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Association between 2-dimensional panoramic image area analysis and 3-dimensional computed tomography volume analysis of the same patient for evaluating decompression of ameloblastoma and odontogenic keratocysts

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We investigated the correlation between two-dimensional (2D) panoramic imaging (PI) analysis and three-dimensional (3D) computed tomography (CT) analysis for evaluating the decompression of ameloblastoma (AME) and odontogenic keratocysts (OKC). Using each patient's individual data, we examined the correlation between decompression indices and patient characteristics to find correlations between the 2D and 3D evaluations, using the latter as the gold standard. We also evaluated the correlation between PI and CT analyses of lesion reduction and percent lesion reduction. The correlations were found between volume reduction and area reduction, as well as initial volume and initial area in both AME and OKC. Volume reduction rate and area reduction rate correlated with initial volume and initial area only for OKC. For AME, the regression equations were (volume reduction) = 6.7 + (area reduction) × 0.7 and (percent volume reduction) = 30.4 + (percent area reduction) × 0.6. Correlations were observed between the PI and CT evaluations and the utility of PI was verified for estimating lesion reduction from the initial size in AME and for lesion reduction and lesion reduction rate from the initial size in OKC. For AME, regression equations were obtained for estimating lesion reduction and percent lesion reduction on CT from PI. (J Osaka Dent Univ 2021 ; 55 : 113-121)

Key words : Decompression ; Ameloblastoma ; Odontogenic keratocyst ; Panoramic imaging ; Computed tomography

INTRODUCTION

The incidence of ameloblastoma (AME) and odontogenic keratocysts (OKC), which were named keratocystic odontogenic tumors by the World Health Organization in 2005, is 36.5% and 38.7%, respectively, of all odontogenic tumors, They are often encountered in the oral and maxillofacial region.[1] Radical resection is sometimes avoided for cosmetic reasons and for prevention of complications from injury to important structures in this region, such as the inferior alveolar nerve. In such cases, decompression is selected with the intent of decreasing pressure inside the lesion, promoting new bone formation from the peripheral margin of the lesion, and ultimately reducing its size. After decompression, enucleation with curettage has long been performed as needed as secondary intervention.[2-9] To determine the necessity or timing of enucleation with curettage, image evaluation of the effectiveness of decompression is imperative. Two-dimensional (2D) panoramic imaging (PI) area analysis and three-dimensional (3D) computed tomography (CT) volume analysis are often used for imaging evaluation.[8, 10-14] PI is widely used because it is economical and has low radiation exposure.

Regarding the accuracy of PI analysis, Kubota *et al.* reported good correlation between the lesion volume measured by filling the cavity with saline and the radiolucent area.[15] However, it is often difficult to accurately evaluate lesion reduction because PI has limitations, such as magnification, distortion and overlap.[8, 16] By contrast, Krennmair *et al.* and Zhao *et al.* reported that 3D analysis was more precise and reliable than 2D analysis.[17, 18] However, due to the high economic cost and radiation dose of CT, it is desirable to establish other diagnostic imaging modalities.[12] At present, CT and PI analyses have been independently reported for the decompression effect of AME and OKC. For example, Asutay *et al.* evaluated the volume reduction and percent volume reduction on CT.[11] In addition, Lizio *et al.* and Song *et al.* reported the correlation between decompression effect and patient characteristics, such as initial volume.[8, 19] In PI evaluation, Nakamura *et al.*[6] examined the area reduction rate and Park *et al.* examined the correlation between decompression effect and patient characteristics. However, there has been no report examining the decompression effect on CT and PI using the same patient's data. Therefore, there is limited information about the accuracy of PI analysis in comparison with that of 3D CT analysis. Moreover, no study has investigated which parameters are useful indicators of decompression on PI compared with CT.

The aim of this study were to investigate the association between 2D PI analysis and 3D CT analysis as evaluation modalities for decompression of AME and OKC, and to verify which PI parameters can accurately reflect the changes after decompression. Correlations were also examined between CT and PI for lesion reduction and percent lesion reduction in AME and OKC.

MATERIALS AND METHODS

Patients

We reviewed medical records from the First Department of Oral and Maxillofacial Surgery at Osaka Dental University Hospital to select patients based on the following inclusion criteria : pathological diagnosis of mandibular AME or OKC between January 2008 and December 2017 ; a treatment plan to undergo decompression and enucleation with curettage as secondary intervention ; and completion of both PI and CT before and after decompression.

PI

PI was performed using the Super Veraview X 500 AE Panoramic System (J Morita, Kyoto, Japan). Tube voltage and current were 98 kV and 9 mA, respectively.

CT scanning procedure

CT scanning was performed using a BrightSpeed Elite CT scanner (GE Healthcare, Chicago, IL, USA) or a Somatom Scope CT Scanner Siemens Healthcare, Erlangen, Germany) at 120 kV or 130 kV. The electrical current was automatically optimized for thickness specific to each patient (maximum 120 mA). CT imaging was performed at a slice thickness of 0.5-0.65 mm, a pitch and tube voltage of 0.625 : 1, and a field of view of 16.8 × 16.8 cm.

