Use of Various Quantification Techniques for Dental Radiological Images for Research Purposes

Bunyamin SAHIN [1], Mert NAHIR[2], Amani ELFAKI[3]

[1] Department of Anatomy, Faculty of Medicine, Ondokuz Mayis University, Samsun, TÜRKIYE, e-mail: bsahin@omu.edu.tr, ORCID: 0000-0001-8538-8443
[2] Department of Anatomy, Faculty of Medicine, Tokat Gaziosmanpaşa University, Tokat, TÜRKIYE, e-mail: ORCID: 0000-0002-8492-3704
[3] Department of Anatomy, College of Dentistry, Cihan University, Erbil, IRAQ, e-mail: ORCID: 0000-0002-1742-3849

Abstract—**Quantifying radiological images is important in dental research, providing insights into anatomical and pathological aspects. This study addresses these challenges by exploring various techniques used in our previous studies for quantifying dental radiological images.**
The projection area fraction (PAF) method, using digital planimetry and ImageJ, assesses mandibular cysts on orthopantomograms. Compared with planimetry, the point-counting method evaluates cyst sizes for time efficiency and agreement. The projection area per length squared (PAL) technique analyzes dental curvature. The Cavalieri principle, applied to cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI), estimates mandibular and bone defect volumes and masseter muscle volume in patients.
PAF showed high intra-observer agreement and cost-effectiveness in cyst monitoring. Point-counting and planimetry techniques were sufficiently agreeable for interchangeable use, with the latter being more time-efficient. The Cavalieri principle provided accurate volume estimations in CBCT images, with MRI assessments showing no significant changes in masseter muscle volume post-stabilization splint therapy.
Quantifying radiological images using methods like PAF, point-counting, planimetry, PAL, and the Cavalieri principle provides accurate results for diagnosis, treatment planning, and research in dentistry. These methods enhance precision and objectivity, underscoring the importance of quantitative data in dental advancements.

Index Terms—**Cavalieri Principle; Cone-Beam Computed Tomography; Dental Radiology; Image Quantification; Magnetic Resonance Imaging; Mandibular Cysts; Point-Counting Method; Projection Area Fraction; Projection Area per Length Squared**

INTRODUCTION

Accurate measurement of lesion surface areas in dental radiology is critical. This is especially important for mandibular lesions with a cyst-like appearance, typically ellipsoid and radiolucent. These odontogenic and nonodontogenic lesions are challenging to differentiate based solely on radiographic features. This difficulty underscores the need for precise surface area assessment (Alkan et al., 2004). Traditional methods such as computed tomography (CT) and magnetic resonance imaging (MRI) provide detailed three-dimensional measurements (Maraghelli et al., 2022). However, their high costs and complexity limit their routine clinical use (Sahin et al., 2003a). Two-dimensional radiographs, particularly orthopantomography, are employed to address these limitations. They are favored for their cost-effectiveness and rapid execution. Despite these advantages, orthopantomography has a significant drawback. It needs to provide quantitative size information about the lesions. Such information is essential for accurate diagnosis and treatment planning (Bulut et al., 2012).

The projection area fraction (PAF) method has been developed to overcome this limitation. The PAF utilizes digital planimetry and software like ImageJ for assessing mandibular cysts on orthopantomograms. This method offers a more objective and quantifiable approach to measuring lesion surface areas, enhancing the precision of diagnosis and treatment in dentistry (Bulut and Sahin, 2009).

The projection area per length squared (PAL) method is a valuable radiology tool, particularly for estimating the projection area of structures not confined to predefined reference spaces (Kuru et al., 2008). It's crucial when the PAF method is unsuitable, like in scenarios without a reference space. In dental research, PAL effectively measures curved structures, such as dental arches, on roentgenograms. The method calculates the projection area based on a measured reference distance on X-ray films, using the square of this line's length. PAL offers a precise, adaptable approach for two-dimensional imaging of dental structures, enhancing radiological analysis.
The introduction of cone beam computed tomography (CBCT) has significantly changed volumetric data analysis in dentistry. It offers a three-dimensional imaging method that advances

DOI: http://doi.org/10.24086/biohs2024/paper.1220

both intraoral and extraoral radiography. CBCT enhances the analysis of lesion morphologies, dental caries, roots and jaw fractures. It also reduces patient exposure to radiation compared to traditional medical CT devices (Jain et al., 2019). Specialized software further improves CBCT's capability for detailed volumetric analysis and quantitative prognosis of lesions. This represents a significant advancement in dental imaging technology (Kayipmaz et al., 2011). Additionally, the Cavalieri principle, a stereological method, is used in various imaging modalities like CT, MRI and ultrasonography. It calculates volume from parallel, equally thick sections of an object (Roberts et al., 2000). This method provides precise and unbiased numerical values for volumetric assessments. It significantly enhances diagnostic and treatment processes in dentistry (Tuna et al., 2018).

The aim of this study is to explore and evaluate the effectiveness of various quantification techniques. These techniques include surface measurement methods, PAF, PAL and volumetric analysis using the Cavalieri principle. The focus is on their application in quantifying dental radiological images. This study also aims to demonstrate how these advanced methods can enhance precision, objectivity and clinical applicability in dental radiology. Doing so contributes to more accurate diagnosis and effective treatment planning in dentistry.

Materials and Methods

Accurate measurement of oral structures is crucial for diagnosing and treating various dental conditions. Point-counting and planimetry are used to quantify projection areas on X-ray films to achieve this. These methods are key in converting two-dimensional X-ray images into precise quantities for the structures. This conversion is essential for assessing both normal and pathological entities in dentistry. Additionally, the PAF and PAL techniques are employed. These techniques enhance the assessment of structures in dental radiology, particularly for areas outside predefined reference spaces. Moreover, the Cavalieri principle offers a method for estimating the volume of irregularly shaped structures. This principle addresses the limitations of traditional measurement methods.

