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Three-dimensional reconstruction of multidetector computed tomography images of paranasal sinuses of New Zealand rabbits**

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Abstract: This study was conducted to produce a 3-dimensional reconstruction using multidetector computed tomography (MDCT) images of the anatomic structures forming the paranasal sinuses of New Zealand rabbits and to present biometric properties of the sinuses and conchae. A total of 16 adult New Zealand rabbits, comprising 8 males and 8 females, were included in the study. After high-resolution MDCT images of the paranasal sinuses were obtained, they were reconstructed using a 3-dimensional modeling program (Mimics) by overlapping the images and the biometric measurements of the structures forming the paranasal sinuses. The maxillary sinuses of New Zealand rabbits were made up of 2 compartments. It was also observed that their conchae were more developed with an uneven structure. The frontal sinus and sphenoid sinus were not seen and the ethmoid sinus was not observed. There was not a significant statistical difference between sinus and conchae constituting the right and left paranasal sinuses of the same sex; however, a significant statistical difference was observed between the sexes ($P < 0.05$). This study's data can be used for purposes of modern anatomy education and research and may form a basis as a model for future studies to be performed on the paranasal sinuses.

Key words: Computed tomography, paranasal sinuses, rabbit, 3-dimensional reconstruction

1. Introduction

Morphological information about nasal cavity and paranasal sinuses is clinically very important. This information can be used to study the pathology of the sinus, to determine the treatments, to plan surgery, and to carry out surgical simulations. The most commonly used method for studying the paranasal sinuses is to use index volumetric measurements (1). However, it is not always possible to measure the volume of the sinus clinically because this requires a lot of effort. In the planning of treatment, the healthy sinus can be compared with the diseased sinus (2). Detailed anatomic information about the sinus is important in the determination and application of the method to be used for endoscopic sinus surgery (3,4).

The sinuses are physically close to brain, eyes, and major arteries and, therefore, endonasal sinus operation requires a high degree of accuracy (5). Generally, it is difficult to define the size and location of lesions in the head region through clinical and radiographic studies (6). Since traditional radiology overlaps the structures, it does not yield a complete view of the region (7).

For the last 10 years, computed tomography (CT) and magnetic resonance (MR) imaging techniques have replaced the imaging of paranasal sinuses by traditional X-ray. These 2 technological modalities can be used in the precise diagnosis and in the determination of more detailed anatomic structure of the diseased region (8). The axial, sagittal, and coronal sections obtained by CT and MR enable better evaluation of these structures (9).

CT is used not only in human medicine but also in veterinary medicine. It is commonly used in the evaluation of sinonasal diseases of cats and dogs (10,11).

Recently, 2-dimensional images of sinuses obtained by multidetector computed tomography (MDCT) have been transformed into 3-dimensional reconstructions by using a 3-dimensional computer program. In particular, 3-dimensional reconstructions of the maxillary sinus applied in odontotherapy were performed and their volumes were calculated (12,13). Moreover, the volume of maxillary sinuses was calculated by using sectional views obtained from CT of pig skulls (14).

There are limited reconstructive studies in the literature. This study was performed in order to provide information

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in this field, focusing on the analysis of MDCT images of paranasal sinuses in New Zealand rabbits, 3-dimensional anatomic properties of rabbit paranasal sinuses by modeling of these images, and the study of their biometric measurements.

2. Materials and methods

This study was accepted by the ethics committee of the Veterinary Faculty of Selçuk University on 24 June 2009 (decision number: 2009/056).

2.1. Age and weight

In this study, a total of 16 New Zealand rabbits of both sexes aged 1–1.5 years and weighing between 3 and 3.5 kg were used.

2.2. Anesthesia

The rabbits were intravenously anesthetized with a mixture of 5 mg/kg ketamine-HCl (Ketamidor, RicherPharma AG, Austria) and 20 mg/kg propofol (Propofol amp., Fresenius Kabi, Austria).

