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Original Research Article

Morphometric Analysis of the Mandibula in Sheep, Goat and Rabbit

Key words

mandible;
anatomy;
measurements;
animal models;
experimental oral surgery

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Abstract: Understanding the morphological and morphometric properties of the mandible is crucial for the selection of an appropriate animal model for applications including implants, screws, prostheses, or bone defects. The purpose of this study is to present morphological data concerning the geometrical properties of the mandible in rabbits, sheep, and goats, which are used as models in experimental oral surgery. Length and height measurements of the mandibles were made on x-ray images of the mandibles. The cortical thicknesses and inner-outer diameters were also measured on the CT sectional images. In comparison to ruminants, the mandibular canal in rabbits is relatively shorter. In rabbits, the mental foramen is positioned caudally and closer to the molar teeth, while in sheep and goats, it is located rostrally and closer to the incisive teeth. In addition, the incisive roots are very extended and curved in rabbits and extend to the caudal border of the diastema. In ruminants, the incisive tooth roots are shorter and terminate close to the rostral border of the diastema, and there is a wider working area. Sheep and goats have wider and thicker bones in the rostral, intermediary and caudal regions of the mandible. The ramus region of rabbits has a thin bone structure, which makes it difficult to apply screws and other devices. The lateral side has a thicker cortical bone towards the rostral of the rabbit mandible, while the medial side is thicker in ruminants. The morphologic and geometric data of the mandible may support a study with critical size defects and screw, plate, or other implantations in rabbits and small ruminants to avoid problems or mistakes during experimental oral surgery. Also, the supplementary files can be used by researchers to investigate mandible x-ray images and CT sections of that animal species, as well as sections in different planes based on the intended position during pre-operative planning.

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Introduction

For the selection of a suitable animal model in experimental oral surgery research such as implant, screw, prosthesis, or bone defect applications, it is critical to understand the morphological and morphometric characteristics of the mandibular region (1, 2). It is very well known that no animal model can fully imitate human bones, so in experimental studies, the most appropriate model is selected for the targeted research designs (3). Rabbit is the commonly used animal in experimental orthopaedics because of easy care, low economic value, ease of working, easy creation of homogeneous breed groups, sufficient bone size compared to rodents, high bone metabolism, and rapid bone growth (1, 4-6-8). Small ruminants are also easy to find and easy to work with. Moreover, it is increasingly preferred due to reasons such as bone sizes, some histological features, and the metabolic rate and bone remodelling are similar to humans (2, 3, 7-9). Therefore, rabbit, sheep, and goat are frequently preferred as large animal models in experimental oral surgery (1, 2, 6, 9, 10, 12). Knowledge of the general morphological features of the mandible in animal species is already found in classical anatomy books (14, 15). However, there are few studies to address some morphometric evaluations from the perspective of experimental oral surgery in rabbits (1, 6), sheep (13), and goats (16). In addition, detailed information on the thickness of the cortical bone fragments to be tested for screw

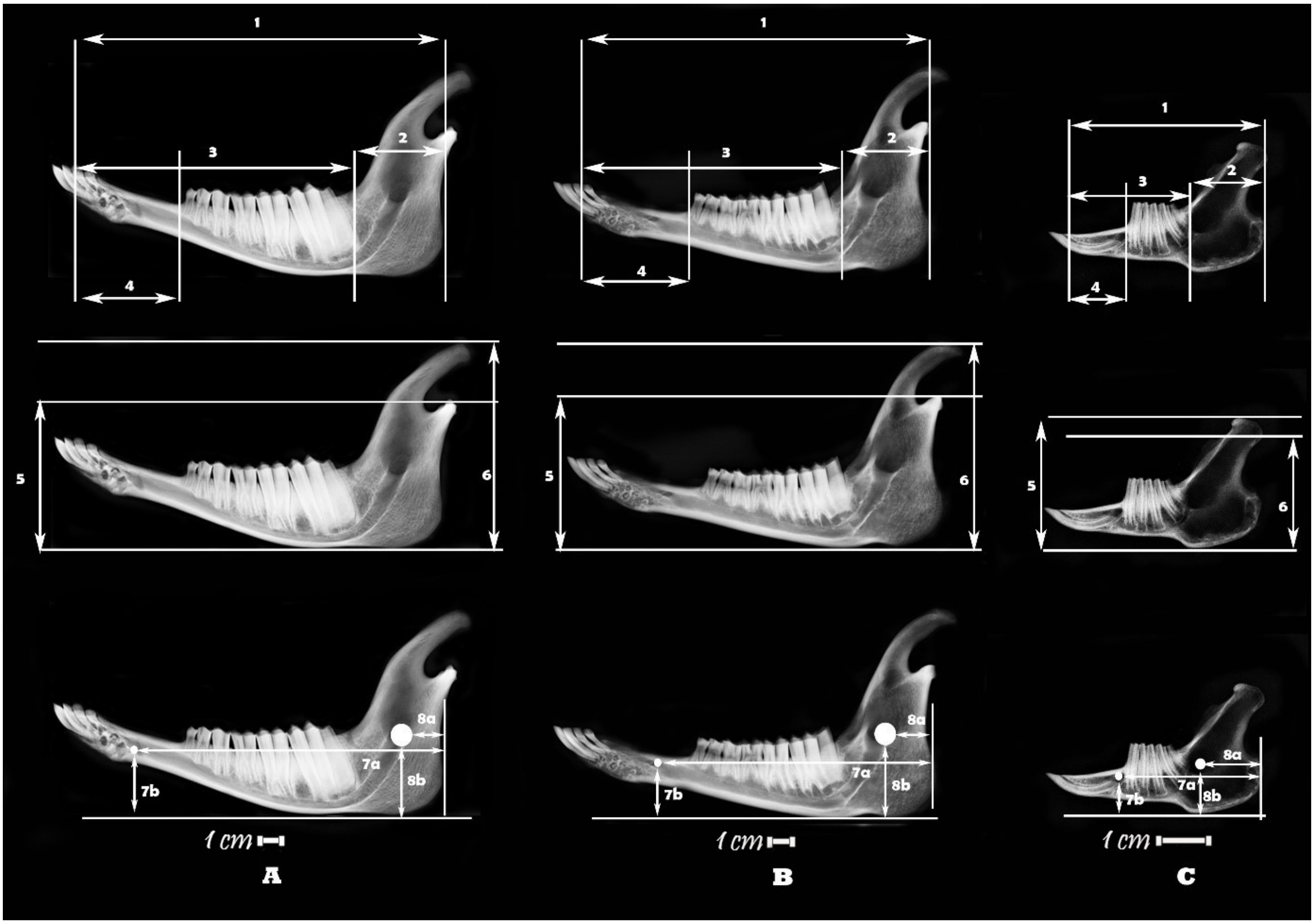

Figure 1: The distance measurements in the medio-lateral x-ray image of sheep (A), goat (B) and rabbit (C) mandibles 1; Length of the mandible, 2; Length of the ramus, 3; Length of the body 4; The diastema length, 5; Condylar height, 6; Total height, 7a; The caudal distance of the mental foramen, 7b; The ventral distance of the mental foramen, 8a; The caudal distance of the mandibular foramen, 8b; The ventral distance of the mandibular foramen

applications or bone defects is insufficient. Further studies are needed with a larger sample and in different species (6, 9). This study aims to present morphological data on the geometrical features of the mandible in rabbits, sheep, and goats, which are used as models in experimental oral and maxillofacial surgery studies in engineering and medicine.

