**

The same letters (a) in each column represent no significant difference between vertebrae (n = 10, $p < 0.05$).

Table 7. Morphometric measurements of coccygeal vertebrae of 10 rabbits (mean ± standard deviation in cm).

Coccygeal vertebrae	EPH	EPW	VBL	PDW	PDL	SCW	SCD
Cd_1	0.2 ± 0.02a	0.3 ± 0.04a	0.7 ± 0.06a	0.1 ± 0.006a	0.03 ± 0.02a	0.06 ± 0.04a	**0.05 ± 0.02a**
Cd_2	0.2 ± 0.02a	0.3 ± 0.01a	0.5 ± 0.06a	0.1 ± 0.04a	0.02 ± 0.01a	0.06 ± 0.006a	**0.05 ± 0.03a**

The same letters (a) in each column represent no significant difference between vertebrae (n = 10, $p < 0.05$).

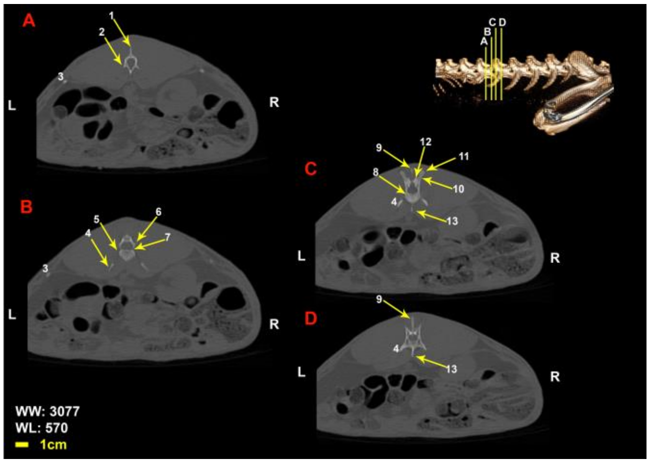

***Figure 1**.* Transverse computed tomography images (bone window) of second and third lumbar vertebrae in rabbit. The picture at the right top of this figure shows the section of transverse CT images (3D reconstruction image, osseous-shaded-vp).

1. Spinous process of second lumbar vertebra, 2. Transverse process of second lumbar vertebra, 3. Twelfth rib, 4. Transverse process of third lumbar vertebra, 5. Body of second lumbar vertebra, 6. Accessory process of second lumbar vertebra, 7. Intervertebral notch of second lumbar vertebra, 8. Body of third lumbar vertebra, 9. Spinous process of third lumbar vertebra, 10. Cranial articular process of third lumbar vertebra, 11. Mammillary process, 12, caudal articular process of second lumbar vertebra, 13. Ventral crest.

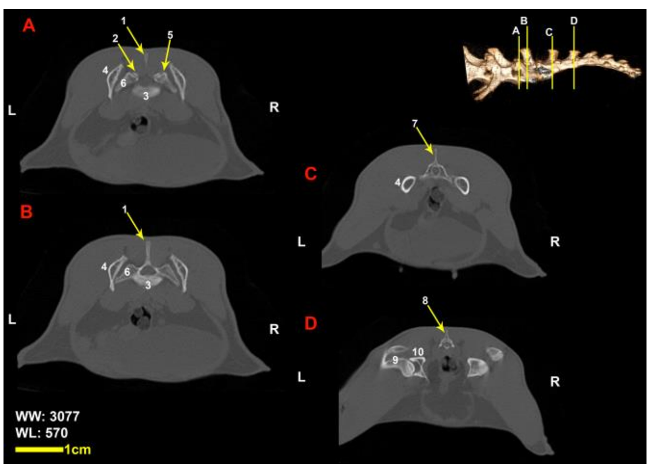

***Figure 2**.* Transverse computed tomography images (bone window) of the seventh lumbar vertebra and the first and the second sacral vertebrae in rabbit. The picture at the right top of this figure shows the section of transverse CT images (3D reconstruction image, osseous-shaded-vp).

1. Spinous process of first sacral vertebra, 2. Caudal articular process of seventh lumbar vertebra, 3. Body of first sacral vertebra, 4. Ilium, 5. Cranial articular process of first sacral vertebra, 6. Wing, 7. Spinous process of second sacral vertebra, 8. Spinous process of third sacral vertebra, 9. Femur, 10. Acetabulum.

