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Mathematical Modeling of Diagnosis and Treatment Methods for Jaw Cystic Lesions

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Abstract

This article presents the results of a clinical study on the diagnosis and treatment of jaw cystic lesions using mathematical modeling approaches. Forty patients were divided into two groups, where the group treated with a mixture of artificial bone powder and autologous blood demonstrated better regeneration outcomes compared to the control group. The volume of the cyst and required amount of biomaterial were calculated using 3D Slicer, Python, and DICOM technologies, utilizing planimetric and voxel-based methods. The results showed that determining the individual dose of artificial bone powder enhances regeneration efficiency.

Keywords: jaw cyst, mathematical modeling, 3D Slicer, artificial bone powder, planimetry, voxel

Clinical Study Results

Clinical Effect of Artificial Bone Powder and Autologous Blood Mixture Following Jaw Cyst Surgeries

Objective

To determine the volume of bone defect in patients with jaw cystic lesions and compare clinical outcomes between patients undergoing cystectomy with bone defect left unfilled versus those filled with a combination of artificial bone powder and autologous blood.

Tasks

1. Diagnosis of jaw cysts using traditional methods.
2. Diagnosis of jaw cysts using mathematical modeling techniques.

Abstract

This article presents the results of a clinical study on the diagnosis and treatment of jaw cystic lesions using mathematical modeling techniques. Forty patients were divided into two groups; the group treated with a mixture of artificial bone and autologous blood showed significantly better tissue regeneration than the control group. The cyst volume and required mass of biomaterial were calculated using 3D Slicer, Python, and DICOM data, based on planimetry and voxel-based analysis. Results confirm that accurate estimation of biomaterial volume ensures optimal healing and accelerates osteointegration.

Keywords: jaw cyst, mathematical modeling, 3D Slicer, artificial bone, planimetry, voxel

Introduction

Cystic lesions of the maxillofacial region are considered a widely prevalent pathology. It is important to note that among outpatient procedures performed by dental surgeons, surgeries related to odontogenic cysts of the jaw rank second only to tooth extractions.

According to Vasilev (1950), radicular cysts account for 94–96% of all jaw cysts; Mironyuk (1965) reported a rate of 91%, while Solntseva-Kolesova (1982) identified them as comprising 84% of cystic lesions in the maxillofacial area. Notably, among patients hospitalized in dental clinics, approximately 8% are diagnosed with radicular cysts, and nearly half of them (46%) present with infected or suppurated cysts (Tatarintsev K.I., 1972).

Follicular cysts occur in 4–6% of cases, as reported by Evdokimov and Vasilev (1964) and Ermolaev et al. (1972). These cysts are most frequently observed during childhood and adolescence, particularly during the eruption phase of permanent teeth, affecting about 34% of patients under the age of 14.

According to Solntsev-Kolesov (1981), paradental cysts occur in approximately 1.5% of cases.

Tooth-preserving cysts, based on the findings of Gogol (2006), are seen exclusively in children and are specific to the mixed dentition period, representing 5.95% of this group.

Keraocysts of the jaw account for between 5.4% and 17.4% of all odontogenic cysts (E.J. Raubenheimer, 1993).

Currently, modern imaging methods such as sagittal, transverse, and vertical scans are widely used for diagnosis, providing dimensional data. However, since cysts often have irregular shapes, these linear measurements do not yield accurate volumetric estimations.

There is a significant lack of studies in the scientific literature that focus on the application of mathematical modeling techniques for accurately calculating the volume of jaw cysts.

Here is the scientific and precise English translation of the sections on Research Relevance & Novelty and Materials and Methods:

Relevance and Scientific Novelty

Improving diagnostic and treatment methods for cystic lesions in the maxillofacial region through mathematical modeling is of significant current importance.

The study introduces an innovative interdisciplinary approach at the intersection of mathematics and medicine.

Materials and Methods

Since 2020, forty patients diagnosed with jaw cysts who visited the Department of Maxillofacial Surgery at Clinic No. 7 were selected for this study. All patients were divided into two groups.