Material and methods

In the study, the unilateral (Right side) mandibles of goats (n: 10), sheep (n: 6) and rabbits (n: 12) were used. These bones were taken from sheep (Karacabey Merino), goat (Saanen), and rabbit (New Zealand) skeletally mature female cadavers previously used for another anatomical study (TUBITAK- COST 115-O830). According to the information of this research project, the study was conducted with the permission of Adnan Menderes University Animal Experiments Ethics Committee (ADUHADYEK/2008/037 and 2014/188). The rabbits were obtained from the SYLAB experimental animal unit, and sheep and goats were obtained from local certified breeders. According to the information given by the breeders, it was noted that rabbits give birth four times on average, sheep give birth two to three times, and goats give birth three to four times. In addition, information was received from the breeder that rabbits were fed pellet feed, while sheep and goats were fed pellet feed and dry grass. The cadavers of frozen animals were thawed and the mandibles were dissected for the study. The used sheep, goats, and rabbits were 38–40, 46–48, and 14–15 months old, respectively. The average weights were also 61.1±3.87 kg, 60.3±14.10 kg, and 3.39±0.33 kg, sheep, goat and rabbit, respectively. To prepare the cadavers, euthanasia was performed under general anaesthesia via exsanguination (14). For anaesthesia, rabbits received 0.2 mg/kg/SC Atropine (Vetas Atropin®) followed by 5 mg/kg/IM xylazine (Xylazinbio®), and 35 mg/kg/IM ketamine (Alfamine®). Sheep received 0.5 mg/kg/SC atropine, followed by 0.2 mg/kg/IM xylazine and 5 mg/kg/IV ketamine. Goats received 0.1 mg/kg/IM xylazine and 5 mg/kg/IV ketamine (18, 19). Mandibles without deformities such as osteoarthritis, fractures, cracks, calluses, and developmental disorders were used. The terminology is used as medial (lingual), lateral (buccal), dorsal, ventral, rostral and caudal.

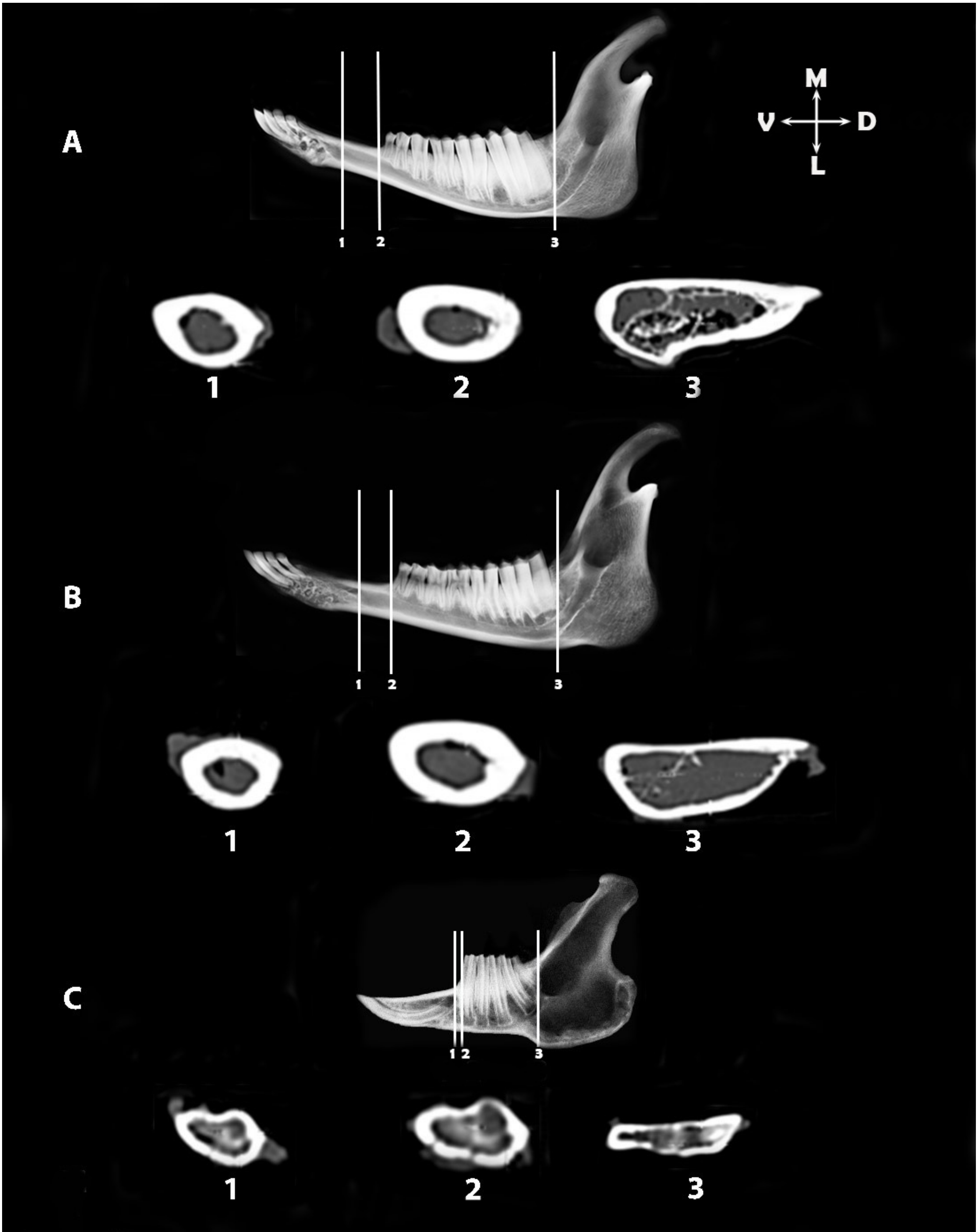

Figure 2: Cross sectional shapes in the rostral (1), intermediary (2) and caudal (3) regions of sheep, goat and rabbit mandibles M: Medial side of the mandible (Lingual side), L: Lateral side of the mandible (Buccal side), D: Dorsal side of the mandible, V: Ventral side of the mandible

Table 1: The length and height measurements of the mandible (mm)