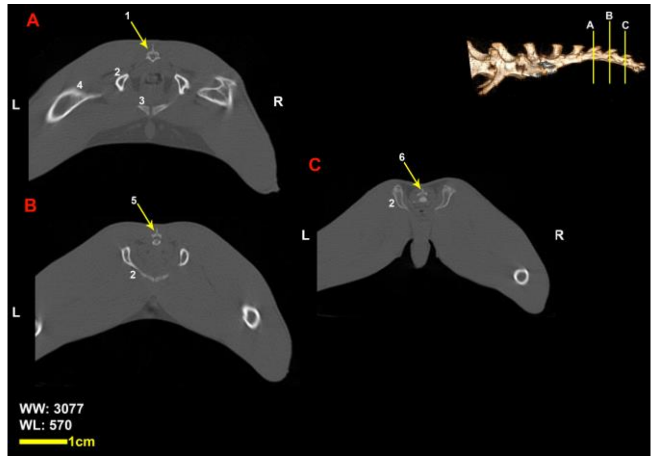

***Figure 3**.* Transverse computed tomographic images (bone window) of the last sacral vertebra and the first and second coccygeal vertebrae in rabbit. The picture at the right top of this figure shows the section of transverse CT images (3D reconstruction image, osseous-shaded-vp).

1. spinous process of fourth sacral vertebra, 2. Ischium, 3. Pubis, 4. Femur, 5. Spinous process of first coccygeal vertebra, 6. Spinous process of second coccygeal vertebra.

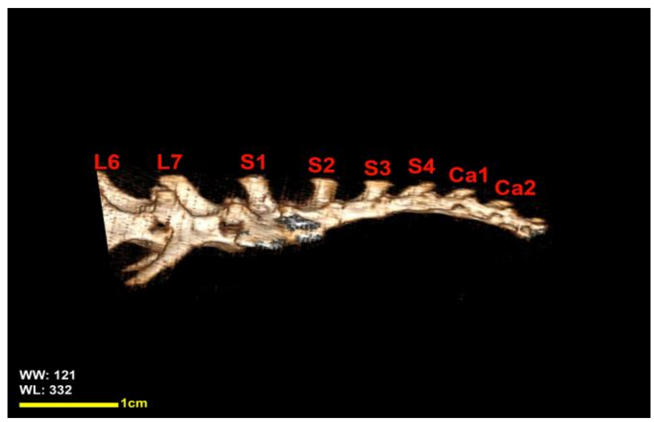

***Figure 4**.* 3D reconstruction image, osseous-shaded-vp, lumbar vertebrae in rabbit.

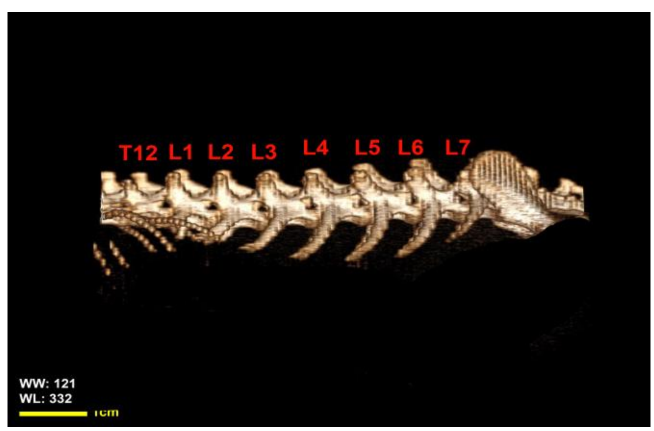

***Figure 5**.* 3D reconstruction image, osseous-shaded-vp, sacral and coccygeal vertebrae in rabbit.

Discussion

In the present study, different parts of lumbosacral and coccygeal vertebrae were described and the changing courses of measured parameters in CT were evaluated. Wilke *et al*. in 1997 evaluated the anatomy of vertebral canal in sheep and its comparison with human. In this study which is similar to our study, 5 cases were obtained and almost all parameters of vertebrae were evaluated and measured.[18] In conclusion, in this study lumbosacral and coccygeal vertebrae were evaluated with CT modality and each part of vertebrae was described and mentioned parameters were measured. Vertebral body height (VBH) had an invariable measure from the lumbar vertebrae to the second sacral vertebra. At the third sacral vertebra this parameter decreased and then was invariable up to the location of the second coccygeal vertebra.