Decompression and follow-up

After incision of the mucous membrane, a bony window was opened under local anesthesia, and a rubber tube or sterilized gauze was placed to maintain the window. Biopsy was performed at the same time. After the decompression procedure, the patient underwent regular intraoral examinations and PI. Post-decompression CT was performed when the surgeon judged by PI that the lesion had been sufficiently reduced. Enucleation with curettage was then performed if necessary, considering the effect of decompression based on CT analysis and the general condition.

Volume measurements of the lesion

A single observer (H.A.) measured the lesion size to eliminate interobserver discrepancy. Measurements were performed using the data at the initial visit and just before enucleation with curettage. Digital Imaging and Communications in Medicine (DICOM) viewer software, Expert INTAGE (Cybernet Systems, Tokyo, Japan) was used for volume measurement. First, we performed a preliminary experiment to check the correctness of our measurement method and confirm the accuracy of the software. A cube of known volume (3 cm×3 cm×3 cm) was scanned using CT, and the area was calculated by contouring the margin of the cube as the region of interest (ROI) in a cross-sectional image at window level 1000 and window width 3000. This process was performed on all cross-sections.

Using these area data, volume was obtained using the following two methods. Method A: all the areas were added up and the sum was multiplied by the slice thickness. Method B: using the volume rendering function of the software at a window level of 1000, window width of 3000, and a linear positive slope for the opacity curve, the volume of the ROI was output after 3D reconstruction. The above operations were repeated three times each to minimize intraobserver discrepancy, and the average was taken as the volume for method A or method B. The average of the volumes obtained by both methods was taken as the true cube volume. Then, we loaded CT DICOM data of the patients into the software. On every cross-sectional image, the ROI was set on the margin of the bone expanded by the lesion, and the area was calculated at window level 1000 and window width 3000. This process was carried out on all cross-sections. We calculated the lesion volume in the same way as for the volume measurement of the cube in the preliminary experiment. The average of the volumes obtained by both methods was regarded as the true lesion volume.

Area measurements of the lesion

PI DICOM data were loaded into the DICOM viewer software Onis 2.5.16 Free Edition (Digital Core, Tokyo, Japan). The margin of the radiolucent area absorbed by the lesion was drawn as a ROI, and the area was calculated automatically. These processes were repeated three times to minimize intraobserver discrepancy, and the average was regarded as the true lesion area.

Calculation of decompression indices

The decompression indices below were calculated by the following formulas using the values obtained from the volume and area measurements:[8, 13, 20]

Volume reduction (cm^3)＝initial volume－final volume

Area reduction (cm^2)＝initial area－final area

Volume reduction rate (cm^3/day)＝(volume reduction)/(duration of decompression)

Area reduction rate (cm^2/day)＝(area reduction)/(duration of decompression)

Percent volume reduction (%)＝(volume reduction)/(initial volume)×100

Percent area reduction (%)＝(area reduction)/(initial area)×100

Percent volume reduction rate (%/day)＝(percent volume reduction)/(duration of decompression)

Percent area reduction rate (%/day)＝(percent area reduction)/(duration of decompression)

We defined duration of decompression as the period between the date of decompression and CT or PI just before enucleation with curettage.

Ethical considerations

This study was approved by the Institutional Review Board of Osaka Dental University (Approval No.110967) and was conducted in compliance with the Declaration of Helsinki. We obtained informed consent through an opt-out process.

Statistical analysis

The Kolmogov-Smirnov test was used to confirm the normality of the continuous data. In comparing patient characteristics, for continuous variables, Welch's t-test was used for parametric data, and the Mann-Whitney U test for nonparametric data. Fisher's exact test was used for categorical variables. To compare the volume and area before and after decompression in both conditions, the paired t-test was used for parametric data and the Wilcoxon signed rank sum test was used for nonparametric data. For comparison of the decompression indices between the two conditions, Welch's t-test (parametric) and the Mann-Whitney U-test (nonparametric) were used. To examine the correlations between decompression indices and patient characteristics in order to find correlations from the 2D evaluation that matched those from the 3D evaluation using the latter as a gold standard, Spearman's rank correlation coefficient matrix was used for continuous data and the correlation ratio was used for categorical data. Simple regression analysis was performed to obtain a linear regression equation for estimating the volume of the lesion from its area for lesion reduction and percent lesion reduction. In addition, scatterplots and regression lines were drawn using the scatterplot matrix. Statistical analysis was performed using BellCurve for Excel (Social Survey Research Information, Tokyo, Japan), with statistical significance set at 5%.

RESULTS

We concluded that the accuracy of our measurement method and the accuracy of the Expert INTAGE software could be considered reliable, based on the results of the preliminary experiment.