2.3. MDCT images

Under anesthesia, MDCT images of animals in the prone position were obtained. The parameters of the MDCT (Somatom Sensation 64; Siemens Medical Solutions, Germany) instrument were adjusted as follows: physical detector collimation, 32 × 0.6 mm; final section collimation, 64 × 0.6 mm; section thickness, 0.75 mm; gantry rotation period, 330 ms; kVp, 120; mA, 300; resolution, 512 × 512 pixels; resolution range, 0.92 × 0.92. Dosage parameters and scanning were done on the basis of predictions from standard protocols and the current literature (15,16). An attempt was made to obtain radiometric resolutions (MONOCHROME2; 16 bits) at the lowest radiation level with optimum image quality. The axial images obtained were saved in DICOM format and then evaluated in a personal computer.

2.4. Three-dimensional reconstruction

In the first stage of the automatic segmentation process, the limits of the sinus cavities and conchae were determined. The points that were not correctly positioned on boundaries of sinuses and conchae were edited point by point with a computer mouse by only one and the same operator who was the head researcher of the present study (as shown in Figures 1–3). Manual correction was performed after controlling again with the naked eye, deleting unneeded places, and then reconstruction was carried out with the 3-dimensional translator component of the mentioned program by overlapping the images, the limits of which were determined. Three-dimensional images, localization, modeling of this region, and volume and surface area of paranasal sinuses were presented. The biometric measurements of the paranasal sinuses were carried out using 3-D modeling software (Mimics 13.1 Materialise Group, Belgium).

2.5. Statistical analysis

The statistical analysis was performed by using SPSS 13.0 for Windows. The independent samples t-test was carried

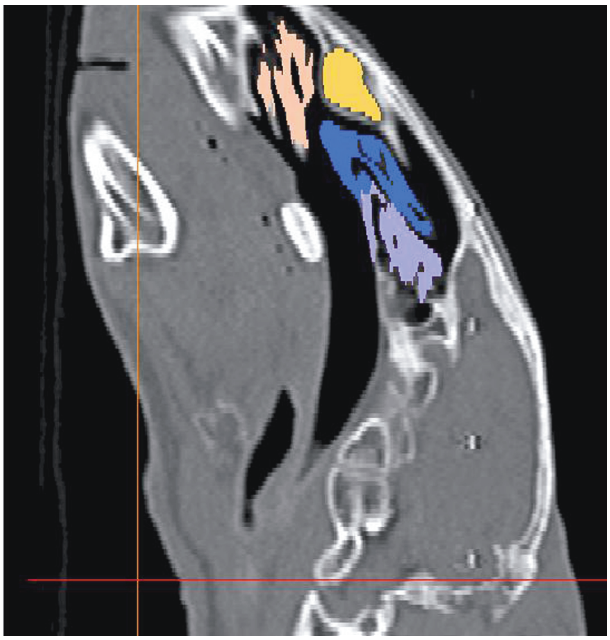

Figure 1. Limitation of conchae on sagittal section with different colors (pink: ventral nasal concha, blue: middle nasal concha, yellow: dorsal nasal concha, and purple: endoturbinalia).