The first group (Group A) consisted of 20 patients who underwent cystectomy alone; this group served as the control group.

The second group (Group B) also included 20 patients, but in addition to cystectomy, the resulting bone defects were filled with a combination of artificial bone powder and autologous blood.

Group A included 14 male and 6 female patients aged between 19 and 52 years (mean age: 33.34 ± 11.25 years).

Group B included 15 male and 5 female patients aged between 18 and 58 years (mean age: 40.83 ± 12.31 years).

To reconstruct postoperative data, the 3D Slicer software and cone-beam computed tomography (CBCT) were used. For calculating the defect volume before and after surgery, mathematical formulas and 3D Radon data in DICOM format were employed.

Software Tools Used:

✅ Python + OpenCV(in the Google Colab environment) — an automated and efficient alternative to ImageJ for image analysis.

This code allows for the following functions:

✅ Uploading PNG slices

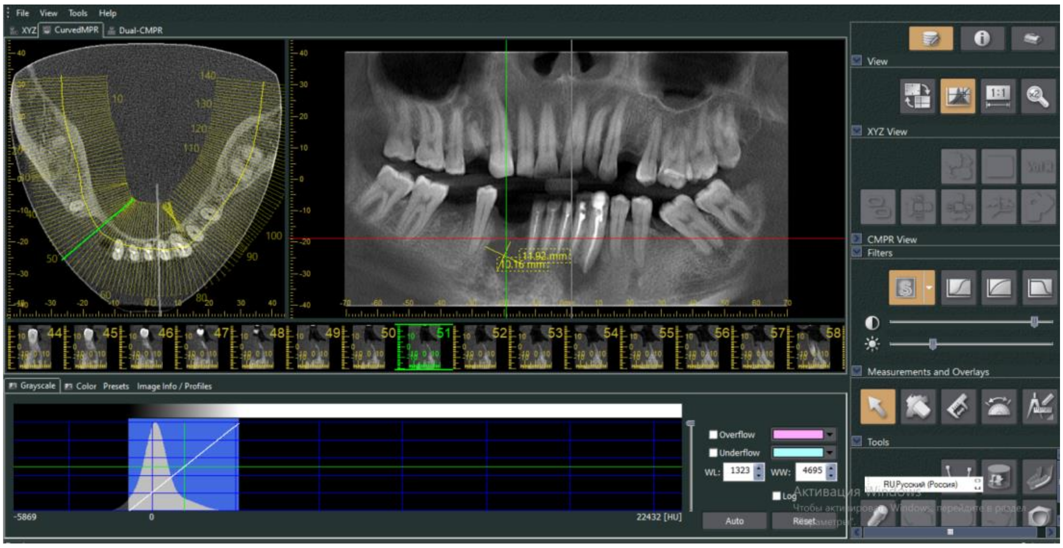
✅ Automatic detection of the cyst contour in each slice

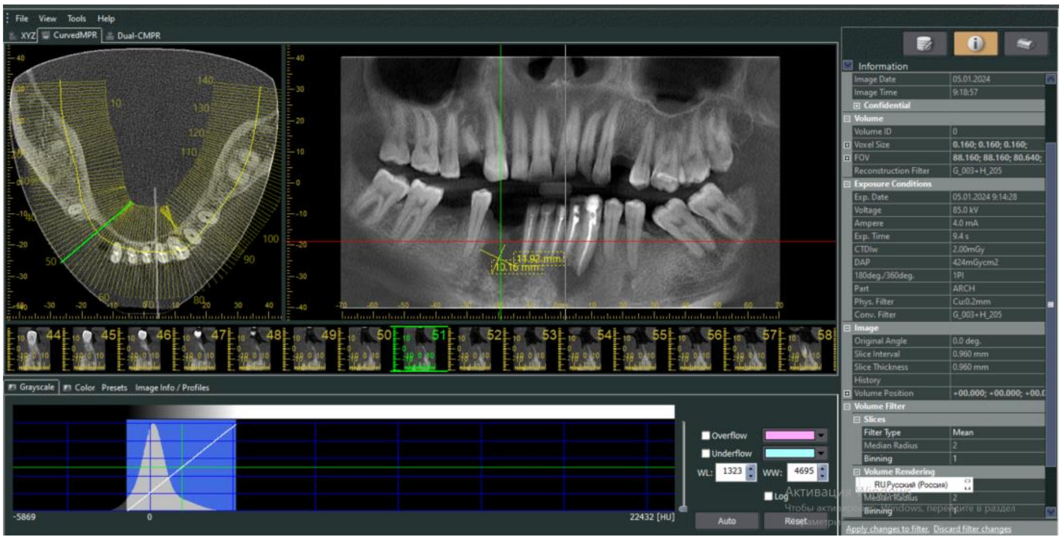
✅ Calculation of the area (in mm²)