Measuring Projection Areas on X-Ray Films

Projection areas on X-ray films represent the two-dimensional manifestation of three-dimensional structures. Accurate measurement of these areas is commonly used in various medical fields, particularly dentistry, for assessing normal or pathological structures. Point-counting and planimetry are two primary techniques employed for this purpose (Bulut & Sahin, 2009).

Measuring Projection Areas Using Point-Counting Technique

Transparent papers or layers are placed over radiographs, and the boundaries of structures like cysts within the mandible are visualized. A straight line is drawn at the midline of the mandibles to serve as a reference. If the picture is in a DICOM file, there is no need for a reference line since the pixel ratio is already embedded into the picture. Transparent sheets with a grid of '+' shaped points or transparent layers are randomly placed over the areas of interest, such as lesions. The grid is designed with distances representing 20 mm^2 area for cysts. The number of grid points intersecting the area of interest is counted, focusing on the upper right corner of the crosses (Figure 1). The total area of the cysts or other structures is estimated by multiplying the area represented by each cross with the total number of crosses hitting the structure (Gundersen et al., 1981).

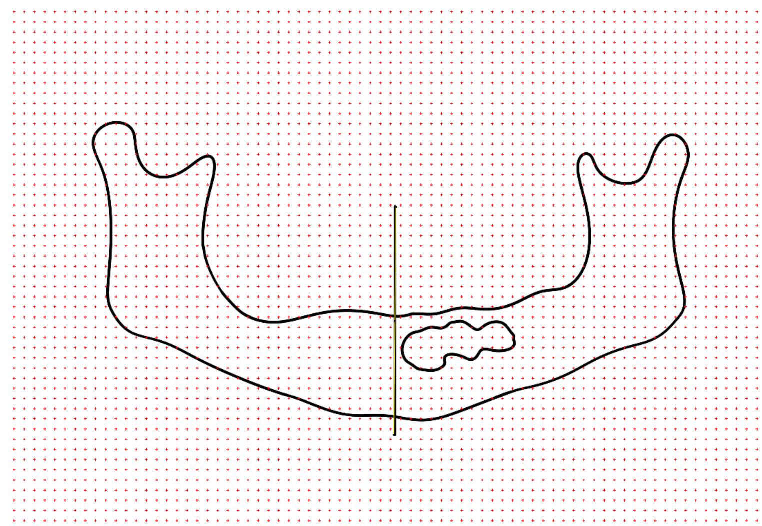

Figure 1. Application of the point-counting technique for calculation of the projection area of a mandibular cyst on a drawing.

Measuring Projection Areas Using Planimetry Technique

Hand orthopantomogram drawings are enhanced with a straight line of known length for scale reference. These drawings are scanned and stored in high-resolution JPEG format. The digital images are imported into ImageJ software, a freeware provided by the National Institute of Health (USA). The known length line on the films is used to calibrate the scale within the ImageJ program. If the picture is in a DICOM file, there is no need for a reference line since the pixel ratio is already embedded into the picture. The outermost boundaries of the cyst are outlined using the polygon selection tool (Figure 2). ImageJ software automatically calculates the area enclosed within the delineated boundaries (Barboriak et al., 2005).

DOI: http://doi.org/10.24086/biohs2024/paper.1220

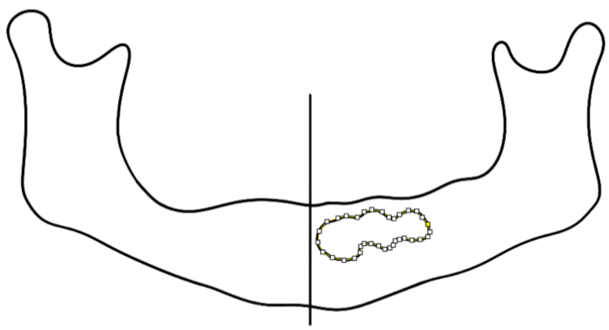

Figure 2. Application of the planimetry technique for calculation of the projection area of a mandibular cyst on a drawing.

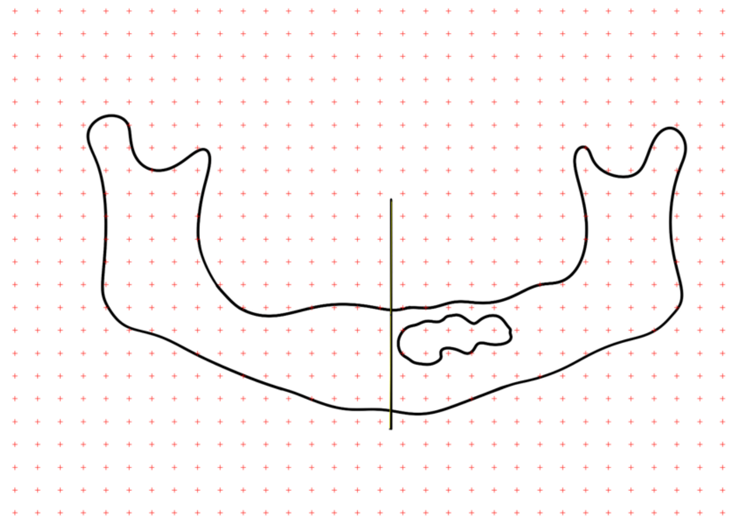

Figure 3. A point-counting grid is superimposed over a mandible for calculation of projection area fraction using a drawing.