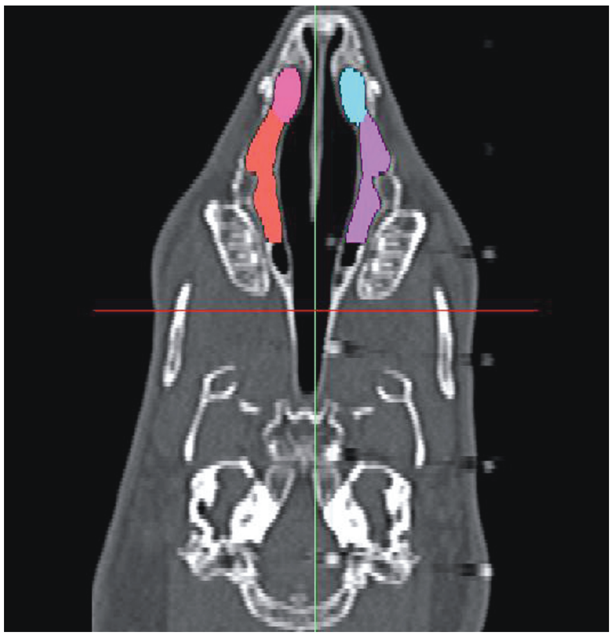

Figure 2. Limitation of dorsal nasal concha and maxillary sinus in the right and left sides on coronal section with different colors.

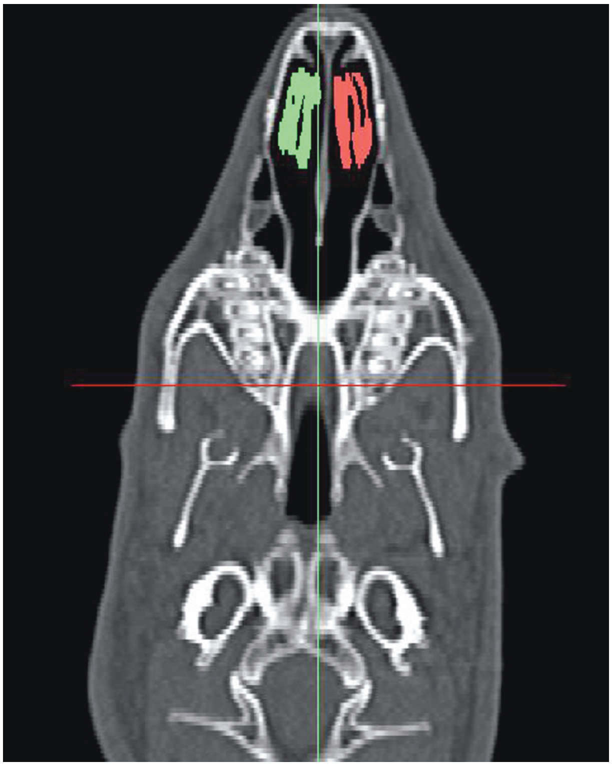

Figure 3. Limitation of ventral nasal concha in the right and left sides on coronal section with different colors**.**

out and the mean values, standard deviations, and P-values of biometrical measurements belonging to the paranasal sinuses in the right and left side for males and females were calculated separately. In this study, a statistically significant difference was observed for the paranasal sinuses within and between both sexes.

Nomina Anatomica Veterinaria (17) was used in terminology.

3. Results

As a result of reconstruction, it was determined that each half of the head had the dorsal nasal concha, middle nasal concha, ventral nasal concha and endoturbinalia (as shown in Figures 4–7), and maxillary sinus, which consisted of 2 compartments (as shown in Figure 8). The statistical analysis of volumetric values and surface area measurements of the reconstructed maxillary sinus and concha were performed (as shown in Tables 1–6). There was no statistically significant difference between the right and left paranasal sinuses of the same sex ($P > 0.05$). However, significant statistical differences were determined between cavities forming paranasal sinuses on the same sides of male and female rabbits ($P < 0.05$). While performing statistical analysis, we did not consider the weights of the rabbits because in this study they were selected on the basis of having similar weights.

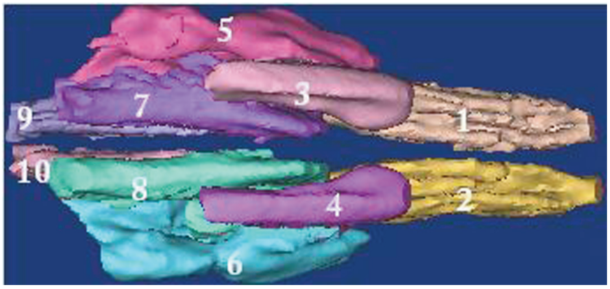

Figure 4. Dorsal view of paranasal sinuses. 1: Left ventral nasal concha, 2: right ventral nasal concha, 3: left dorsal nasal concha, 4: right dorsal nasal concha, 5: left maxillary sinus, 6: right maxillary sinus, 7: left middle nasal concha, 8: right middle nasal concha, 9: left endoturbinalia, 10: right endoturbinalia.