Measurement	Rabbit (n:12)	Sheep (n:6)	Goat (n:10)
Length of mandible	74.21±2.74 (72.46-75.95)	207.03±7.43 (199.22±214.83)	201.96±10.40 (194.52±209.40)
Length of the ramus	25.92±1.36 (25.05-26.79)	46.87±10.24 (36.12-57.61)	53.06±4.76 (49.66-56.48)
The diastema length	25.31±1.31 (24.48-26.14)	54.67±5.00 (49.45-59.95)	58.73±7.78 (53.17-64.30)
The length of the body	47.41±1.67 (46.35-48.48)	156.38±8.13 (147.85-164.90)	146.32±4.80 (142.88-149.75)
Condylar height	42,87±2.18 (41,49-44,25)	86.17±3.07 (82.95-89.39)	82.72±2.64 (80.73-84.61)
Total height	37,07±1.91 (35,86-38,29)	118.06±3.64 (114.23-121.88)	115.06±3.22 (112.75-117.36)
The caudal distance of the mental foramen	48.53±1.98 (47.27-49.78)	174.04±4.49 (169.32-178.75)	148.33±33.98 (124.03-172.64)
The ventral distance of the mental foramen	11.37±1.47 (10.44-12.30)	32.85±3.85 (28.81-36.89)	24.31±6.64 (19.56-29.06)
The caudal distance of the mandibular foramen	19.94±1.46 (18.89-20.98)	21.46±2.54 (18.79-24.12)	19.91±1.86 (18.58-21.24)
The ventral distance of the mandibular foramen	12.89±1.11 (12.10-13.68)	43.16±1.40 (41.69-44.63)	41.69±1.05 (40.94-42.44)

* The data are presented as Mean value ± Standard deviation (MV±SD) and 95% confidence intervals.

Table 2. The dorso-ventral and medio-lateral diameters in the three regions of the mandible (mm)

	Region	Rabbit (n:12)	Sheep (n:6)	Goat (n:10)
Dorso-ventral inner diameter	Rostral	5.23±0.53 (4.89-5.57)	8.41±0.33 (8.06-8.75)	8.01±0.91 (7.36-8.66)
	İntermedier	7.58±0.73 (7.11-8.04)	8.44±0.75 (7.65-9.23)	8.94±1.26 (8.04-9.84)
	Caudal	13.57±1.08 (12.84-14.29)	36.32±4.46 (31.64-41)	31.34±2.13 (29.82-32.86)
Dorso-ventral outer diameter	Rostral	8.03±0.71 (7.57-8.48)	15.05±0.43 (14.60-15.50)	15.01±0.77 (14.46-15.57)
	Intermedier	11.03±0.57 (10.67-11.40)	17.66±0.48 (17.16-18.17)	17.23±0.95 (16.55-17.91)
	Caudal	16.72±1.22 (15.90-17.54)	42.66±3.64 (38.84-46.48)	37.42±1.60 (36.28-38.57)
Medio-lateral inner diameter	Rostral	3.20±0.34 (2.98-3.41)	5.61±0.73 (4.85-6.37)	5.14±0.72 (4.62-5.65)
	Intermedier	4.23±0.45 (3.94-4.52)	5.80±0.23 (5.56-6.04)	5.18±0.75 (4.64-5.71)
	Caudal	2.90±0.26 (2.74-3.07)	10.09±2.12 (7.87-12.32)	9.50±1.65 (8.32-10.68)
Medio-lateral outer diameter	Rostral	5.54±0.31 (5.35-5.74)	10.32±0.56 (9.72-10.91)	9.87±0.69 (9.38-10.36)
	Intermedier	6.36±0.47 (6.06-6.66)	11.42±0.60 (10.79-12.04)	10.42±0.56 (10.02-10.82)
	Caudal	4.84±0.20 (4.71-4.97)	13.58±2.18 (11.29-15.87)	13.54±1.20 (12.68-14.39)

* The data are presented as Mean value ± Standard deviation (MV±SD) and 95% confidence intervals