Projection Area Fraction (PAF) Technique in Dental Radiology

The PAF technique is a method in dental radiology for quantifying the size of structures on roentgenograms. This technique is beneficial for assessing the magnitude of structures in two-dimensional images, especially when direct roentgenograms lack a magnification or reduction scale, as is common with CT or MR imaging. This technique can be applied using two distinct approaches: the point-counting and planimetry techniques. Both methods aim to provide a quantitative assessment of the pathological profiles' areas in relation to the mandible, expressed as a percentage. Below is the description of two techniques for assessing the PAF of cysts in the mandible (Bulut et al., 2012).

PAF Calculation Using Point-Counting Technique

For the point-counting technique, transparent sheets are used. Transparent sheets with a grid of '+' shaped points are randomly placed over the areas of interest, such as lesions and mandible areas. The grid is designed with distances representing 20 mm^2 for cystic areas and 100 mm^2 for half mandibles (Figure 3). Since the representing area of the points for the half mandible is five times larger than that of the representing area for the cyst, the number of points hitting the half mandible was multiplied by 5 in the formula. The number of grid points intersecting the area of interest is counted, focusing on the upper right corner of the crosses. The PAF is then estimated using the following formula:

$$PAF = \frac{\Sigma \quad P_{Cyst}}{\Sigma \quad P_{Halfmandible} \times 5} \times 100 \quad (1)$$

Where ΣP_{cyst} indicates the number of points hitting the cyst and $\Sigma P_{halfmandible}$ is the number of points hitting the half mandible. The unit of the final data is a percentage.

PAF Calculation Using Planimetry Technique

In the planimetry technique for PAF calculation, orthopantomograms are utilized. The process involves placing transparent paper over the roentgenograms to delineate the boundaries of mandibles and cysts. A straight line of known length is drawn on the films for scale calibration. If the picture is in a DICOM file, there is no need for a reference line since the pixel ratio is already embedded into the picture. These hand drawings are then scanned in high-resolution JPEG format. ImageJ software measures the surface areas of the half mandibles and cysts (Figure 4). The PAF of cysts within the half mandibles is calculated using the following formula:

$$PAF = \frac{A_{Cyst}}{A_{Halfmandible}} \times 100 \quad (2)$$

Where A_{cyst} indicates the surface area of the cyst and $A_{halfmandible}$ is the surface area of the half mandible. The unit of the final data is a percentage.

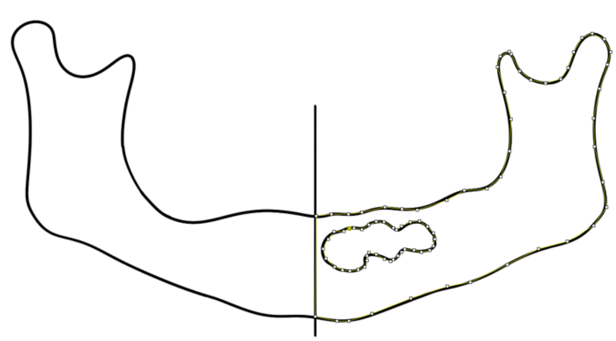

Figure 4. Application of the planimetry technique for calculation of projection area fraction of a cyst on a drawing.

DOI: http://doi.org/10.24086/biohs2024/paper.1220

Projection Area Per Length Squared (PAL) Technique in Dental Radiology

The PAL method is a significant advancement in dental radiology, beneficial for estimating the projection area of structures on radiological images when the structure is not confined within a predefined reference space (Kuru et al., 2008). This method is especially crucial for evaluating structures like the mandibular dental arch on orthopantomograms, where the traditional PAF method may not be applicable. Below is a detailed description of the PAL method, including its application in assessing the PAL value of the area within the dental curvature.

PAL Calculation Using Planimetry Technique

In applying the PAL method, the process begins with the preparation and orientation of the image. A head MR image is opened in a DICOM viewer software, such as Horos, and reoriented into the Talairach coordinates. This orientation is important for optimal viewing and accurate measurement. The axial image that displays the junction of the most posterior molar tooth to the mandibular branch is then selected and exported as a DICOM file.

The DICOM file is opened, and a straight line is drawn between the posterior medial corners of the third molar teeth between both sides. The length of this line is measured using the software. The free-hand selection tool of the software is then used to delineate the inner borders of the tooth, forming a closed area within the dental arch (Figure 5). The software measures the area enclosed within this boundary, and the results of the line and area measurements are used to estimate the PAL of dental arches using the following formula:

$$PAL = \frac{A}{l^2} \times 100 \qquad (3)$$

Where A is the projection area of the region within the dental arch and l is the distance between both sides of the third molar teeth on the films. The result is expressed as a percentage.

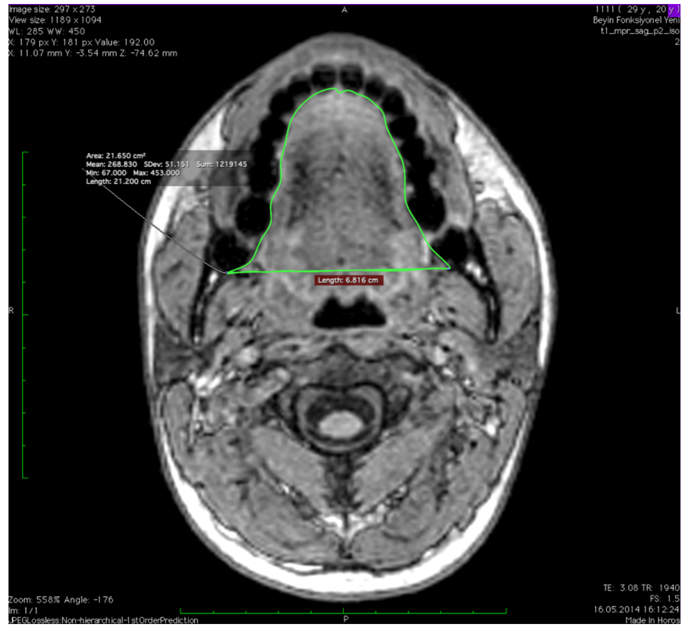

Figure 5. Application of the planimetry technique for calculation of projection area per length squared on a magnetic resonance image.