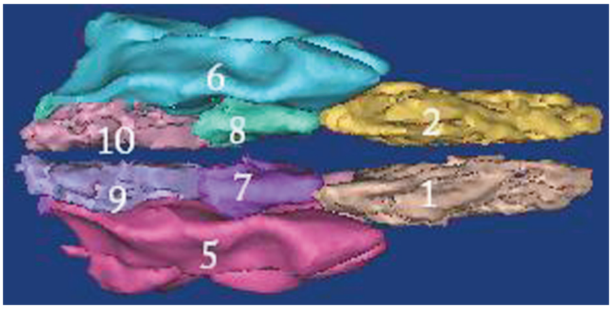

Figure 5. Ventral view of paranasal sinuses. 1: Left ventral nasal concha, 2: right ventral nasal concha, 5: left maxillary sinus, 6: right maxillary sinus, 7: left middle nasal concha, 8: right middle nasal concha, 9: left endoturbinalia, 10: right endoturbinalia.

Figure 6. Caudal view of paranasal sinuses. 3: Left dorsal nasal concha, 4: Right dorsal nasal concha, 5: Left maxillary sinus, 6: Right maxillary sinus, 7: Left middle nasal concha, 8: Right middle nasal concha, 9: Left endoturbinalia, 10: Right endoturbinalia

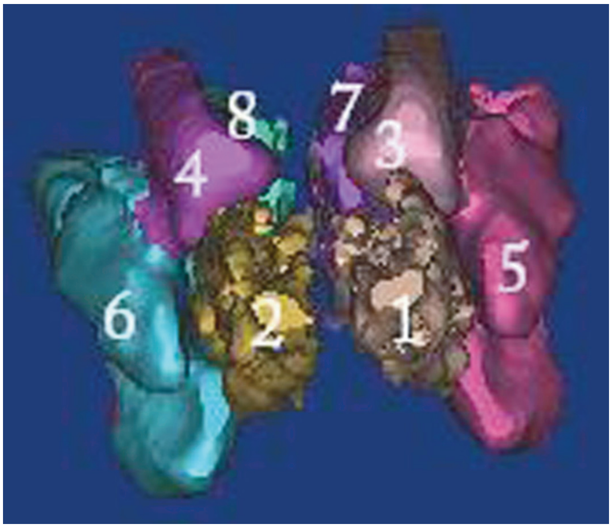

Figure 7. Cranial view of paranasal sinuses. 1: Left ventral nasal concha, 2: right ventral nasal concha, 3: left dorsal nasal concha, 4: right dorsal nasal concha, 5: left maxillary sinus, 6: right maxillary sinus, 7: left middle nasal concha, 8: right middle nasal concha.

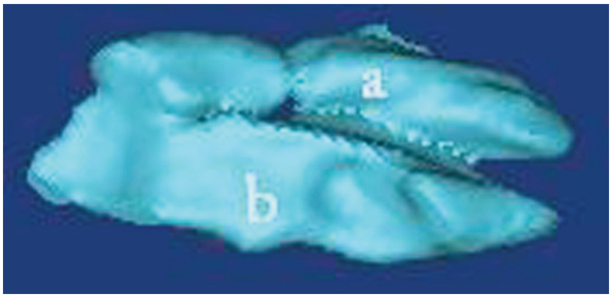

Figure 8. Maxillary sinus. a: Upper compartment, b: lower compartment.