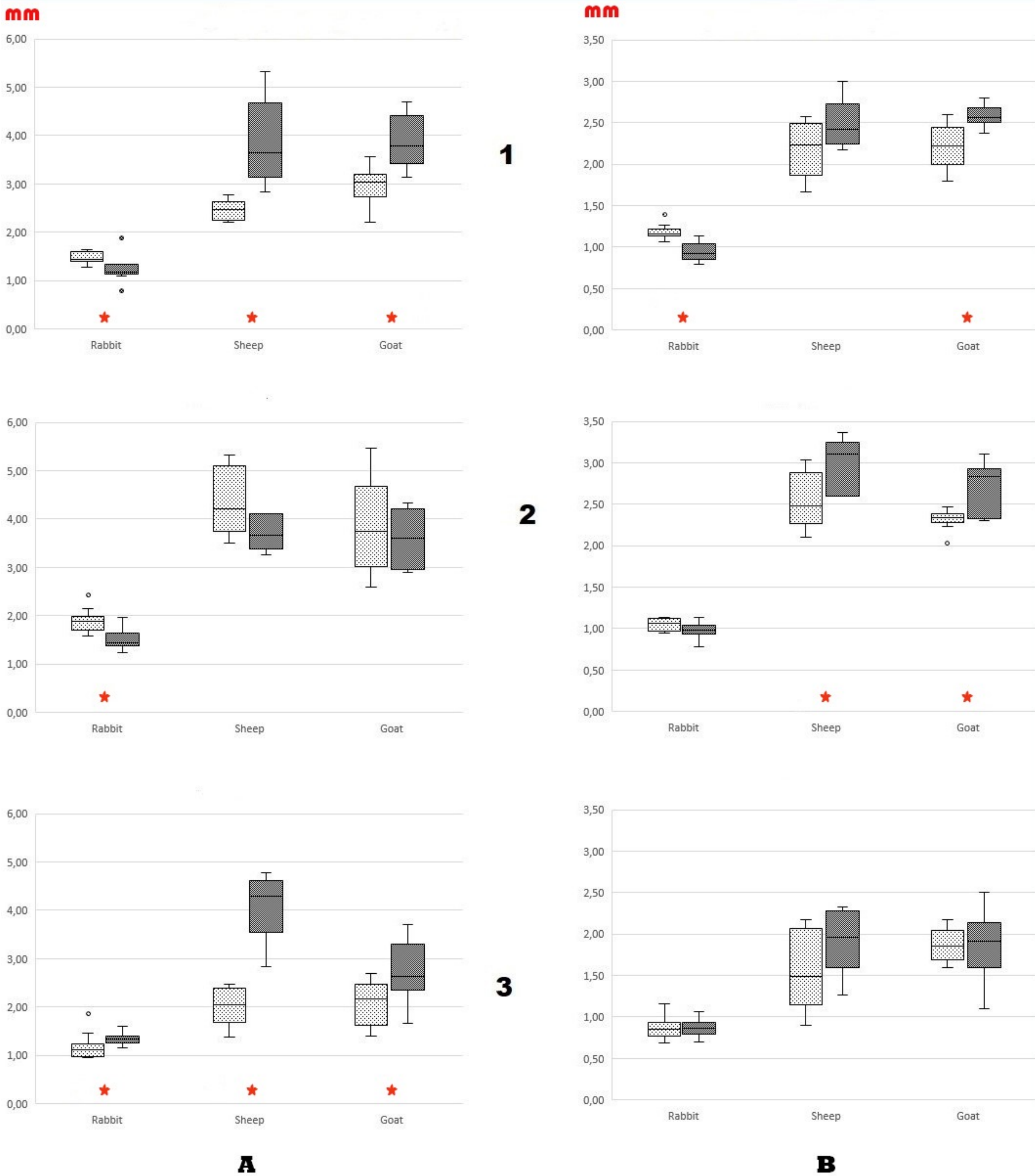

Figure 3: Comparison of the bone cortical thicknesses between dorsal-ventral and lateral-medial sides in the rostral (1), intermediary (2) and caudal (3) regions of rabbit, sheep and goat mandibles (mm). A: The white pattern demonstrates the cortical thicknesses of the dorsal side, and the dark pattern demonstrates the ventral side. B: The white pattern demonstrates the cortical thicknesses of the lateral side, and the dark pattern demonstrates the medial side

*There are statistical differences between the two sides on the cortical thicknesses ($p<0.05$)

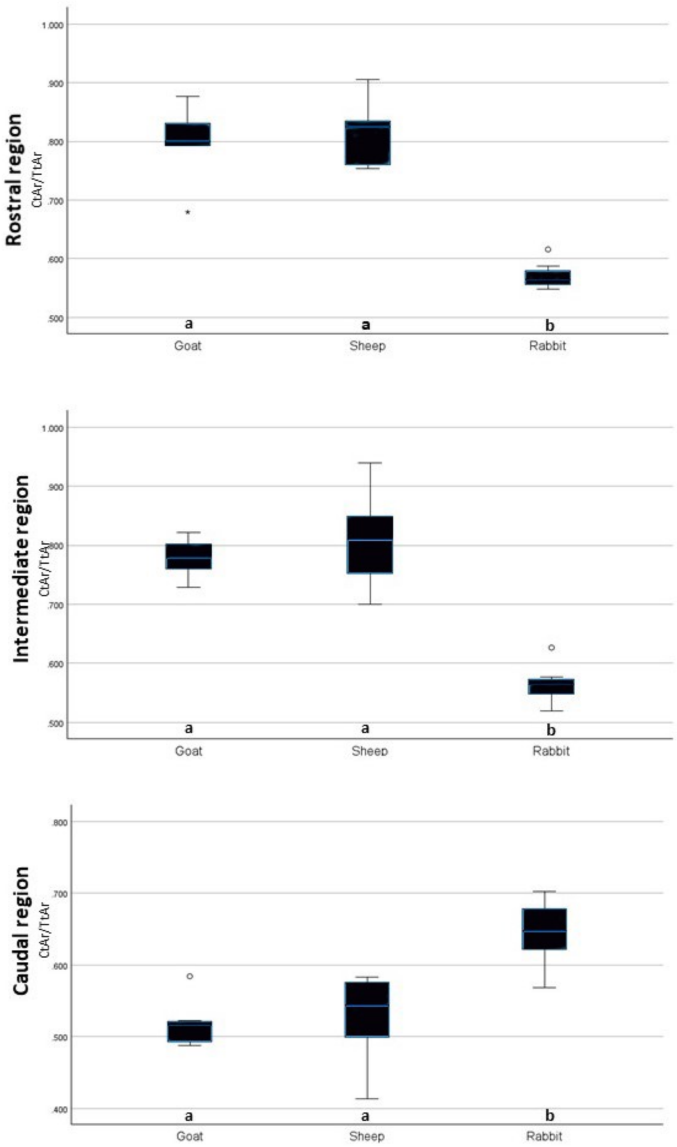

Figure 4: Figure 4. Cortical area fraction (CtAr/TtAr) in the rostral, intermediate and caudal regions of rabbit, sheep and goat mandibles

a, b Means with the same superscript across the columns were not significantly different.

Length and height measurements of mandibles were made on mediolateral radiographs. Digital x-ray images were taken with an EVA-HF750 x-ray equipment and saved in ".jpeg" format. The measurements were taken using ImageJ 1.53g version 4 December 2020 bundled with 64-bit Java 8 for windows (Figure 1).

The computed tomography (Toshiba Aquilion Premium multi-slice) was used to obtain the cross sectional images. In order to determine the bone boundaries more clearly and to align the anatomical axis, the bones were placed on the table of the device by supporting them with cotton. The sectional images were taken at 1mm thickness and 1mm interval. Cross-sectional measurements were taken in three regions that are frequently employed in experimental oral surgery studies (1, 6, 12, 18, 20-21). The caudal border of the mental foramen (Rostral region), the rostral side of the first premolar tooth (intermedier region), and the caudal border of the last molar tooth (Caudal region) were used for this aim. (Figure 2). Cortical thicknesses and diameters were made as stated in the literature (22, 23). In cross-sectional images, measurements were obtained in three consecutive sections from each region, and the average of three measurements were used as the data for the statistical analysis. The cortical thicknesses and inner-outer diameters were measured using the Sectra Pacs (Sectra Workstation IDS7, Linköping, Sweden).

Cortical area and total bone area were measured by were performed with the bone j plugin, an extension of ImageJ bundled with 64-bit Java 8, cortical area fraction was calculated as the cortical area (CtAr) / total area (TtAr) (24).

The same researcher (BE) performed all of the measurements in an attempt to eliminate any possibility of inter-observer variability. To test the reliability of the X-ray measurement methods used, all points and axes were re-determined in the X-ray image of a randomly selected bone, and measurements were taken five times. The coefficient of variation of these measurements was calculated with the formula "%CV = (Standard deviation / Average value/) x 100". The lowest coefficient of variation for the X-ray measurements was found in rabbit mandible length measurement (0.20), while the highest coefficient of variation was found in the inferior distance of the mental foramen (6.15) in sheep. Therefore, the test of repeatability suggests that the method of measurement is reliable for the study (25, 26). Since the average of the measurements taken from three consecutive slices is already used in the cortical thickness and diameter measurements obtained from the computed tomography cross-section images, the coefficient of variation for these parameters was not calculated. Statistical analyses were made using SPSS 19.0 (SPSS Inc., Chicago, IL, USA). The comparison of cortical thicknesses between dorso-ventral and medio-lateral measurements in cross-sectional images was made separately for each region. The normal distribution of the data was made using the Shapiro-Wilk test. Paired t-test was used for parametric data, and the Wilcoxon test was used for non-parametric data. The one-way analysis of variance (One-Way ANOVA) was used for statistical comparisons of the cortical area fraction data obtained from different species. The homogeneity of variances was also explored with Levene's test. Because of the normality and homogeneity of the data the one-way-ANOVA and post-hoc Bonferroni tests were used. The data are presented as Mean value ± Standard deviation (MV±SD) and 95% confidence intervals in the tables. Statistical significance was accepted as $p<0.05$.