Estimation of Volume Using the Cavalieri Principle in Dental Radiology

The Cavalieri principle offers a solution for estimating the volume of irregularly shaped structures. This task is not feasible with traditional methods like water displacement for living subjects or isolated structures within an organ. Introduced over 300 years ago by Bonaventura Cavalieri, this principle enables an unbiased estimate of an object's volume, irrespective of its shape and size. The principle requires a complete set of two-dimensional slices through the object. These slices must be parallel, equally spaced, and randomly positioned within the object. Standard sectional radiological imaging techniques typically meet these criteria (Sahin et al., 2003b). The following is a detailed description of the Cavalieri principle and its application in volume estimation.

Estimation of Volume Using the Planimetry Method

Planimetry involves manually tracing the boundaries of objects of interest on section images. In our example, the boundaries of the masseter muscle are delineated in a whole section series on magnetic resonance images (Figure 6). The measured areas of sections obtained by planimetry are multiplied by the section thickness to estimate the volume. This method is commonly used with free software like ImageJ. To ensure unbiased results, the first section in the series must be placed at a uniform and random position within a constant interval of length (t). The entire series of sections should encompass the object completely. The volume estimate is obtained by multiplying the total area of the section cut surfaces through the structure of all sections.
The planimetric volume estimation formula is:

$$est_1 V = t \times \sum \quad a\ cm^3 \qquad (4)$$

Where Σa denotes the section areas in cm^2 and t is the sectioning interval in cm for the consecutive sections.

DOI: http://doi.org/10.24086/biohs2024/paper.1220

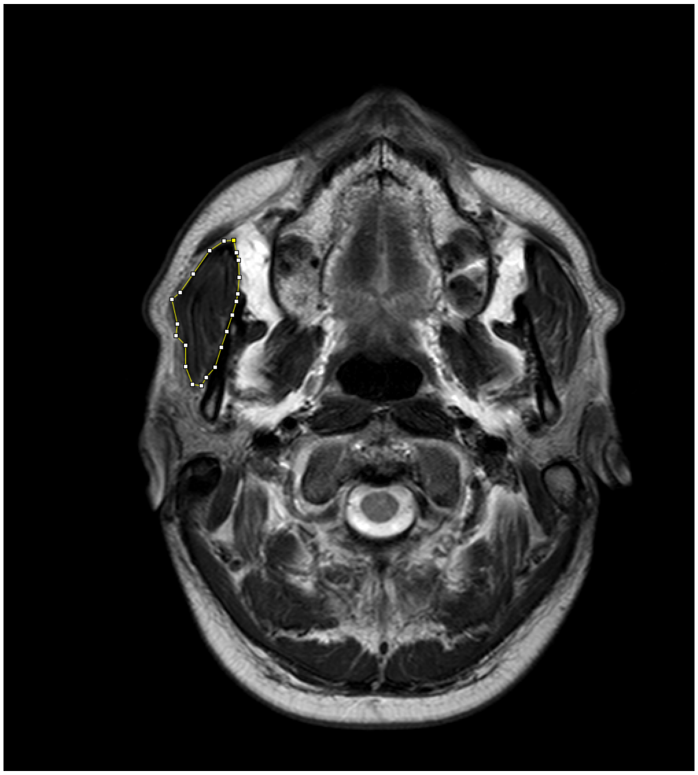

Figure 6. Delineation of the boundaries of the masseter muscle using the planimetry technique for estimation of the volume of the muscle on a magnetic resonance image.

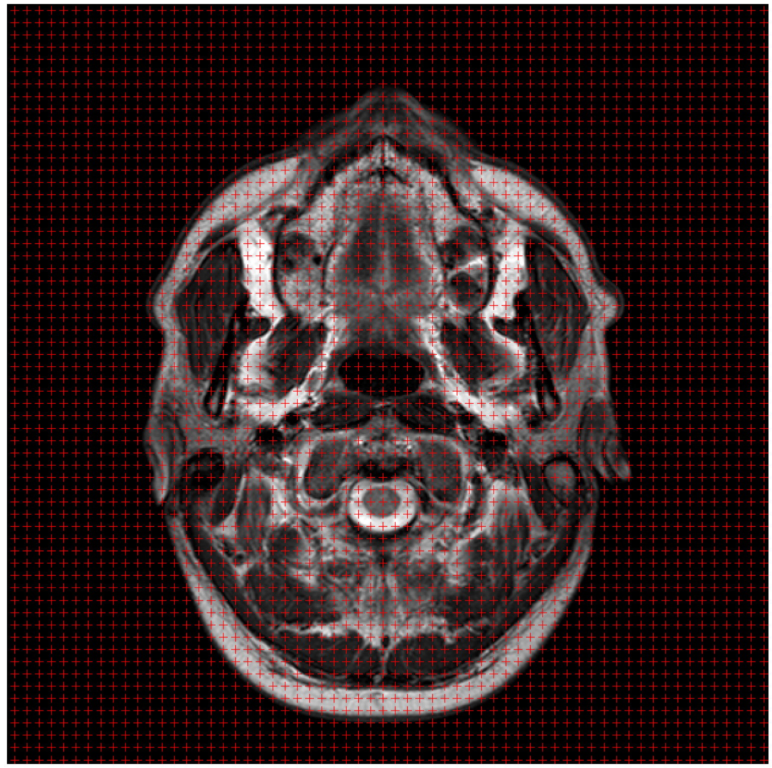

Figure 7. A point-counting grid superimposed on the masseter muscle for estimation of the volume of the muscle on a magnetic resonance image.