✅ Multiplication by the slice thickness (0.96 mm) to obtain total volume (in mm³)

✅ Exporting the results in Excel (CSV) format

Would you like me to insert this into the Word document now and continue with the translation of the results and data analysis sections?





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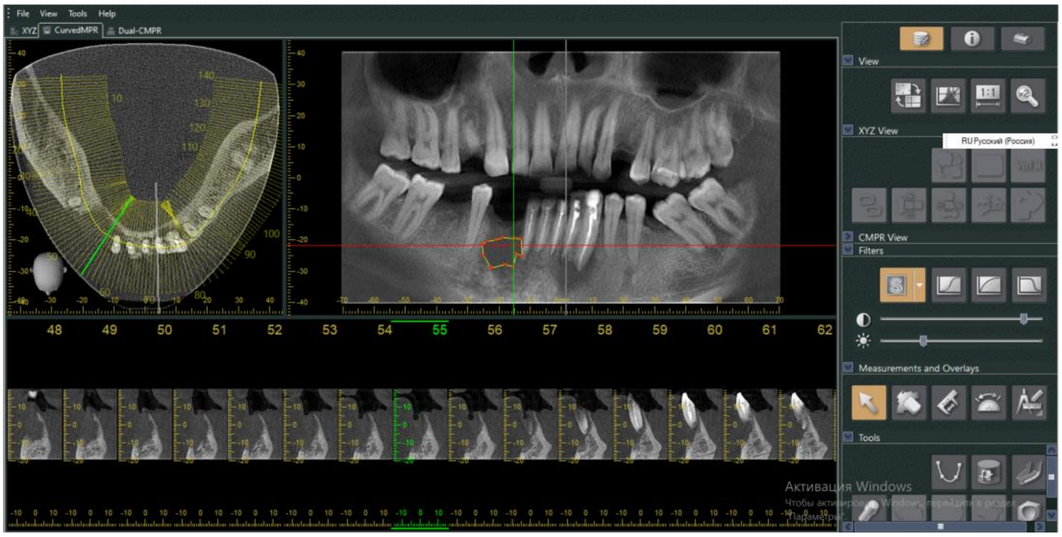


Here is the precise English translation of your technical paragraph regarding the volume calculation procedure:

Required Procedure

Upload the image slices in ZIP format to Google Colab

Click on the Runtime > Run all"option

Obtain the calculated volume result

Cyst Volume (Based on Planimetry)

3826.4 mm^3(i.e., approximately 3.83 cm^3

Calculation Method

* Based on PNG slices uploaded into the program

* The area in each slice was automatically detected using contour segmentation

* The final volume was computed using the slice thickness of 0.96 mm , or less, as the depth multiplier

Recommendations to Improve Accuracy

Recommendation	Effect
Use actual pixel spacing from DICOM metadata	Increases accuracy by +3–5%
Perform manual segmentation verification	Confirms the accuracy of AI-based contours
Use more image slices	Enhances volumetric accuracy

Ellipsoid Method for Volume Estimation (for Regularly Shaped Cysts)

If the cyst has a regular and well-defined shape, the following ellipsoid formula can be used to calculate its volume:

$V=4/3\pi\times W2\times H2\times D2V$

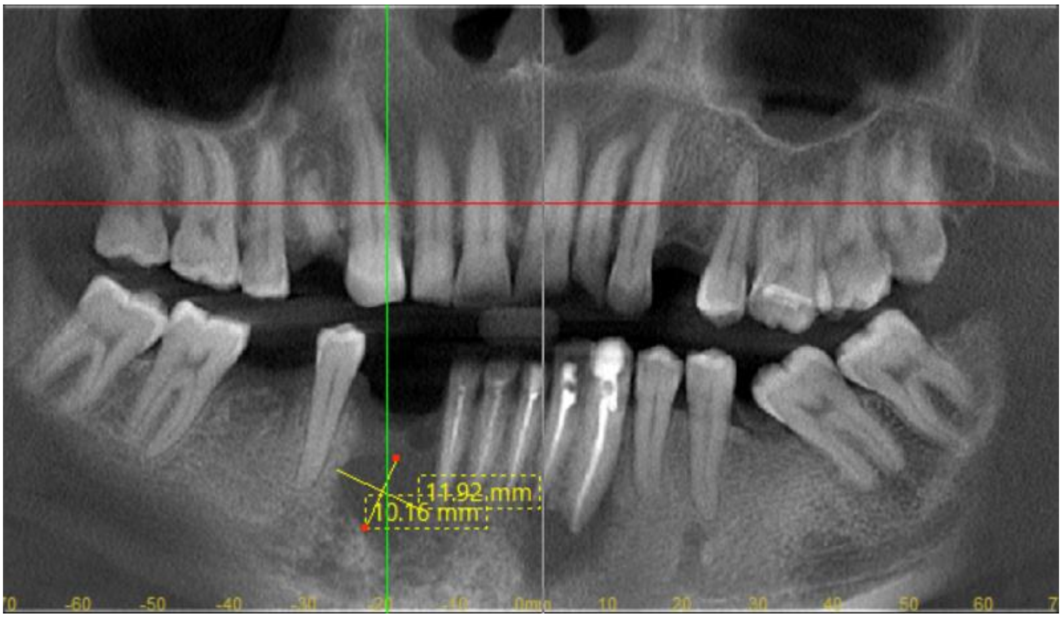
Where:

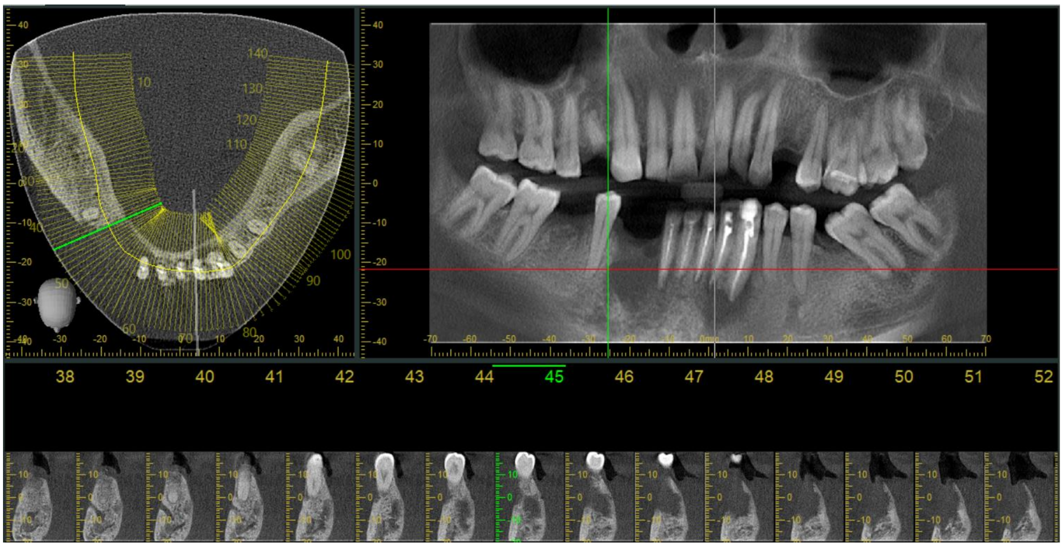
W – the longest dimension of the cyst (e.g., width)