Results

According to morphological observations, the mandibular ramus region is very thin, the trabecular bone structure is very low, and the coronoid process and mandibular notch in rabbits, those two structures cannot be seen and labelled even on rabbit's skeleton.

The mandibular canal begins near the root of the last molar, continues at the root of molar teeth, and ends in the mental foramen, which is close to the first premolar tooth at the caudal border of the diastema. It was noted that the root of the incisive teeth is very long, extending significantly to the molar teeth and mental foramen (Figure1). In sheep and goats, the region of the ramus is thicker trabecular bone structure than in rabbits. It is also noteworthy that in sheep and goats, the mandibular foramen is located more caudally and underneath the mandibular notch compared to the rabbit. In addition, the coronoid process is prominent and the mandibular notch is deeper in sheep and goats than in rabbits, but unlike rabbits, the roots of the incisors are not very prominent, the roots do not extend towards the diastema, and this group of teeth is weaker. It has been noted that the mental foramen is located rostrally on the diastema in sheep and goats.

The length and height measurements of mandibles were presented in Table 1. The length of the molar row is about 45-51% of the total length of the mandible in sheep and goats, this ratio is 31% for rabbits. The ratio of the length of the mandibular canal to the total length of the mandible is approximately 64-74% in sheep and goats, and approximately 38% in rabbits. Mental foramen is located more rostrally in sheep and goats than in rabbits. It was located approximately 16-26 % of the mandibular length behind the infradentale and approximately 29-38% of the mandibular height above the ventral base in the sheep and goat. It was located approximately 35 % caudal to the infradentale and approximately 27% dorsal to the ventral base, in the rabbit. The mandibular foramen is placed dorsally and more caudally in sheep and goats than in rabbits. It is located approximately 90 % caudal to the infradentale and approximately 50% dorsal to the ventral border of the mandible in sheep and goats. In rabbits, it is located approximately 73 % caudal to the rostral mandible and 30% dorsal to the ventral border of the mandible.

When cortical bone thickness was evaluated in cross-sectional images, it was determined that the higher cortical thickness in the rostral region was dorsal side in rabbits and ventral side in sheep and goats mandibles. For all species, the cortical thickness was found to be higher on the ventral side in the caudal region of the mandible. It was noted that while the lateral cortical thickness in the rostral region was higher than the medial cortical thickness in rabbits, the medial cortical thickness was higher in sheep and goats. It was observed that medial and lateral cortical thickness values approached each other in all species towards the caudal region of the mandible (Figure 3). The dorso-ventral and medio-lateral diameters in the three regions of the mandibles were also presented in Table 2.

Discussion

When selecting an animal model for experimental oral surgery, the convenience and size of the bone are the primary factors evaluated to ensure ease of surgical access, defect creation, or implantation (1, 6, 27). Thus, it becomes crucial to have a thorough understanding of the mandible's morphology, including its dimensions, cross-sectional diameters, and cortical thicknesses in various regions (1, 6, 27-26). Experimental studies often prefer the premolar, molar regions, or mandibular ramus (5, 6, 27-32). In this study, we present morphological comparisons, dimensions, and cortical thickness measurements for these specific regions of the mandible in three large animal models.

Knowing the differences in mandibular canal morphology between animal species may make research easier. Providing neural stimulation by minimising nerve damage is an important factor in ensuring optimal bone regeneration (31, 33). The mandibular canal is relatively short in rabbits compared to sheep and goats. Previous studies have used a 6–10 mm bone defect in the molar region in the rabbit (6, 31, 34). Considering that the average molar zone length is 22 mm in adult rabbits, it is necessary to work in an area of at least one third of the molar zone length. In this case, it may be necessary for surgeons to work very sensitively to ensure the ideal healing process by considering the proportional size of the defect for the rabbit.

Rabbits and ruminants have no canine teeth, and there is a toothless zone called the diastema between incisive and molar teeth (35). The diastema appears to be an easy and secure application area on the front of the mouth because it is about one-third the length of the mandible and toothless. Nevertheless, depending on the species, it is important to pay attention to some of the morphological features mentioned below. While the distance between the mental foramen and infradentale in sheep and goats is approximately 12–16% of the mandibular length, this ratio is 30% in rabbits. Therefore, the mental foramen is positioned caudally and closer to the molar teeth in rabbits, while in sheep and goats it is located rostrally and closer to the incisive teeth. In addition, the incisive tooth roots, which are very extended and curved in rabbits, extend to the caudal border of the diastema. In sheep and goats, incisive tooth roots are shorter and terminate close to the rostral border of the diastema. Thus, there is a wider working area in this region for ruminants.

In order to ensure the stability of an implant, it is desired that the area where the implant will be applied has the appropriate cortical bone thickness (6, 31, 36-37). Borie et al. (6) indicated that the defects be performed with a depth of 1.2 mm and a safety margin of 0.1–0.2 mm. In rabbits, even in sections obtained just behind the molar teeth, the average mediolateral diameter is 4.84 mm, while the cortical thickness ranges between 0.80-1.35 mm. These measurements align with the rostral borders of the area where the masseter muscles attach laterally and the pterygoid muscles attach medially across all three animal species. Upon examining the DICOM files in the supplementary data, it becomes evident that cortical bone thickness decreases towards the caudal region. Specifically, in the central area where these muscles attach, the lateral and medial cortical bone layers combine to form a very thin cortical layer in rabbits. On the other hand, all regions of the sheep and goat mandible exhibit greater cortical thickness for such applications. However, in the mandibular ramus, both the medial and lateral cortical thickness measurements are generally lower compared to the rostral regions.

While direct mechanical testing is accepted as the best option to understand the bone strength, there are indirect methodologies to assess the mechanical strength of bones. Some imaging techniques (DEXA, MicroCT, pQCT etc.) are used to understand bone strength with measuring bone density. The cross-sectional geometry and ash content may also considered to assess bone strength (38). The cortical bone area and cortical bone thickness are the best predictors of the failure load for the mandible. The structural properties are also more strongly associated with changes in cross sectional geometry than in material properties (39). Cortical analysis is one of the simplest methods used for many years to determine bone strength, as it is an important data reflecting bone density (40, 41). The cortical thicknesses of the mandible were presented on the different animals and three different regions. The cortical area fraction (cortical area/total area) data were also presented. Because standard CT sections were used, the trabecular bones of the mandible were not truly marked in the sections when determining ROIs. Thus just the cortical bone area were used because there are highly significant correlation between the cortical area fraction and the bone density (42). More detailed analysis can be perform with Micro CT. The cortical area ratio is lower in rabbits on rostral and intermediate regions than ruminants. It may be related the incisive roots are very extended and curved in rabbits in this region. In the caudal region this ratio is higher in rabbits than ruminants. It may be related that the lower ratio of trabecular bone volume on the caudal side of the rabbit mandible.

