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THE EFFECT OF SLICE THICKNESS ON THE VOLUME ESTIMATIONS PERFORMED BY USING CONE BEAM CT

Konik Işınlı BT Kullanılarak Yapılan Hacim Hesaplamalarında Kesit Kalınlığının Etkisi

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ABSTRACT

Objective: The purpose of this study is to investigate possible effects of the slice thickness on volume estimations with Cone Beam Compute Tomography (CBCT).

Materials and Methods: Intraosseous cavities representing bone defects on femoral condyles of bovines were scanned by CBCT. Consecutive slices at 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm thickness were used to estimate the volumes of the cavities using Cavalieri principle of stereological methods then compared with the volumes obtained by Archimedean principle.

Results: The volumes estimated by Cavalieri principle in 0.1 mm, 0.2 mm and 0.3 mm thickness slices were consistent with the volumes obtained by Archimedean principle ($p>0.05$). For all the defects on the CBCT images, the volumes of the defects which were calculated with Cavalieri principle in 0.1 mm, 0.2 mm and 0.3 mm slice thickness were found to be consistent with the actual volumes, however, the volumes that were calculated in 0.4 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm slice thickness were found to differ from the actual volumes.

Conclusion: When volume calculations were made by Cavalieri principle, the thinnest slice section should be chosen to make calculations consistent with actual volumes.

Keywords: Radiography, Dental, Cone Beam Computed Tomography, Quantitative Evaluation, Cavalieri Principle

ÖZ

Amaç: Bu çalışmanın amacı Konik Işınlı Bilgisayarlı Tomografi (KIBT) ile hacim hesaplamalarında kesit kalınlığının olası etkilerini araştırmaktır.

Materyal ve Metod: Sığır femur başında kemik defektlerini taklit eden intraosseoz kaviteler KIBT ile tarandı. Kavitelerin stereolojik bir metod olan Cavalieri prensibiyle hacim hesaplamalarında 0,1 mm, 0,2 mm, 0,3 mm, 0,4 mm, 0,5 mm, 1 mm, 2 mm, 3 mm, 4 mm ve 5 mm kalınlığında ardışık kesitler kullanıldı. Hesaplanan hacimler daha sonra Arşimet prensibiyle hesaplanan hacimlerle kıyaslandı.

Bulgular: 0,1 mm, 0,2 mm ve 0,3 mm kesit kalınlığında Cavalieri prensibiyle hesaplanan hacimler Arşimet Prensibiyle hesaplanan hacimlerle uyumluydu ($p>0,05$). KIBT görüntülerinde tüm defektler için, 0,1 mm, 0,2 mm, 0,3 mm kesit kalınlığında hesaplanan hacimler gerçek hacimlerle uyumluyken, 0,4 mm, 0,5 mm, 1 mm, 2 mm, 3 mm, 4 mm ve 5 mm kesit kalınlığında hesaplanan hacimler gerçek hacimlerden farklı bulundu.

Sonuç: Cavalieri prensibiyle hacim hesaplanalanacağı zaman, gerçek hacimle uyumlu hesaplamalar yapılabilmesi için en ince kesit kalınlığı seçilmelidir.

Anahtar Kelimeler: Radyografi, Dental, Konik Işınlı Bilgisayarlı Tomografi, Kantitatif Değerlendirme, Cavalieri Prensibi

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INTRODUCTION

The use of three-dimensional imaging methods for the maxillofacial region has become common due to the limitations of two-dimensional images obtained by conventional radiography. Cone Beam Computed Tomography (CBCT) was developed for several medical applications, such as angiography[1,2] mammography[1-3] and radiotherapy guidance[1, 2, 4] and it was approved by the Food and Drug Administration (FDA) in 2001 for the visualization of maxillofacial tissues. It is also used in almost all areas of dentistry.[3, 5-7] Using CBCT, it is possible to obtain sectional images on the axial, sagittal and coronal planes. From these images, the volume of an anatomic or pathologic structure in any plane can be calculated with Cavalieri principle. According to this principle, the volume of an amorphous object can be calculated by multiplying the total area of the sections, which are taken randomly from the overall structure of an object, and the lengths between these sections.[8]

In the literature, there are several studies which use CBCT images for volumetric calculations[8-12], however, only few studies published regarding the effect of the slice thickness on these calculations.

The aim of this study is to investigate the effect of slice thickness on volume estimation by applying Cavalieri principle to CBCT images.

MATERIALS AND METHODS

In this study, 13 bovine femurs were used and 30 different intraosseous defects with different volumes were created on the femoral condyles by using an oval tungsten carbide burr. The upper borders of the defects were filled with dental stone (Fig. 1).