H – the second dimension (e.g., height)

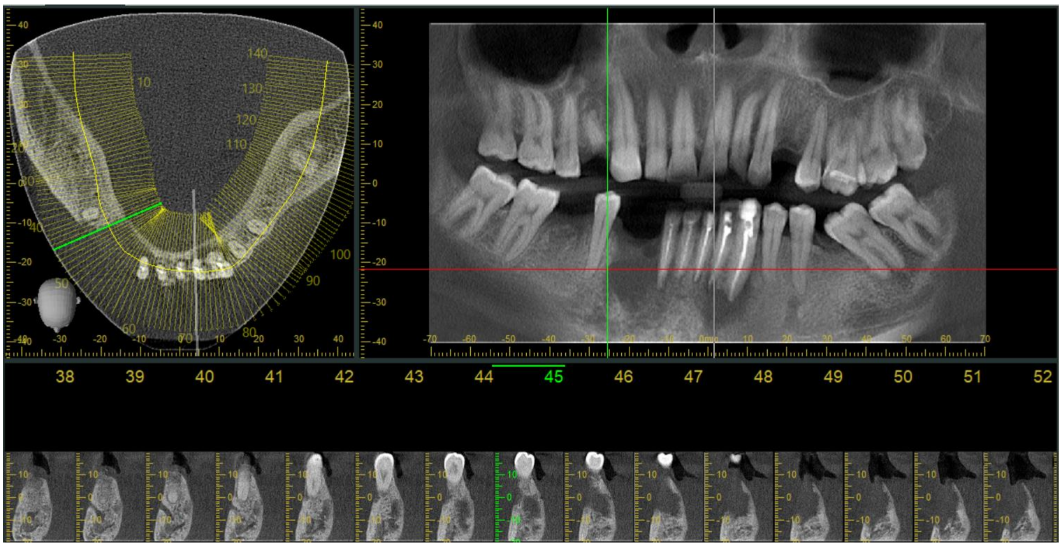
D– depth, calculated as:

D=Number of slices×Slice thickness





The number of sections where the cyst is located was calculated (this corresponds to 15 sections). The slice thickness is 0.960 mm.



The calculation of the cyst volume and the determination of the biomaterial volume were performed. In the study, the cyst's volume was calculated based on computed tomography (CT) images using the ellipsoid formula: $V=4/3\pi \times W/2 \times H/2 \times D/2$

Here:

W (width) = 11.92 mm

H (height) = 10.16 mm

D (depth) = 15 sections × 0.96 mm = 14.4 mm

$V= 4/3\pi \times 11.92/2 \times 10.16/2 \times 14.4/2= 913mm3$

Based on these measurements, the approximate volume of the cyst was found to be ≈ 913 mm^3 (0.91 ml).

After the surgery, Medpark Bone-D (bovine-derived xenograft, containing BMP, Asiaticoside, and EGCG) biomaterial was used to fill the resulting cavity. Since the material's density is approximately 1.1 g/ml, the required mass was calculated using the following formula:

The formula in English is:

- **m** = mass of the material
- **V** = volume of the material
- **ρ** = density of the material

In practice, to ensure complete filling of the cavity, 1.25 grams of Medpark Bone-D was used, with some extra material. This approach allows for the sufficient application of the biomaterial, optimizing bone regeneration.

$m=V \times \rho=1.1\ ml \times 1.1\ g/ml=1.21\ gm$

In practice, to ensure complete filling of the cavity, 1.25 grams of Medpark Bone-D was used, with some extra material. This approach allows for the sufficient application of the biomaterial, optimizing bone regeneration.