Estimation of Volume Using the Point-Counting Method

This method overlaps each selected section with a randomly positioned grid of test points. In our example, a test point sheet is superimposed over the masseter muscle in a whole section series on magnetic resonance images (Figure 7). The number of test points hitting the structure on the sections is counted, and the volume is estimated by multiplying the section thickness, the total number of points, and the area represented by each point in the grid. The unbiased estimator for volume using the point-counting method is below:

$$est_2V = t \times a/p \times \sum P \ cm^3 \quad (5)$$

Where ΣP denotes the point counts, a/p represents the area associated with each test point and t is the sectioning interval in cm for the consecutive sections.

Estimation of Coefficient of Error (CE)

The Cavalieri principle includes the calculation of the coefficient of error (CE) to evaluate the reliability of the point density of the grids and sectioning intervals. The CE represents the precision of the volume estimate and is calculated using specialized formulas. It's important to note that the appropriate grid size and number of slices should be determined at the beginning of the study to minimize the need to recalculate the CE in repeated sessions.

In the planimetry method, the CE of estimates may be obtained using the following formula:

$$CE = \left(\sum_{i=1}^{m} A_i\right)^{-1} \times \left[\frac{1}{12}\left(3\sum_{i=1}^{m} A_i^2 - 4\sum_{i=1}^{m-1} A_i A_{i+1} + \sum_{i=1}^{m-2} A_i A_{i+2}\right)\right]^{1/2} \quad (6)$$

Where, i=1, 2, …, m is the number of sections. A is the measured area of the sections using planimetry and the others are constants. This formula allows the researcher to evaluate the area changes and the measured cut surface areas in the consecutive section series (Sahin et al., 2008).

DOI: http://doi.org/10.24086/biohs2024/paper.1220

RESULTS

The surface area of the cysts within the mandible is assessed using point-counting and planimetry techniques. The PAF of the cysts within the half mandible is also estimated in percentages. The area within the dental arches is determined by the PAL method. Finally, the masseter muscle volume is estimated using the Cavalieri principle on the MR images series.

Measuring Projection Areas on X-Ray Films

Two techniques are employed for the estimation of the projection area of the cysts: point-counting and planimetry.

Measuring Projection Areas Using Point-Counting Technique

A transparent sheet with a grid of '+' shaped points or transparent layers is randomly placed over the cyst. The grid distance represents a 20 mm^2 area. The number of grid points intersecting the area of interest is counted at 33 points. The total area of the cyst is estimated by multiplying the area represented by each cross with the total number of crosses hitting it. The projection area of the cyst is estimated to be 660 mm^2. It is calculated as follows:

$$A = a/p \times \sum \quad a = 20 \times 33 = 660\, mm^2$$

Measuring Projection Areas Using Planimetry Technique

The outermost boundaries of the cyst are outlined using the polygon selection tool. ImageJ software automatically calculates the area enclosed within the delineated boundaries and gives the projection area of the cyst to be 673 cm^2.

Projection Area Fraction (PAF) Technique in Dental Radiology

The projection area fraction of the cyst is estimated using point-counting and planimetry techniques as given below.

PAF Calculation Using Point-Counting Technique

A transparent sheet with a grid of '+' shaped points is randomly placed over the areas of the cyst and mandible. The grid is designed with distances representing 20 mm^2 for the cystic area and 100 mm2 for the half mandible. The number of grid points intersecting the area of interest is counted. The number of points hitting the cyst was 33, and hitting the half mandible was 68. The PAF of cysts within the half mandibles found to be 9.70 %. The PAF is then estimated using the following formula:

$$PAF = \frac{\sum \quad P_{Cyst}}{\sum \quad P_{Halfmandible} \times 5} \times 100 = \frac{33}{68 \times 5} = 9.70\,\%$$

PAF Calculation Using Planimetry Technique

The projection areas of the half mandibles and cysts are measured using the polygon selection tool of the ImageJ software. The projection areas of the cyst and half mandible are estimated to be 673 mm^2 and 6850 mm^2, respectively. The PAF of cysts within the half mandibles found to be 9.82%. The calculation is done using the following formula:

$$PAF = \frac{A_{Cyst}}{A_{Halfmandible}} \times 100 = \frac{673}{6850} \times 100 = \ 9.82\,\%$$

Projection Area Per Length Squared (PAL) Technique Using Planimetry

The length of this line between the posterior medial corners of the third molar teeth is measured as 6.82 cm using the software. The free-hand selection tool of the software is then used to delineate the inner borders of the tooth, forming a closed area within the dental arch. The area enclosed within this boundary is measured as 31.65 cm^2. The PAL is estimated at 46.54 %. The PAL of dental arches using the following formula:

$$PAL = \frac{A}{l^2} \times 100 = \frac{31.65}{6.82^2} \times 100 = 46.54\,\%$$

Application of the Cavalieri Principle Using the Planimetry Method

The boundaries of the masseter muscle are delineated in a whole section series on MR images. The software automatically gives the sectional cut surface areas of the muscle. The volume estimate is obtained by multiplying the total area of the section cut surfaces through the structure of all sections. The section thickness of the images was 3.3 mm. The sectional cut surface areas of the sample are given in Table 1. The total volume of the masseter muscle is estimated as 24.48 cm^3 in this sample. The CE of the volume estimation
is found to be 0.29 %.