Fig.1: Intraosseous defects on the condyle of bovine femurs

CBCT scans of intraosseous cavities were taken with Kodak 9300 Cone Beam 3D System (Kodak Dental Systems, Carestream Health, Rochester, NY) with the following parameters 5×5 cm field of view, 0.09 mm voxel size, 84 kV tube voltage, 5 mA tube current, and 20. s scan time for the defects with a diameter smaller than 4.5 mm and 8×8 cm field of view, 0.2 mm voxel size, 90 kV tube voltage, 4 mA tube current, and 8 s scan time for defects with a diameter is larger than 4.5 mm.

Cavalieri principle was applied to calculate the volume of each intraosseous defect. For this purpose, each defect was obtained into consecutive sections of 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm and 5 mm using 3D-DOCTOR software (3D-DOCTOR Able Software Corp, Lexington, USA). There were no intervals between sections. The planimetry method was used to calculate the surface area of these sectional images (Fig. 2). The software automatically gave the total volume by multiplying the total surface area with the section thickness. This procedure was followed for all defects in every section thickness.

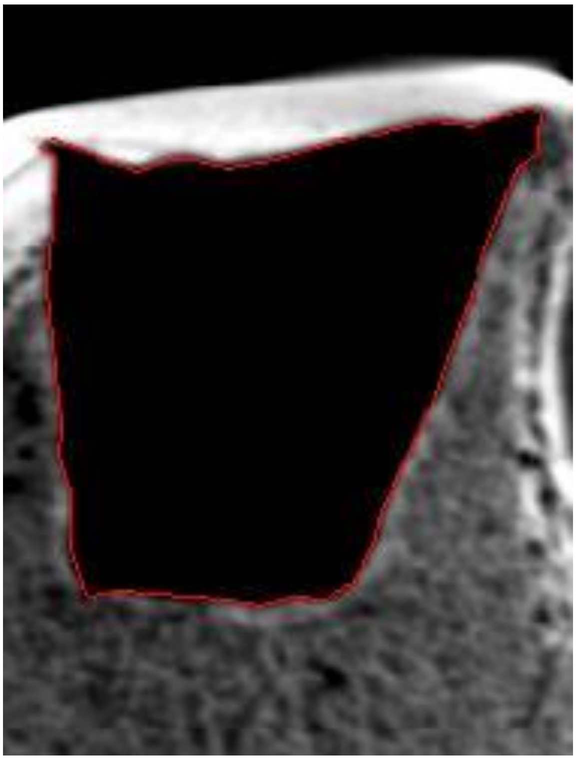

Fig.2: Borders of intraosseous defects traced manually surface of area calculate planimetry method by 3D-DOCTOR software

To calculate the actual volumes of the intraosseous defects, the intraosseous cavities were filled with low-viscosity silicon impression material. After polymerization, silicon impressions were immersed into a pycnometer filled with water, and the volumes were calculated using the density and weight of the water run-over, based on Archimedean principle. These measurements by the water-displacement method served as the gold standard.

The data were analyzed using SPSS, version 13 (Chicago, IL, USA). The One Sample Kolmogorov-Smirnov normality test was applied for all samples. The actual volumes, which were determined by the Archimedeans principle, and the volumes that were calculated using Cavalieri principle in 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm section thickness, were compared with Paired Sample T-tests separately. All statistical tests were set at the 95% confidence level ($p \leq 0.05$).

In order to analyze the relationship between the number of sections and defect volumes, measurements were categorized under 10 different groups such as 1-5, 6-10, 11-15, 16-20, 21-30, 31-50, 51-100, 101-200, 201-300 and 301-570, according to the number of sections. The average absolute percent variance values of each group were compared.

RESULTS

The results of the volume estimations using CBCT images and the actual volumes via Archimedean principle are shown in Table 1.

Table 1: Actual and estimated volumes of intraosseous defects (mm^3)