The experimental bone defect or implant application can be made on either the medial or lateral sides. The cortical thicknesses on the medial and lateral sides may differ according to species, especially in rostral sections. The lateral side has a thicker cortical bone towards the rostral sides of the rabbit mandible. In ruminants, the medial side is thicker as in human (43). This should be taken into account when monitoring bone amounts in defect-gap healing or when applying screws to the cortical bone. Moreover, the bending tests are generally preferred as biomechanical testing procedures for the mandible (30, 39, 44-45). Bending causes compression on the loading side and tension on the opposite side of the bone (46). In this case, since the cortical bone thicknesses show significant differences, there may be differences in the test results when the compression direction is changed in mechanical tests, even if applied in the same region. Researchers should pay attention to the fact that the compression direction and region are the same in the mechanical tests applied in the study when they compare the bone strength values of the mechanical tests they apply with the data of other studies they refer to.

Although diameter measurements in mandible sections are generally similar for sheep and goats, it is noteworthy that the dorso-ventral outer diameter measurement taken behind the last molar tooth is smaller in goats. This can be explained by the presence of a distinct depression in the rostral-upper border of the ramus mandible behind the last molars in the goat mandible, unlike in the sheep mandible (47).

The limitation of this study is that only the right-sided mandible halves of female animals were used. As well as we know, there is no standard information available about the sex of the animals used in morphological or experimental studies related to oral surgery, as well as which side of the mandible to employ. Borie et al. (6) performed lineer measurements on the calvaria and mandible of rabbits regarding experimental surgery. They used female and male rabbits. No information regarding the gender differences was noted. There are no notable differences for length, height, or thickness measurements between the right and left sides. Campillo et al. (1) aimed to describe the anatomy of the rabbit mandible and to estimate the available bone volume for experimental studies. They use one-half of the mandible of four adult female rabbits. Wang et al. (48) used male and female rabbits to establish an animal model for a mandibular defect by using an intraoral approach and to explore the size of a critical-sized defect in the rabbit mandible. The morphometric, densitometric, and mechanical studies of the sheep mandible were carried out by Szabelska et al. (13). They used a male sheep's mandibles that was five months old. They reported no significant differences between the right and left mandibular halves' morphometric, densitometric, and mechanical properties. Carvalho et al. (2) aimed to evaluate the length and resistance of the sheep mandible under the biomechanical loading. They used mandibles from seven month old sheep collected from the abattoir. No information regarding the gender of the sheep was noted. They also stated that when using the entire mandible for biomechanical testing, the reliable simulation with freedom in the three axes in space can be more accurate, which is impossible when using the hemi-mandible. Corte et al. (49) measured the liner morphometric properties of the mandibles of female mini-pigs and compared them to those of humans. On morphometric measurements, they could not find any statistically significant changes between the left and right hemimandibles. Cheng et al. (5) used adult male rabbits in their mandibular defect experiment. Kim et al (21) used male rabbits to analyse the customized guide and titanium implants experiments on mandibular defect. Abu-Serriah et al (50) used female sheep model to mechanical evaluation of mandibular defect study. For human mandible, sex was also found to be unrelated to cortical thickness pattern (51). Considering that there may be unilateral mastication of species, gender or individual, and that the morphometry of the mandible may also change accordingly, it may be recommended to conduct studies comparing the mandibular variations due to these characteristics. Secondly, the mean values of the measurements and the 95% confidence interval values are also presented directly in the tables. These data should be evaluated by considering the weights of the animals. Since the mandible sizes of animals of different sizes will also differ, comparison of direct measurement data with the results of different studies without an index (6) may lead to inaccurate assessments. Moreover, calculating the coefficient of variation by making repeated measurements in the same sample is a preferred method for testing the reliability of the measurement method (26, 52). The values of the coefficients of variation ranged from 0.20% to 6.15% in the study. The results from the test of repeatability suggest that the method of measurement is reliable for the study. The inter-observer reproducibility has not been evaluated because the measurements were carried out by the same observer (25).

In conclusion, although the toothless area, defined as the diastema, seems to be a suitable area for experimental applications, the incisive tooth roots extend along this area in rabbits, as does the presence of the mandibular canal in sheep and goats. Rabbits have a thin bone structure in the ramus region, which can complicate the application of screws, etc. The cortical bone thicknesses on the medial and lateral sides may differ according to the animal species. It is undoubtedly accepted that sheep and goats have a wider working area and thicker cortices in all three regions of the mandible for experimental implant, screw, prosthesis, or bone defect applications. Besides, they are beneficial to the surgeons in pre-operative planning or directly for in vitro studies because they are easily available as slaughtered animals. The morphologic and geometric data of the mandible may help a study with the critical size defects and screw, plate, or other implantations in rabbits and small ruminants to avoid problems or mistakes during experimental oral surgery. Also, the supplementary files can be used by researchers to investigate mandible x-ray images and CT sections of that animal species, as well as sections in different planes based on the intended position during pre-operative planning.

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References

1. Campillo VE, Langonnet S, Pierrefeu A, Chaux–Bodard AG. Anatomic and histological study of the rabbit mandible as an experimental model for wound healing and surgical therapies. Lab Anim 2014; 48(4): 273–7. doi: 10.1177/0023677214540635

2. Carvalho PH, Saavedra MSFA, Ballester RY, Luz JGC. Biomechanical evaluation of the sheep mandible as a model for studying fixation methods. 2018; 36(3): 926–30. doi: 10.4067/S0717-95022018000300926

3. Pearce AI, Richards RG, Milz S, Schneider E, Pearce SG. Animal models for implant biomaterial research in bone: a review. Eur Cell Mater 2007; 13: 1-10. doi: 10.22203/ecm.v013a01

4. Monfared AL. Applied anatomy of the rabbit's skull and its clinical application during regional anesthesia. Global Vet 2013; 10(6): 653–7. doi: 10.5829/idosi.gv.2013.10.6.72111

5. Cheng G, Li Z, Wan Q, Lv K, Li D, Xing X, Li Z. A novel animal model treated with tooth extraction to repair the full-thickness defects in the mandible of rabbits. J Surg Res 2015; 94(2): 706–16. doi: 10.1016/j.jss.2014.11.010

6. Borie E, Calzzani R, Dias FJ, Fuentes R, Salamanca C. Morphometry of rabbit anatomical regions used as experimental models in implantology and oral surgery. Biomed Res(India) 2017; 28(12): 5468–72