Spinous process height (SPH) had an invariable measure up to the location of the first sacral vertebrae then was invariable up to the location of the fourth sacral vertebra and decreased at the location of the first coccygeal vertebra and again was invariable until the second coccygeal vertebra.

Transverse process length (TPL) was invariable from the first to the second lumbar vertebra. It increased at the location of the third lumbar vertebra and was invariable up to the location of the seventh lumbar vertebra. It decreased at the location of the first sacral vertebra then decreased at the second sacral vertebra and was invariable up to the location of the second coccygeal vertebrae. The TPL in the human exhibits a drastic increase in the lumbar spine, with a maximum of 71.4 mm at L3.[1]

Transverse process width (TPW) increased from the first to fourth lumbar vertebrae and from the fourth lumbar vertebrae to the sixth lumbar vertebrae it decreased at the seventh lumbar vertebra. It decreased at the first sacral vertebra and it decreased at the second sacral vertebrae it again deceased at the third sacral vertebra and was invariable up to the second coccygeal vertebra.

Spinous process angle (SPA) had an invariable measure from the first to the second vertebra, then increased at the location of the third lumbar vertebra and was invariable up to the seventh lumbar vertebra and decreased from the first sacral vertebra up to the second coccygeal vertebra. Transverse process angle (TPA) was invariable up to the second lumbar vertebra and decreased at the third lumbar vertebra and again was invariable up to the location of the seventh lumbar vertebrae. It decreased at the first sacral vertebra and was invariable up to the fourth sacral vertebra and increased up to the second coccygeal vertebrae. Spinal canal depth (SCD) had an invariable measure from the first lumbar vertebra up to the third sacral vertebrae and decreased at the location of the fourth sacral vertebra and was invariable up to the second coccygeal vertebra. The SCD in the human exhibits a gradual decreasing trend from L1 to L5, with an average value of 11.4 mm at L5[1]. Spinal canal width (SCW) was invariable up to the third sacral vertebra. It decreased at the fourth sacral vertebra and then was invariable up to the second coccygeal vertebra. The SCW in the human is almost constant from L1 to L3 and increases towards a maximum of 23.5 mm at L5.[1]

Pedicle length (PDL) had an invariable measure from the first lumbar vertebra up to the third sacral vertebra. It decreased at the fourth sacral vertebra and was invariable up to the second coccygeal vertebra. Pedicle width (PDW) had an invariable measure from the first cervical vertebra up to the second coccygeal vertebra. The pedicle width in human increases steeply from L1 to a maximum mean of 11.6 mm at L5.[1]

Vertebral body length (VBL) was invariable up to the location of the seventh lumbar vertebra then it decreased at the location of the first sacral vertebra and was invariable up to the second coccygeal vertebra. This parameter is equivalent to vertebral body height (VBH) in the studies of Tan *et al*. in 2003 on humans. They have mentioned about VBH that there is a constant increase from L1 to L4.

Endplate width (EPW) had an invariable measure from the first lumbar vertebrae up to the first sacral vertebra then it decreased at the second sacral vertebra and was invariable up to the second coccygeal vertebra. Endplate height (EPH) had an invariable measure from the first lumbar vertebra up to the second coccygeal vertebra.

Comparative studies between rabbit vertebrae and other animals have also been performed. For example, comparison of back and loin locomotor bony structures in cat and rabbit was studied.[14] Of course, different parameters have been examined with our study, there are similar cases that we compare with our study. They point out that the mammillary processes in cats and rabbits were well-defined beard on the lumbar cranial articular processes, that closely similar to dogs. However, the accessory processes were present in both species in all lumbar vertebrae except the last two.[14] This process was not observed in the seventh lumbar vertebra of our rabbits.

In this study computed tomographic anatomy of lumbosacral and coccygeal vertebrae in 10 wWhite New Zealand rabbits were evaluated and different parts of vertebrae had been named and described and also some parameters of vertebra were measured in computed tomography.

Acknowledgments

The authors thank the Faculty of Veterinary Medicine, University of Tehran, Tehran, Iran, for all of the facilities.

Conflict of Interest

The authors declare that they have no conflict of interest.

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