TABLE 1. THE SECTIONAL CUT SURFACE AREAS OF THE RIGHT MASSETER MUSCLE.

Section No	Area (mm^2)
1	128
2	152
3	337
4	366
5	466
6	472
7	481
8	489

DOI: http://doi.org/10.24086/biohs2024/paper.1220

9	458
10	467
11	478
12	478
13	530
14	540
15	378
16	369
17	256
18	204
19	200
20	168
Total Surface Area	7417

The planimetric volume estimation is done using the following steps:

$$est_1V = t \times \sum a\, cm^3 = 3.3 \times 7417 = 24{,}476\, mm^3 = 24.48 mm^3 \quad (4)$$

DISCUSSION

This study examines techniques for quantifying dental radiological images, focusing on point-counting and planimetry methods to measure projection areas on X-ray films. Point-counting involves overlaying a grid on radiographs to estimate the size of areas like cysts, while planimetry uses software like ImageJ for digital area calculation from orthopantomograms. These methods assess the PAF of mandibular cysts, showing no significant post-therapy differences in muscle volume or fat and water content, nor between genders. The study also introduces the PAL technique for structures like the mandibular dental arch on MRI, and the Cavalieri principle for volume estimation of irregular structures using planimetry. These methods collectively enhance the quantitative assessment of dental images, aiding in accurate diagnosis and treatment planning.

Measuring Projection Areas on X-Ray Films

Orthopantomograms are widely used in oral and maxillofacial surgery to assess bone lesion dimensions. They are important for diagnosing and monitoring lesion progression, utilizing two-dimensional images from radiographs to critically evaluate lesion size (Flint et al., 1998). The planimetry method, known for its precision in surface area determination, is significant in organ volume calculations. It has been validated in various studies (Mazonakis et al., 2004; Acer et al., 2007). This method, along with digital planimetry and transparency tracing, has been examined for its effectiveness in surface area measurements (Wang et al., 2008). Additionally, the point-counting technique has emerged as an alternative. Its efficacy in assessing dermatologic lesion surface areas has also been explored (Aydin et al., 2007).

Bulut et al. (2012) emphasized the reliability of planimetry and point-counting methods for measuring mandible cyst sizes. The point-counting method may have inaccuracies due to the thickness of the pen used for delineation. Similarly, the accuracy of planimetry can vary based on the observer's choice of the line's border. Despite these potential issues, both methods show high intra-observer and inter-observer agreements, confirming their dependability. While three-dimensional measurement methods like CT scans and MR images provide detailed assessments, they are often limited by high costs, complexity, and time consumption for routine clinical use.

In contrast, point-counting and planimetry methods are more cost-effective and involve less radiation exposure. They are thus more suitable for regular clinical application. Notably, planimetry is faster than point-counting, not considering the time needed for scanning and image transfer.

In summary, the study underlines the effectiveness of both point-counting and planimetry techniques in the quantitative assessment of X-ray film areas, recommending selecting either method based on the study's specific needs and the characteristics of the measured structures.

Projection Area Fraction (PAF) Technique in Dental Radiology

Radiographs are important in dental radiology, providing two-dimensional views of three-dimensional structures. They are essential for assessing the size and magnitude of various structures in both clinical and research settings. The introduction of orthopantomography has been a significant advancement in this field. It is beneficial for tracking cysts, although it lacks a magnification scale for quantitative dimension assessments (Meningaud et al., 2006).

In contrast, CT scans and MRI, including contrast-enhanced MRI, offer more detailed imaging capabilities. However, they come with higher costs and longer processing times. Orthopantomography is highly valued in dental specialties for its numerous benefits. These include reduced radiation exposure and comprehensive anatomic coverage. However, it also has drawbacks, such as image distortion and sensitivity to patient positioning (Flint et al., 1998; Kambylafkas et al., 2006).

Our research contributes to this field by introducing the PAF technique. This new method evaluates the size relationship between cysts and mandibles. It provides a practical and magnification-independent solution suitable for various imaging devices. This study confirms the reliability and repeatability of the point-counting and planimetry techniques for PAF assessment. Our findings highlight the PAF method's practicality, economy, and speed. These attributes make it a suitable alternative to more expensive and time-consuming imaging methods. It is beneficial for routine clinical use where cost and radiation exposure are significant concerns.

DOI: http://doi.org/10.24086/biohs2024/paper.1220

In conclusion, the PAF technique employs both planimetry and point-counting methods. It is a precise and strong tool for measuring projection areas in dental radiology. This technique aids in the accurate assessment of both pathological and normal structures on X-ray films. It is especially beneficial when standard scaling information is absent. The PAF method provides a systematic and quantifiable approach. It is used to accurately diagnose and monitor cystic lesions in dental practice and research.

Projection Area Per Length Squared (PAL) Technique in Dental Radiology

The PAL method represents a significant advancement in dental radiology. It effectively estimates the projection area of structures in radiological images, which is handy for areas like the mandibular dental arch on MRI where the PAF method is less effective (Kuru et al., 2008). This innovative method quantitatively assesses curved structures or areas relative to a reference space. It simplifies the application of digital images, making it highly efficient (Golpinar and Komut, 2022).