Actual	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.5 mm	1 mm	2 mm	3 mm	4 mm	5 mm
34.19	34.281	34.665	35.501	36.349	34.573	32.043	32.233	31.479	26,754	13,672
83	81,716	83.211	83.671	82.974	82.791	79.864	83.34	64.304	70.42	38.797
201.7	200.849	201.638	202.056	202.6	201.194	204.463	197.12	213.401	217.718	230.741
204.7	206.9	208.9	208.2	208.1	207.8	207.7	203.5	207	224.5	163.8
240.5	237.962	239.77	238.915	217.001	224.461	214.14	213.571	233.735	229.946	169.029
252.3	255.4	247.9	248.454	247.229	248.163	245.407	250.306	252.764	245.654	174.216
758.57	748.094	734.15	727.081	763.094	745.045	748.337	755.237	755.442	766.562	812.652
1107.87	1126.875	1118.75	1104.359	1112.601	1128.37	1123.547	1127.913	1128.446	1130.047	1110.58
1965.424	1982.84	2002.259	1995.981	1984.497	1977.445	1991.603	1966.157	1948.801	1968.576	1932.35
3123.449	3151.126	3152.77	3192.42	3173.792	3180.704	3183.876	3186.841	3115.794	3225.317	3000.612
3688.741	3665.944	3705.968	3754.495	3773.161	3725.585	3783.47	3827.369	3670.824	3541.282	3573.174
4354.66	4288.111	4314.057	4336.441	4331.779	4356.851	4321.192	4301.269	4227.796	4280.707	4245.395
4880.609	4889.039	4793.465	4893.452	4845.549	4797.292	4876.001	4894.586	4938.995	5013.117	4905.436
7063.061	7124.638	7050.054	7112.738	7103.6	7056.952	7070.474	7039.619	7026.694	7347.047	7258.131
7295.303	7233.158	7072.326	7196.554	7271.611	7249.662	7197.744	7329.884	7166.811	7169.352	7160.988
8900.204	8809.134	8917.495	8889.06	8833.628	8812.946	8897.47	8813.795	8750.177	8837.565	8613.372
9790.969	9829.73	9596.648	9546.473	9648.328	9506.895	9745.128	9458.328	9637.772	9371.204	9468.459
10519.9	10326.72	10229.96	10339.2	10253.3	10424.42	10265.13	10349.08	10348.78	10504.75	10454.96
10802	10801.8	10684.66	10753.45	10795.52	10665.02	10546.15	10557.38	10677.74	10475.7	10687.64
11059.55	11098.28	11048.74	10924.27	10787.43	10884.33	10951.21	10906.51	10740.19	10877.76	10572.54
13730.69	13984,74	13887.75	13890.01	13870.48	13781.29	13684.11	13756.94	13753.31	13841.93	13895.69
14575.41	14432.91	14427.01	14509.31	14395.57	14311.5	14335.68	14373.26	14205.47	14136.72	14132.21
16710.02	16619.23	16507.96	16711.94	16699.68	16579.83	16543.64	16389.9	16503.93	16127.9	16771.62
17088.5	17116.05	17173.75	17079.99	17028.86	17099.26	17057.74	17202.74	16982.99	17206.83	17153.43
17835.74	17964.94	17698.56	18062.1	18027.63	17816.03	17868.37	17961.43	17926.61	17983.51	18036.02
19095.31	19055.14	19011.39	18962.99	18847.66	19057.91	18798.32	18688.44	18696.25	18780.24	19003.96
23361.8	23785.2	23634.71	23347.89	23222.23	23657.16	23637.6	23759.38	23526.65	23522.19	23280.64
24495.29	23420.66	23538.81	23649.45	23817.93	24223.32	24098.58	24062.74	23978.97	23936.24	24284.46
27662.36	27252.03	27699.63	27434.79	27457.27	27395.91	27434.51	27232.23	27307.97	27135.36	27235.01
30052.7	29140.59	29165.9	29350,93	29200.83	29247.43	29538.98	29187.92	29046	28685.66	28888.8

The Paired Sample T-test was used to compare the volumes, which were calculated in every section thickness by Cavalieri principle, and the actual volume, separately. The Paired Sample T-tests showed that there was not a statistical significance between the actual volumes and the calculated volumes in the 0.1 mm, 0.2 mm and 0.3 mm section thickness, however, there was a statistically significant difference between the actual volumes and the calculated volumes in the 0.4 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm section thicknesses (Table 2).

Table 2: Evaluation of the results with the paired sample t-test ($p \geq 0.05$)

	Sig. (2-tailed)		Sig. (2-tailed)
0.1 mm	0.169	1 mm	0.015
0.2 mm	0.056	2 mm	0.037
0.3 mm	0.078	3 mm	0.004
0.4 mm	0.030	4 mm	0.031
0.5 mm	0.032	5 mm	0.016

According to the average absolute variance percentages of the volumes of the defects which were calculated by Cavalieri principle, the lowest variance was 1.1% at the 0.1 mm section thickness and this value was followed by the 0.3 mm (1.25%), 0.5 mm (1.26%), 0.2 mm (1.28%), 0.4 mm (1.58%), 1 mm (1. 8%), 2 mm (1.86 %), 3 mm (2.3%), and 4 mm (3.72%). The highest variance was calculated as 8.59% at the 5 mm section thickness (Table 3).