3.1. Statistical results obtained as a result of reconstruction

The results presented in Tables 1–4 show that there are no differences between surface area and volumetric parameters of right and left paranasal sinuses of male and female New Zealand rabbits.

Results from Table 5 show that there are statistically significant differences between surface area parameters belonging to the right and left paranasal sinuses of male and female New Zealand rabbits. Surface area measurement values of maxillary sinus, ventral nasal concha, middle nasal concha, dorsal nasal concha, and endoturbinalia are higher in the male rabbits than those of female New Zealand rabbits.

Significant differences were found between volumetric parameters belonging to the right and left paranasal sinuses of male and female New Zealand rabbits. Volumetric measurement values of maxillary sinus, ventral nasal concha, middle nasal concha, dorsal nasal concha, and endoturbinalia were found to be higher in male rabbits than in female New Zealand rabbits (Table 6).

4. Discussion

Unlike human beings, the maxillary sinuses of New Zealand rabbits are made up of 2 compartments. Conchae, on the other hand, are more developed and have a more complex structure than those of human beings. The frontal sinus and sphenoidal sinus were not encountered. A real

Table 1. Statistical results of surface area parameters of paranasal sinuses of male New Zealand rabbits obtained through 3-dimensional reconstruction of CT images ($mm^2 \pm$ SD).

	Right (n = 8)	Left (n = 8)
Maxillary sinus	804.95 ± 44.39	814.19 ± 53.41
Ventral nasal concha	879.72 ± 94.41	846.40 ± 82.18
Middle nasal concha	666.49 ± 135.04	659.89 ± 117.78
Dorsal nasal concha	280.12 ± 53.62	275.08 ± 47.81
Endoturbinalia	455.63 ± 124.14	463.63 ± 96.15

Data expressed as the mean ± SD.

Table 2. Statistical results of surface area parameters of paranasal sinuses of female New Zealand rabbits obtained through 3-dimensional reconstruction of CT images ($mm^2 \pm$ SD).

	Right (n = 8)	Left (n = 8)
Maxillary sinus	583.34 ± 52.13	591.00 ± 56.42
Ventral nasal concha	355.96 ± 18.64	364.22 ± 22.38
Middle nasal concha	449.85 ± 31.21	445.86 ± 41.48
Dorsal nasal concha	240.09 ± 18.61	240.37 ± 22.37
Endoturbinalia	288.31 ± 62.61	281.66 ± 57.54

Data expressed as the mean ± SD.

Table 3. Statistical results of volumetric parameters of paranasal sinuses of male New Zealand rabbits obtained through 3-dimensional reconstruction of CT images ($mm^3 \pm$ SD).

	Right (n = 8)	Left (n = 8)
Maxillary sinus	812.95 ± 105.69	822.12 ± 69.94
Ventral nasal concha	539.03 ± 92.38	529.27 ± 105.21
Middle nasal concha	427.99 ± 95.69	442.01 ± 70.96
Dorsal nasal concha	267.23 ± 71.62	258.52 ± 81.12
Endoturbinalia	289.69 ± 102.29	320.87 ± 88.66

Data expressed as the mean ± SD.

Table 4. Statistical results of volumetric parameters of paranasal sinuses of female New Zealand rabbits obtained through 3-dimensional reconstruction of CT images ($mm^3 \pm$ SD).

	Right (n = 8)	Left (n = 8)
Maxillary sinus	561.15 ± 80.27	563.05 ± 90.51
Ventral nasal concha	259.50 ± 73.20	268.78 ± 71.38
Middle nasal concha	300.75 ± 44.12	293.54 ± 57.90
Dorsal nasal concha	210.15 ± 24.27	218.34 ± 43.67
Endoturbinalia	195.10 ± 42.34	185.62 ± 37.97

Data expressed as the mean ± SD.

ethmoidal sinus was also not present. However, Özer (18) regarded aerial cavities similar to the sinus ethmoidalalis as a single ethmoidal sinus. Bahadir et al. (19) determined that it was technically quite difficult to set the volume of the ethmoidal sinus.