In our study, the PAL method has provided an objective criterion. It evaluates the area within the dental arch of the upper jaw, thereby standardizing the assessment of curved structures. Previously, this assessment was challenging due to the reliance on reference points.

The PAL method has developed into a precise and efficient tool by utilizing the planimetry technique through ImageJ software. It quantifies the projection area of dental structures in radiological images. It is beneficial for evaluating structures that do not fit within conventional reference spaces. As a result, the PAL method dramatically improves the accuracy and utility of radiological evaluations in dentistry.

Estimation of Volume Using the Cavalieri Principle in Dental Radiology

The Cavalieri principle, used with dental CBCT devices, significantly advances the volumetric analysis of oral structures. It enables three-dimensional assessments, which are important for diagnosing conditions like periapical infections, cysts, tumors, and periodontal diseases (Agbaje et al., 2009). In our study, this principle was employed without requiring specialized software. It allows for accurate volume estimation using either planimetric or point-counting techniques. Various studies have proven this reliable (Mayhew & Gundersen, 1996; Roberts et al., 2000; Mazonakis et al., 2002). Our research demonstrated the effectiveness of the Cavalieri principle in measuring the volume of sheep mandibular defects using CBCT images. The results closely matched those obtained through the pycnometric method (Kayıpmaz et al., 2011; Sezgin et al., 2013).

Stereological methods enable researchers to adjust sampling and estimating procedures involving the calculation of the coefficient of error (CE) for volume measurements. Expressed as a percentage, the CE indicates potential variability and high values can affect accuracy and interpretation. To mitigate this, observers can modify the grid's point spacing or slice count, ensuring a reasonable CE. Once the grid size and slice number are set initially, there's no need to recalculate the CE in subsequent sessions, simplifying the process to just using the sixth equation for planimetry. Empirically, about 13 sections are typically sufficient to achieve an adequate CE of 5% or less (Sahin et al., 2003b).

In summary, the Cavalieri principle and point-counting and planimetry techniques form a comprehensive method for precise volumetric assessment in dental radiology and related fields. This methodology is essential for accurately measuring volumes in radiological and pathological applications. It offers a non-invasive and cost-effective alternative to traditional measurement techniques.

The techniques discussed in this paper, including the PAF, PAL methods and the Cavalieri principle, exhibit certain limitations despite their innovative and practical nature. The PAF method, not reliant on magnification scales, can encounter variability due to subjective factors. For instance, the pen thickness used to delineate lesions and mandibles may lead to consistency among observers. The PAL method standardizes the assessment of dental curvature. Additionally, its reliance on two-dimensional imaging restricts its ability to capture the three-dimensional nature of dental curvatures fully.

The Cavalieri principle is effective for volume estimation but may overlook subtle changes in tissue composition. This includes variations in fat and water content within muscle tissue. The accuracy of this principle also hinges on the quality of the imaging used. Factors such as section thickness and voxel dimension can impact the results.

In conclusion, the methods discussed in this paper, including the PAF, PAL and the Cavalieri principle, represent significant advancements in radiographic and volumetric analysis. The PAF method, independent of magnification scales, is reliable and practical. It is particularly effective for assessing cystic lesions in orthopantomograms, making it valuable in dental diagnostics. The method's high intra- and inter-observer agreement underscores its consistency and reproducibility, which are essential for clinical and research applications.

The PAL method offers an innovative and standardized approach for evaluating lumbar lordosis. It overcomes the limitations of traditional techniques and provides a more objective assessment. Due to its simplicity and cost-effectiveness, the PAL method is suitable for routine clinical use.

The Cavalieri principle measures complex structures like bone defects and muscle volume with minimal invasiveness. It is compatible with CBCT images and produces results comparable to traditional methods, such as the pycnometric method based on the Archimedean principle. This makes the Cavalieri principle a valuable tool in research and clinical settings.

DOI: http://doi.org/10.24086/biohs2024/paper.1220

These methods enhance the precision and efficiency of radiographic measurements and analyses. They underscore their importance in advancing medical and dental research and practice.