7. Bottogisio M, Coman C, Lovati BA. Animal models of orthopaedic infections. A review of rabbit models used to induce long bone bacterial infections. Journal of Medical Microbiology 2019; 68: 506–37 DOI 10.1099/jmm.0.000952

8. Frosch S, Buchhorn GH. Considerations on the animal model and the biomechanical test arrangements for assessing the osseous integration of orthopedic and dental implants. MethodsX 2021; 8: 101352. doi: 10.1016/j.mex.2021.101352

9. Alvites RD, Branquinho MV, Sousa AC, et al. Small ruminants and its use in regenerative medicine: recent works and future perspectives. Biology (Basel) 2021; 10: 249 doi: 10.3390/biology10030249

10. Wittenberg JM, Mukherjee DP, Smith BR, Kruse RN. Biomechanical evaluation of new fixation devices for mandibular angle fractures. Int J Oral Maxillofac Surg 1997; 26(1): 68–73. doi: 10.1016/S0901-5027(97)808521

11. Alshehri F, Alshehri M, Sumague T, et al. Evaluation of peri-implant bone grafting around surface-porous dental implants: an in vivo study in a goat model. Materials 2019; 12(21): 3606. doi: 10.3390/ma12213606

12. Cancedda R, Giannoni P, Mastrogiacomo M. A tissue engineering approach to bone repair in large animal models and in clinical practice. Biomaterials 2007; 28(29): 4240–50. doi: 10.1016/j.biomaterials.2007.06.023

13. Szabelska A, Tatara MR, Krupski W. Morphological, densitometric and mechanical properties of mandible in 5-month-old Polish merino sheep. BMC Vet Res 2017; 13(1): 1–7. doi: 10.1186/s12917-016-0921-3
14. McLaughlin CA, Chiasson RB. Laboratory anatomy of the rabbit. Briston: Mc Graw Hill, 1990.
15. Dyce K, Sack W, Wensing CJG. Veteriner Anatomi Konu Anlatımı ve Atlas. 4, 13987, R. Amsterdam: Elsevier, 2018.
16. Pal TK, Chakraborty A, Banerjee S. A micro-anatomical comparison of goat jaw cancellous bone with human mandible: histomorphometric study for implant dentistry. J Int Clin Dental Res Orga 2014; 6(1): 20. doi: 10.4103/2231-0754.139088
17. Leary S, Underwood W, Anthony R, et al. AVMA guidelines for the euthanasia of animals: 2013 edition. Schaumburg: American Veterinary Medical Association, 2013.
18. Flecknell, P. Laboratory animal anaesthesia. London: Elsevier , 2009.
19. Cornick–Seahorn, JL. Veterinary anesthesia. Woburn: Butterworth–Heinemann, 2000.
20. Gencer RC, Ozel A, Uckan IS, Bilateral sagittal split ramus osteotomy using a conventional osteotome-hammer and a magnetic mallet device: an in vitro comparison. Eur Rev Med Pharmacol Sci 2023; 27 (Suppl. 4): 58–65. doi: 10.26355/eurrev_202307_32745
21. Kim MK, Ham MJ, Kim WR, et al. Investigating the accuracy of mandibulectomy and reconstructive surgery using 3D customized implants and surgical guides in a rabbit model. Maxillofac Plast Reconstr Surg 2023; 45(1): 8. DOI 10.1186/s40902-023-00375-9
22. Wang SH, Shen YW, Fuh LJ, Peng SL, Tsai MT et al. Relationship between Cortical Bone Thickness and Cancellous Bone Density at Dental Implant Sites in the Jawbone. Diagnostics (Basel) 2020; 10(9): 710. doi: 10.3390/diagnostics10090710
23. Arsan B. Cone beam computed tomography analysis of mandibular inferior cortical thickness and bone texture in cemento-osseous dysplasia. Oral Surg Oral Med Pathol Oral Radiol 2022; 134(1): 110–8. doi: 10.1016/j.oooo.2022.02.008
24. Hsu JT, Chen YJ, Ho JT, et al. A comparison of micro-ct and dental ct in assessing cortical bone morphology and trabecular bone microarchitecture. PLoS One 2014; 9(9): e107545. doi: 10.1371/journal.pone.0107545
25. Özdamar K, Yayinlari, NK. SPSS ile Biyoistatistik. Ankara: Nisan kitabevi, 2015.
26. Sevil-Kilimci F, Kara ME. The geometry of the proximal femoral medullary canal in German shepherd and Kangal dogs. J Fac Vet Med Istanbul Univ 2017; 43: 52–60. doi: 10.16988/iuvfd.270288
27. Olivera LB, Sant´ana E, Manzato AJ, Guerra FLB, Arnett GW. Biomechanical in vitro evaluation of three stable internal fixation techniques used in sagittal osteotomy of the mandibular ramus: a study in sheep mandibles. J Appl Oral Sci 2012; 20(4). 419–26 doi: 10.1590/S1678-77572012000400006
28. Bavitz JB, Harn SD, Hansen CA, Lang M. An anatomical study of mental neurovascular bundle-implant relationships. Int J Oral Maxillofac Implants 1993; 8(5): 563–7.
29. Watanabe H, Abdul MM, Kurabayashi T, Aoki H. Mandible size and morphology determined with CT on a premise of dental implant operation. Surg Radiol Anat 2010; 32(4): 343–9. doi:10.1007/s00276-009-0570-3
30. Gomes PP, Filho RG, Mazzonetto R, Evaluation of the bending strength of rigid internal fixation with absorbable and metallic screws in mandibular ramus sagittal split osteotomy – in vitro study. Pesqui Odontol Bras 2003;17(3): 267–72. doi:10.1590/S1517-74912003000300012
31. Shah SR, Young S, Goldman JL, Jansen JA, Wong ME, Mikos AG. A composite critical-size rabbit mandibular defect for evaluation of craniofacial tissue regeneration. Nature Protocols 2016; 11(10): 1889–2009. doi: 10.1038/nprot.2016.122
32. Nuntanaranont T, Promboot T, Sutapreyasri S. Effect of expanded bone marrow-derived osteoprogenitor cells seeded into polycaprolactone/tricalcium phosphate scaffolds in new bone regeneration of rabbit mandibular defects. J Mater Sci Mater Med 2018; 29(3): 24. doi: 10.1007/s10856-018-6030-z
33. Gandur IV, Walton VT, Lobato PC, Luaces VL, Céspedes MVM. Mandible measurements and dental midline deviation after alveolar nerve transection in growing rabbits. Int J Morphol 2011; 29(1): 52–6. doi: 10.4067/S0717-95022011000100008
34. Lee SW, Gyorgy S, Choi JB, Choi JY, Kim SG. Carbon plate shows even distribution of stress, decreases screw loosening, and increases recovery of preoperative daily feed intake amount in a rabbit model of mandibular continuity defects. J Craniomaxillofac Surg 2014; 42(5): e245–51. doi: 10.1016/j.jcms.2013.09.006
35. Liebich HG, König HE. Skeleton axiale In: Liebich HG, König HE, eds. Veterinary Anatomy of Domestic Mammals, Textbook and Color atlas. New York: Schattauer, 2007; 69–106.
36. Wu Z, Liu Y, Singare S, Li D. Animal model for evaluation of strain gauge in mandibular distraction osteogenesis in rabbits. British J Oral Maxillofac Surg 2007; 45(8): 633–6. doi: 10.1016/j.bjoms.2007.04.004
37. Motoyoshi M, Yoshida T, Ono A, Shimizu N. Effect of cortical bone thickness and implant placement torque on stability of orthodontic mini-implants. Int J Oral Maxillofac Implants 2007; 22(5): 779–84.
38. Khan K, Sevil Kilimci F, Kara ME. (2021). Biomechanical tests: applications and their reliability for the prediction of bone strength in broiler chicken. Vet J Mehmet Akif Ersoy Uni 2021; 6(2): 85–92.
39. Jiang GZ, Matsumoto H, Hori M, et al. Correlation among geometric, densitometric, and mechanical properties in mandible and femur of osteoporotic rats. J Bone Miner Metab 2008; 26(2): 130–7. doi: 10.1007/s00774-007-0811-7
40. Tingart MJ, Apreleva M, von Stechow D, Zurakowski D, Warner JJ. The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. J Bone Joint Surg Br 2003; 85, 611–7. doi: 10.1302/0301-620x.85b4.12843
41. Wescott DJ. Effect of mobility on femur midshaft external shape and robusticity. Am J Phys Anthropol 2006; 130(2): 201–13. doi: 10.1002/ajpa.20316
42. Kiminki A, Tammisalo EH. Cortical ratio as an indicator of the mineral content of human mandibular bones. Acta Odontol Scand 1969; 27(4): 409–15. doi: 10.3109/00016356909040420.
43. Santos IG, Ramos de Faria F, da Silva Campos MJ, de Barros BÁC, Rabelo GD, Devito KL. Fractal dimension, lacunarity, and cortical thickness in the mandible: Analyzing differences between healthy men and women with cone-beam computed tomography. Imaging Sci Dent 2023; 53(2): 153–9. doi: 10.5624/isd.20230042.
44. Elovic RP, Hipp JA, Hayes WC. A Method for measuring the structural properties of the rat mandible. Arch Oral Biol 1994; 39(12): 1029–33. doi: 10.1016/0003-9969(94)90054-x