Tingelhaff et al. (1) performed 3-dimensional reconstruction of human paranasal sinuses manually and semiautomatically. When measurements were taken and compared, it was observed that there was no statistical difference between manual and semiautomatic

Table 5. Statistical results of surface area parameters of paranasal sinuses of male and female New Zealand rabbits obtained through 3-dimensional reconstruction of CT images ($mm^2 \pm SD$).

	Male (n = 16)	Female (n = 16)
Maxillary sinus*	809.57 ± 47.68	587.17 ± 52.62
Ventral nasal concha*	863.06 ± 87.22	360.09 ± 20.35
Middle nasal concha*	663.19 ± 122.46	447.86 ± 35.52
Dorsal nasal concha*	277.60 ± 49.14	240.23 ± 19.88
Endoturbinalia*	459.63 ± 107.34	284.98 ± 58.19

*: P< 0.05. Data expressed as the mean ± SD.

Table 6. Statistical results of volumetric parameters of paranasal sinuses of male and female New Zealand rabbits obtained through 3-dimensional reconstruction of CT images ($mm^3 \pm SD$).

	Male (n = 16)	Female (n = 16)
Maxillary sinus*	817.53 ± 86.71	562.10 ± 82.65
Ventral nasal concha*	534.15 ± 95.78	264.14 ± 70.01
Middle nasal concha*	435.00 ± 81.70	297.14 ± 49.87
Dorsal nasal concha*	262.87 ± 74.06	214.24 ± 34.39
Endoturbinalia*	305.28 ± 93.86	190.36 ± 39.16

*: P< 0.05. Data expressed as the mean ± SD.

3-dimensional reconstructions of paranasal sinuses in terms of statistics. In our study, on the other hand, 3-dimensional reconstruction of rabbit paranasal sinuses was carried out semiautomatically and automatically. The authors noted that, since the measurement values of both methods were similar, semiautomatic and automatic reconstruction data could be used in clinical applications.

Altman et al. (20) determined that the fatty tissues in frontal sinuses of rabbits began disappearing beginning from the 12th week, by which time frontal sinuses disappeared. In this study, frontal sinus was not observed since the rabbits were adult.

Bahadir et al. (19) obtained MDCT images of paranasal sinuses of New Zealand rabbits from both sexes and calculated the volume of the maxillary sinus automatically. According to the results, the volume of maxillary sinus varied between 670 and 910 mm^3 regardless of whether rabbits were male and female. In our study, on the other hand, the mean right side in female rabbits was 561.15 mm^3 and left side was 563.05 mm^3, while the mean right side in male rabbits was 812.95 mm^3 and left side was 822.12 mm^3 according to the results obtained from reconstructions of CT images.

Xu et al. (21) performed 3-dimensional reconstruction of CT images belonging to human maxillary sinuses and determined that the length and width of the maxillary sinus were similar for both sexes both on the right and left sides. In our study, although the volume and surface measurements of the maxillary sinus and concha did not differ for the right and left sides, it was observed that there were differences between male and female rabbits.

In MDCT images, it was determined that the paranasal sinuses in each hemisphere of the head were made up of the maxillary sinus, dorsal nasal concha, middle nasal concha, ventral nasal concha, and endoturbinalia, which have 2 compartments. It was observed that conchae have a quite developed structure. No statistical difference was found between volume measurement and surface area of the paranasal sinuses of the right and left sides of the same sex of rabbits. However, statistically significant differences were found between the sexes regarding the volume measurement and surface area between ipsilateral paranasal sinuses of rabbits. When these results were taken into account, it was presumed that paranasal sinuses of males were more developed than those of females with the same weight.

In conclusion, it is thought that this study, using high technology, will contribute to the present knowledge on paranasal sinuses of rabbits and may add a modern dimension to further anatomical studies on paranasal sinuses.

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