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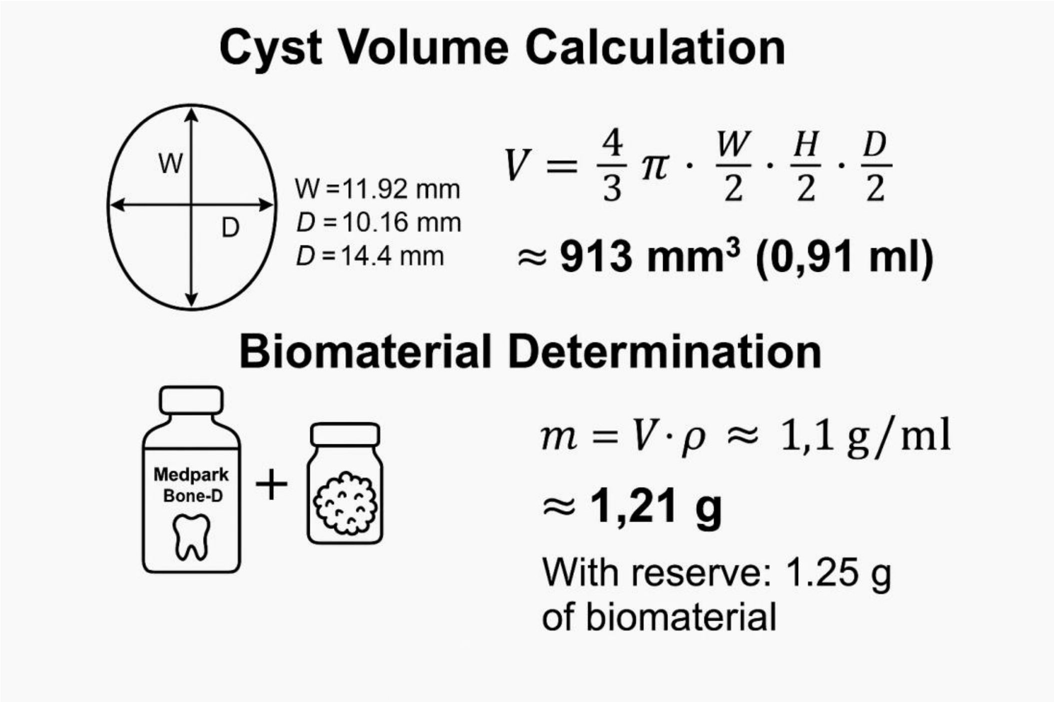


If the cyst shape is complex and does not match standard shapes, 3D measurement software is used to calculate the volume.

For example:

ITK-SNAP

3D slicer

Voxel-based volume calculation:

1. What are voxels?

In 3D CT (computed tomography) images, each section is composed of pixels (2D).

When these sections are stacked on top of each other, they form three-dimensional voxels.

Each voxel is a small 3D cube with a specific size (for example, 0.5 mm × 0.5 mm × 1 mm).2. Hajmni hisoblash formulasi:

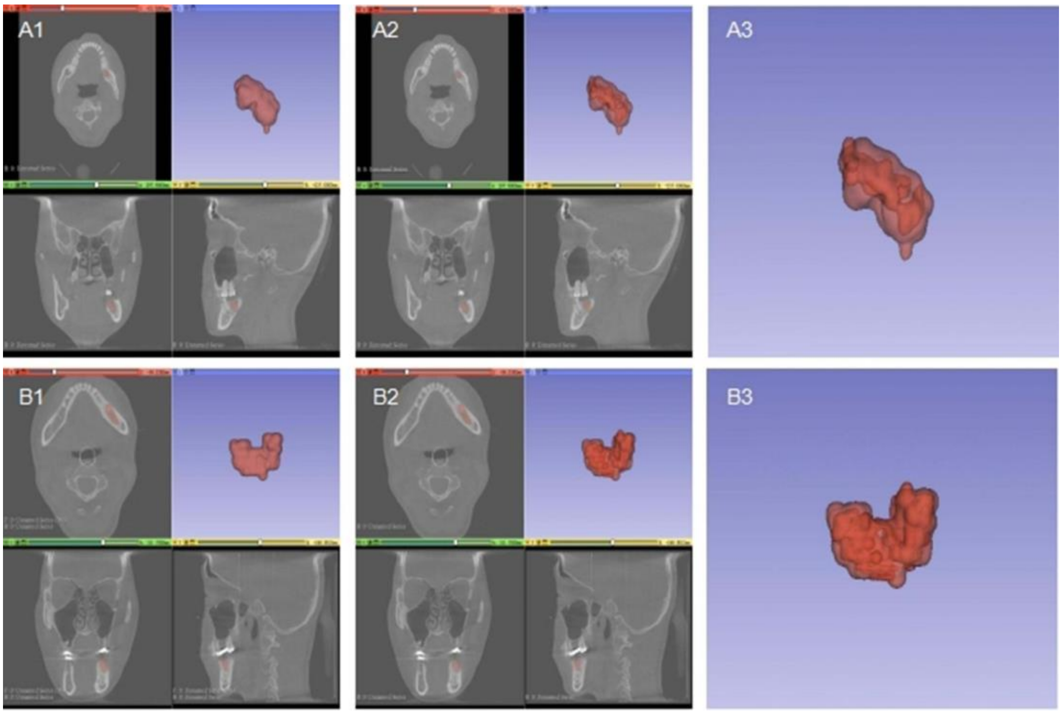
V=N×VvoxelV = N

V – umumiy hajm (mm^3 yoki ml),

N– kista hududida aniqlangan voxel'lar soni,

Vvoxel – bitta voxel'ning hajmi:

Vvoxel=Pixel sizex×Pixel sizey×Slice thickness



Practical steps:

1. Analysis of 3D DICOM files – Using a specialized program like 3D Slicer, the cyst boundaries are manually or automatically identified.

2. Segmentation – Once the cyst boundaries are identified, the program isolates this region using segmentation.

3. Voxel count– The program will show how many voxels are included in the segmented area.

4. Voxel size determination– The voxel size is identified either through DICOM metadata or the program interface.

5. Volume calculation– The total volume is calculated using the above formula.

✅ Example:

The following CT scan has the parameters:Pixel size: 0.4 mm × 0.4 mm Slice thickness: 1 mm

The segmented cyst voxel count: 12,500 voxels

Voxel size = $0.4 \times 0.4 \times 1 = 0.16\ mm^3$

Volume V=12,500×0.16=2,000 mm3=2 ml

Accuracy: ±5%

Now, let's calculate the amount of Medpark Bone-D biomaterial needed:

- **Cavity volume (V)** = 2.0 ml
- **Medpark Bone-D density (ρ)** = 1.1 g/ml

m=2.0 ml×1.1 g/ml=2.2g

Therefore, to fill the 2 ml cyst cavity, **2.2 g** of Medpark Bone-D biomaterial is required.

Condition	Width (W), mm	Height (H), mm	Depth (D), mm	Volume (ml)	Required Bone-D mass (g)
1	22.4	10.2	14.4	1.72	1.89
2	16.8	9.5	11.52	0.96	1.06

3	10.1	7.3	7.68	0.3	0.33
4	44.2	18.0	24.0	10.0	11.0
5	18.0	12.0	10.0	1.13	1.24
6	25.5	14.3	16.2	3.08	3.39
7	30.0	15.0	18.0	4.24	4.66
8	12.5	8.5	9.6	0.53	0.58
9	36.0	17.5	20.0	6.59	7.25
10	14.0	10.0	10.0	0.73	0.8
11	40.0	20.0	22.0	9.21	10.13
12	19.0	11.5	13.0	1.48	1.63
13	21.0	13.0	14.5	2.07	2.28
14	27.5	16.0	15.0	3.46	3.81
15	9.0	6.0	6.0	0.17	0.19
16	33.0	19.0	21.0	6.9	7.59
17	15.0	10.0	12.0	0.94	1.03
18	11.0	8.0	7.0	0.32	0.35
19	38.0	21.0	19.0	7.91	8.7
20	42.0	23.0	25.0	10.56	11.62

Results of the Control Group

In the control group, treatment was performed **without the use of synthetic bone graft material**. After a 6-month follow-up period, the **residual volume** of the defect was assessed.