Table 3: The percent deviance of the measurements (from actual volumes) that were calculated by using Cavalieri principle according to number of sections.

Group	1	2	3	4	5	6	7	8	9	10
Section number	1-5	6-10	11-15	16-20	21-30	31-50	51-100	101-200	201-300	301-570
Percent variance	6,9 %	2%	2%	2%	1%	1%	1%	1%	1%	1%

In the volume calculations by Cavalieri principle, the measurements that were performed to investigate the effect of the number of sections were categorized according to the number of sections. The groups were categorized according to number of sections as 1-5, 6-10, 11-15, 16-20, 21-30, 31-50, 51-100, 101-200, 201-300, 301-570 and named as Group 1, Group 2, Group 3, Group 4, Group 5, Group 6, Group 7, Group 8, Group 9, and Group 10. For each defect, the percent variance (deviance of volumes calculated by Cavalieri principle from actual volumes) was calculated and the group average was determined.

In the calculations performed using Cavalieri principle, the maximum deviance was calculated as 6.9% in the measurements that were done on sections 1-5. This variance was 2% on sections 6-20 and it was 1% in the measurements done on sections 21-570.

DISCUSSION

The pathologies which cause resorptions in the jaw lead to bone defects.[8,10] Knowing the volume of these defects is important for the diagnosis, treatment plan and the evaluation of treatment outcomes[12] and this can be visualized with 3D imaging techniques.[10,12] Cavalieri principle is a common technique which is used for volumetric calculations and stereological methods and it enables the calculation of the volumes of amorphous objects which cannot be isolated from the outside environment on 3D radiological images.[9, 13, 14]

In the literature, there are several studies which use CBCT images for volumetric calculations. Bayram *et al*.[9] calculated volume of nine condyles in the dry human mandible and Kayipmaz *et al*.[8] calculated volume of osseous defects in the sheep mandible.

In the volumetric calculations performed using Cavalieri principle, the thickness of the section affects the accuracy of the calculations. To investigate the effect of section thickness on volumetric calculations in Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and CBCT images, different section thicknesses were used. Odaci *et al.*[15] calculated volumes of 10 lumbar vertebrae whose volumes changes between 26 600 mm^3 and 34 300 mm^3 on CT images using Cavalieri principle in 3 mm and 5 mm section thickness. Even though calculated volumes were higher or lower than actual volumes in both section thickness, there was no statistically significant difference between actual volumes and calculated volumes. Similarly, Bilgic *et al.*[16] also calculated volume of an intervertebral disc whose volume changes between 8 780 mm^3 and 15 360 mm^3 on CT images using Cavalieri principle in 3 mm and 5 mm section thickness. They could not find any statistically significant difference between actual volumes and calculated volumes, in this case either. In our study, also we found that the absolute variance of calculated defect volumes in 3 mm and 5 mm thickness from actual defect volumes were found to be lower than 5%.

In Sezgin *et al.*'s[10,17] study, six defects between 155 mm^3 and 565.7 mm^3 were formed on the two sheep mandible and scanned with CBCT. The volumes were calculated in 0.2 section thickness and 0.8 interval, in 0.6 mm section thickness and 0.4 mm interval and also 1 mm, 1.4 mm, and 2.2 mm section thickness using Cavalieri principle. Results were then compared with the actual volumes and the calculated volumes in thin sections were found compatible with actual volumes.

In our study, the calculated volumes in thin sections (0.1 mm, 0.2 mm, and 0.3 mm) were compatible with actual volumes, however, the calculated volumes in thicker section were different from actual volumes. The section thickness was found more effective on defects with a diameter less than 1 cm, but larger defects were affected less. The highest average variance from actual volume was 60% and it was found at the 5 mm section thickness of the smallest defect. The smallest average absolute variance was 0.001% and it was at 0.1 mm section thickness of the defect with 10 802 mm^3 volume. When we look at the volume-to-section-thickness relationship in all defects used in this study, the lowest average variance from actual volume was seen at 0.1 mm section thickness and the highest average variance was calculated at 5 mm section thickness.

When volume was calculated using Cavalieri principle, the number of sections also affects the accuracy of the calculations. Sahin *et al.*[18] reported that 8-15 sections were enough to calculate volume of a liver on MRI images by Cavalieri principle and they did not find any significant difference between actual and calculated volumes. We also found compatible results in our study which was calculated with six or more sections, however, we could not get compatible results which were calculated with five or fewer sections.

CONCLUSIONS

Consequently, the thinnest section should be chosen to be able to find the closest volumetric value to the actual volume. As volume increases, the effect of section thickness decreases and when the number of sections is fewer than five, a significant difference was seen between the actual and calculated volumes.

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