References

1. Acer N, Sahin B, Bas O, Ertekin T, Usanmaz M. (2007). Comparison of three methods for the estimation of total intracranial volume. Stereologic, planimetric and anthropometric approaches. Ann Plast Surg., 58:48-53.
2. Agbaje JO, Jacobs R, Michiels K, Abu-Ta'a M, van Steenberghe D. (2009). Bone healing after dental extractions in irradiated patients: a pilot study on a novel technique for volume assessment of healing tooth sockets. Clin Oral Investig,13(3):257-61. doi: 10.1007/s00784-008-0231-7.
3. Alkan A, Metin M, Arici S, Sener I. (2004). A prospective randomised cross-over study of the effect of local haemostasis after third molar surgery on facial swelling: an exploratory trial. Br Dent J., 10;197(1):42-4; discussion 32. doi: 10.1038/sj.bdj.4811421.
4. Aydin F, Senturk N, Sahin B, Bek Y, Yuksel EP, Turanli AY. (2007). A practical method for the estimation of vitiligo surface area: a comparison between the point counting and digital planimetry techniques. Eur J Dermatol, 17(1):30-2. doi: 10.1684/ejd.2007.0186.
5. Barboriak DP, Padua AO, York GE, Macfall JR. (2005). Creation of DICOM--aware applications using ImageJ. J Digit Imaging, 18(2):91-9. doi: 10.1007/s10278-004-1879-4.
6. Bulut E, Sahin B. (2009). A new method of assessing the size of mandibular cysts on orthopantomograms: projection area fraction. J Craniofac Surg., 20(6):2020-3. doi: 10.1097/SCS.0b013e3181bd302e.
7. Bulut E, Şahin B, Muğlalı M, Bekçioğlu B. (2012). Comparison of the planimetry and point-counting methods for the assessment of the size of the mandible cysts on orthopantomograms. Med Oral Patol Oral Cir Bucal, 1;17(3): e442-6. doi: 10.4317/medoral.17570.
8. Flint DJ, Paunovich E, Moore WS, Wofford DT, Hermesch CB. (1998). A diagnostic comparison of panoramic and intraoral radiographs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 85(6):731-5. doi: 10.1016/s1079-2104(98)90043-9.
9. Golpinar M, Komut E. (2022). The reliability of the projection area per length squared for measuring lumbar lordosis on lateral radiographs: A comparison with Cobb method. Eur J Ther, 28(4): 285-91.
10. Gundersen HJG, Boysen M, Reith A. (1981). Comparison of semiautomatic digitizer-tablet and simple point counting performance in morphometry. Virchows Arch B Cell Pathol Incl Mol Pathol., 37(3):317-25. doi: 10.1007/BF02892580.
11. Jain S, Choudhary K, Nagi R, Shukla S, Kaur N, Grover D. (2019). New evolution of cone-beam computed tomography in dentistry: Combining digital technologies. Imaging Sci Dent., 49(3):179-190. doi: 10.5624/isd.2019.49.3.179.
12. Kambylafkas P, Murdock E, Gilda E, Tallents RH, Kyrkanides S. (2006). Validity of panoramic radiographs for measuring mandibular asymmetry. Angle Orthod, 76(3):388-93.
13. Kayipmaz S, Sezgin OS, Saricaoglu ST, Bas O, Sahin B, Küçük M. (2011). The estimation of the volume of sheep mandibular defects using cone-beam computed tomography images and a stereological method. Dentomaxillofac Radiol, 40(3):165-9. doi: 10.1259/dmfr/23067462.
14. Kuru O, Sahin B, Kaplan S. (2008). Alternative approach to evaluating lumbar lordosis on direct roentgenograms: projection area per length squared. Anat Sci Int., 83(2):83-8. doi: 10.1111/j.1447-073X.2007.00210.x.
15. Maraghelli D, Pietragalla M, Calistri L, Barbato L, Locatello LG, Orlandi M, Landini N, Lo Casto A, Nardi C. (2022). Techniques, Tricks, and Stratagems of Oral Cavity Computed Tomography and Magnetic Resonance Imaging. Applied Sciences, 12(3):1473. https://doi.org/10.3390/app12031473
16. Mayhew TM, Gundersen HJ. (1996). If you assume, you can make an ass out of u and me': a decade of the disector for stereological counting of particles in 3D space. J Anat, 188 (Pt 1)(Pt 1):1-15.
17. Mazonakis M, Damilakis J, Maris T, Prassopoulos P, Gourtsoyiannis N. (2002). Comparison of two volumetric techniques for estimating liver volume using magnetic resonance imaging. J Magn Reson Imaging, 15(5):557-63. doi: 10.1002/jmri.10109.
18. Mazonakis M, Karampekios S, Damilakis J, Voloudaki A, Gourtsoyiannis N. (2004). Stereological estimation of total intracranial volume on CT images. Eur Radiol, 14(7):1285-90. doi: 10.1007/s00330-004-2253-0.
19. Meningaud JP, Oprean N, Pitak-Arnnop P, Bertrand JC. (2006). Odontogenic cysts: a clinical study of 695 cases. J Oral Sci., 48(2):59-62. doi: 10.2334/josnusd.48.59.
20. Roberts N, Puddephat MJ, McNulty V. (2000). The benefit of stereology for quantitative radiology. Br J Radiol, 73(871):679-97. doi: 10.1259/bjr.73.871.11089458.
21. Sahin B, Alper T, Kökçü A, Malatyalioglu E, Kosif R. (2003). Estimation of the amniotic fluid volume using the Cavalieri method on ultrasound images. Int J Gynaecol Obstet, 82(1):25-30. doi: 10.1016/s0020-7292(03)00122-x.
22. Sahin B, Emirzeoglu M, Uzun A, Incesu L, Bek Y, Bilgic S, Kaplan S. (2003). Unbiased estimation of the liver volume by the Cavalieri principle using magnetic resonance images. Eur J Radiol, 47(2):164-70. doi: 10.1016/s0720-048x(02)00152-3.
23. Sahin B, Mazonakis M, Akan H, Kaplan S, Bek Y. (2008). Dependence of computed tomography volume measurements upon section thickness: an application to human dry skulls. Clin Anat., 21(6):479-85. doi: 10.1002/ca.20664.
24. Sezgin OS, Kayıpmaz S, Sahin B. (2013). The effect of slice thickness on the assessment of bone defect volumes by the Cavalieri principle using cone beam computed tomography. J Digit Imaging, 26(1):115-8. doi: 10.1007/s10278-012-9480-8.
25. Tuna SH, Celik OE, Ozturk O, Golpinar M, Aktas A, Balcioglu HA, Keyf F, Sahin B. (2018). The effects of stabilization splint treatment on the volume of masseter muscle in sleep bruxism patients. Cranio, 36(5):286-293. doi: 10.1080/08869634.2017.1377433.
26. Wang Y, Liu G, Yuan N, Ran X. (2008). A comparison of digital planimetry and transparency tracing based methods for measuring diabetic cutaneous ulcer surface area. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi., 22(5):563-6.

DOI: http://doi.org/10.24086/biohs2024/paper.1220