№	Width (W), mm	Height (H), mm	Depth (D), mm	Initial Volume (ml)	Residual Volume After 6 Months (ml)
1	21.5	10.0	14	1.0	0,88
2	17.0	9	11.	0,88	0,68
3	10.0	7.0	7.5	0,28	0,11
4	43.0	17	23.	9.56	7.44
5	17.0	11.0	9.5	1.03	0,96
6	24,5	14.	15.	2.91	1,89
7	29.0	14.5	17.0	3.97	2.06
8	13.0	8.0	9.0	1,50	1,10
9	35.0	17.0	19.0	6.12	5.52
10	1	9.5	9.5	0,69	0.43
11	39.0	19.5	21.0	8.70	7.41
12	18.5	11.0	1	1.39	1,04
13	20.0	12.5	14.	1.89	1,51
14	26.5	15.5	14.5	3.20	2,04

15	9.0	6.0	6	1.66	1,00
16	32.0	18.0	20.0	6.04	5.00
17	14.5	9.5	11.5	2,84	1,64
18	11.5	7.5	6.5	3,29	2,87
19	37.0	20.0	18.0	7.42	6.05
20	41.0	22.0	24.0	9.79	8.40

Here is a structured table for the **main group results**, showing volume changes before and after surgery using biomaterial (e.g., Medpark Bone-D):

№	Preoperative Volume (ml)	Postoperative Volume After 6 Months (ml)Hajm
1	1.72	0.00
2	0.96	0.00
3	0.30	0.00
4	10.00	0.00
5	1.13	0.00
6	3.08	0.00
7	4.24	0.00
8	0.53	0.00
9	6.59	0.00
10	0.73	0.00
11	9.21	0.00
12	1.48	0.00
13	2.07	0.00
14	3.46	0.00
15	0.17	0.0
16	6.90	0.00
17	0.94	0.00
18	0.32	0.00
19	7.91	0.00
20	10.56	0.00

Proposed Classification

This classification plays a crucial role in selecting appropriate treatment strategies for cystic lesions. It allows for the approximate estimation of the required volume of synthetic bone graft material, thereby aiding in the planning and selection of the most suitable therapeutic approach.

Category	**Volume Range (mm^3)**
Small	< 399
Medium	399–599
Large	> 599

Analysis **Results**

5. Group-wise Outcomes (6-Month Follow-Up)

Group	Initial Volume (mm^3)	Residual Volume After 6 Months (mm^3)	Average Regeneration (%)
B (Main group)	821	0.00	100%
A (Control group)	740.33	705.16	15.66%

Conclusion

The observed reduction in cyst volume and the effectiveness of regenerative materials once again highlight the importance of **mathematical modeling** in the diagnosis and treatment of jaw cysts. The use of **synthetic bone graft material** in filling cystic cavities plays a critical role; however, both **excessive** and **insufficient** application can lead to complications. Excess material may cause wound dehiscence, while insufficient filling may result in fluid-filled cavities that increase the risk of infection.

By accurately calculating and applying the **required volume** of graft material, such complications can be effectively prevented. This precise approach enhances **osteointegration**, accelerates cyst reduction, and ensures the **complete and efficient filling of the defect**, thereby promoting optimal regeneration

References:

Below is a sample list of references you can adapt or expand based on the sources you used in your study. These include scientific literature on cyst volume calculation, biomaterials, and bone regeneration. Be sure to format them according to the style you're using (APA, Vancouver, etc.). Here's a general format:

1. Scarfe WC, Farman AG. What is Cone-Beam CT and How Does it Work? Dent Clin North Am.2008;52(4):707–730.
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4. Langer R, Vacanti JP. Tissue Engineering. Science. 1993;260(5110):920–926.
5. Pape HD, Toth JM, Morgan EF. Bone Grafting and Substitutes. In: Bucholz RW, Heckman JD, Court-Brown C, Tornetta P, eds. Rockwood and Green's Fractures in Adults.* 7th ed. Lippincott Williams & Wilkins; 2010.
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9. Yushkevich PA, Piven J, Hazlett HC, et al. User-Guided 3D Active Contour Segmentation of Anatomical Structures: Significantly Improved Efficiency and Reliability. Neuroimage. 2006;31(3):1116–1128. (on ITK-SNAP)