45. Bulut T, Durmus E, Mihmanlı A, Dolanmaz D, Kalaycı A, Sağlam H. Distracted mandible does not reach the same strength as normal mandible in rabbits. Oral Surg Oral Med Oral Pathol Oral Radiol 2012; 114(Suppl. 5): S140–5. doi: 10.1016/j.oooo.2011.09.024

46. An YH, Draughn RA. Mechanical Testing of Bone and the Bone-Implant Interface.Boca Raton: CRC Press, 1999. doi: 10.1201/9781420073560

47. Halstead P, Collins P, Isaakidou V. Sorting the sheep from the goats: morphological distinctions between the mandibles and mandibular teeth of adult ovis and capra. J Archaeol Sci 2002; 29(5): 545–53 doi: 10.1006/jasc.2001.0777

48. Wang Y, Zhang X, Mei S, Li Y, Khan AA, Guan S, Li X. Determination of critical-sized defect of mandible in a rabbit model: micro-computed tomography, and histological evaluation. Heliyon 2023; 9(7): e18047. doi: 10.1016/j.heliyon.2023.e18047

49. Corte GM, Hünigen H, Richardson KC, Niehues SM, Plendl J. Cephalometric studies of the mandible, its masticatory muscles and vasculature of growing Göttingen Minipigs-A comparative anatomical study to refine experimental mandibular surgery. PLoS One. 2019; 25; 14(4): e0215875. doi: 10.1371/journal.pone.0215875.

50. Abu-Serriah M, Kontaxis A, Ayoub A, Harrison J, Odel E, Barbenel J. Mechanical evaluation of mandibular defects reconstructed using osteogenic protein-1 (rhOP-1) in a sheep model: a critical analysis. Int J Oral Maxillofac Surg 2005; 34: 287–93. doi: 10.1016/j.ijom.2004.09.008

51. Decaup PH, Couture C, Garot E. Is the distribution of cortical bone in the mandibular corpus and symphysis linked to loading environment in modern humans? A systematic review. Arch Oral Biol 2023; 152: 105718. doi: 10.1016/j.archoralbio.2023.105718

52. Klipstein-Grobusch K, Georg T, Boeıng H, Interviewer variability in anthropometric measurements and estimates of body composition. Int J Epidemiol 1997; 26(Suppl. 1): S174–80. doi: 10.1093/ije/26.suppl_1.s174

Morfometrična analiza spodnje čeljustnice pri ovci, kozi in kuncu

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Izvleček: 10-letna sterilizirana škotska mačka z ravnimi ušesi je imela trdno, nepremično maso na desni spodnji čeljusti. V zadnjem mesecu se je masa postopoma večala, kar je povzročilo težave pri prehranjevanju in posledično izgubo telesne mase. Računalniška tomografija (CT) je pokazala, da je bila masa omejena na telo spodnje čeljusti, z izrazito periostalno reakcijo, za katero je bil značilen koničast vzorec. Obsežna in nepravilna morfologija periostalne reakcije je nakazovala malignost. Klinični pregled ali diagnostično slikanje ni odkrilo znakov, ki bi nakazovali na metastaze. Zaradi hitre rasti mase in s tem povezanih kliničnih znakov je bila kirurška resekcija prednostna pred pridobitvijo dokončne diagnoze. Za diagnostične in terapevtske namene je bila opravljena razširjena subtotalna mandibulektomija, ki je razkrila alveolarni osteomielitis. Po operaciji je imela mačka boljšo žvečilno funkcijo brez očitnih znakov bolečine v ustih, kar kaže na dober kirurški izid. V 16-mesečnem obdobju spremljanja je mačka ostala v dobrem splošnem in fizičnem stanju brez ponovitve tvorbe. Po našem vedenju je to prvo poročilo, ki kaže, da se osteomielitis lahko kaže z obsežno, nepravilno periostalno reakcijo z radiacijskimi črtami (podtip »sunburst«), ki je običajno povezana z malignimi tumorji. Poleg tega je kirurška resekcija lahko ključna za povrnitev žvečilne funkcije in lajšanje bolečin v ustih, tudi v primerih benignih lezij mandibule.

Ključne besede: spodnja čeljustnica; anatomija; meritve; živalski modeli; eksperimentalna oralna kirurgija