Patient characteristics

There were 14 patients with AME and 14 with OKC (Table 1). In one of the patients with AME, enucleation with curettage was not performed as secondary intervention because of diabetes mellitus. The male-to-female ratio was 12 : 2 for AME and 5 : 9 for OKC. The incidence of AME was significantly greater in the male patients while that of OKC was significantly greater in the female patients. Median initial volume was significantly greater for AME (26.1 cm^3 with an interquartile range [IQR] of 12.4 to 31.4 cm^3) than for OKC (7.2 cm^3 with an IQR of 3.1 to 14.8 cm^3). No significant differences were observed in other parameters.

Effect of decompression

According to CT analysis, the median volume was reduced by decompression from 26.1 cm^3 (IQR 12.4 to 31.4 cm^3) to 6.7 cm^3 (IQR 2.8 to 11.7 cm^3) in AME, and from 7.2 cm^3 (IQR 3.1 to 14.8 cm^3) to 3.0 cm^3 (IQR 1.9 to 6.3 cm^3) in OKC. In PI analysis, the median area was reduced from 17.8 cm^2 (IQR 13.2 to 23.1 cm^3) to 6.0 cm^2 (IQR 4.4 to 9.7 cm^3) in AME and from 8.5 cm^2 (IQR 4.8 to 20.3 cm^3) to 4.9 cm^2 (quartile range, 2.3 to 7.6 cm^3) in OKC. All were significantly different (Table 2).

Differences in decompression indices between lesion groups

Table 3 shows the decompression indices for AME and OKC. Median volume reduction was significantly greater in AME (14.6 cm^3 with an IQR of 6.4 to 21.6 cm^3) than in OKC (3.3 cm^3 with an IQR of 0.5 to 8.3 cm^3). The median volume reduction rate of AME was 0.067 cm^3/day (IQR 0.029 to 0.131 cm^3/day) and that of OKC was 0.024 cm^3/day (IQR 0.007 to 0.033 cm^3/day), showing a significant difference. No other significant differences were ob-

Table 1 Patients

	Ameloblastoma (n=14)	Odontogenic keratocyst (n=14)	*p* value
Age (yrs)	26 (18.5 to 36.8)	20.5 (17.3 to 33.0)	0.41
Male : Female	12 : 2	5 : 9	0.018*
Initial volume (cm^3)	26.1 (12.4 to 31.4)	7.2 (3.1 to 14.8)	0.0028*
Initial area (cm^2)	17.8 (13.2 to 23.1)	8.5 (4.8 to 20.3)	0.066
Duration of decompression (days)†	159 (141 to 242)	151 (70 to 205)	0.45
Duration of decompression (days)‡	151 (127 to 275)	121 (66 to 205)	0.16
Unilocular : Multilocular	5 : 9	5 : 9	1.0
Root resorption (Yes : No)	5 : 9	1 : 13	0.16
Tooth displacement (Yes : No)	2 : 12	1 : 13	1.0
Tooth involvement (Yes : No)	6 : 8	8 : 6	0.71
Lesion site			
Mandibular body : Mandibular body and ramus	3 : 11	1 : 13	0.596

Data shown as a ratio or median (interquartile range), *$p < 0.05$, †Period between date of decompression and CT just before enucleation with curettage, ‡Period between date of decompression and panoramic image just before enucleation with curettage.

served among the other indices.

Correlation between decompression indices and patient characteristics for each condition

Tables 4 and 5 show the results for AME and OKC, respectively. Significant correlations were observed for AME on CT evaluation between volume reduction and initial volume (correlation coefficient 0.534), between percent volume reduction and duration of decompression (correlation coefficient 0.569), and between percent volume reduction rate and duration of decompression (correlation coefficient −0.556). Among these parameters, the only significant correlation on PI that matched a correlation on CT was between area reduction and initial area (correlation coefficient 0.793). On CT evalu-

Table 2 Volume or area reduction by decompression

	Ameloblastoma		p value	Odontogenic keratocyst		p value
	Before decompression	After decompression		Before decompression	After decompression	
Volume (cm^3)	26.1 (12.4 to 31.4)	6.7 (2.8 to 11.7)	$<$0.001*	7.2 (3.1 to 14.8)	3.0 (1.9 to 6.3)	0.013*
Area (cm^2)	17.8 (13.2 to 23.1)	6.0 (4.4 to 9.7)	$<$0.001*	8.5 (4.8 to 20.3)	4.9 (2.3 to 7.6)	0.015*

Data shown as median (interquartile range), *$p < 0.05$.

Table 3 Comparison of decompression indices between ameloblastoma and odontogenic keratocysts

	Ameloblastoma	Odontogenic keratocysts	p value
Volume reduction (cm^3)	14.6 (6.4 to 21.6)	3.3 (0.5 to 8.3)	0.012*
Area reduction (cm^2)	8.5 (2.5 to 15.3)	3.8 (1.7 to 11.2)	0.358
Volume reduction rate (cm^3/day)	0.067 (0.029 to 0.131)	0.024 (0.007 to 0.033)	0.0191*
Area reduction rate (cm^2/day)	0.032 (0.011 to 0.084)	0.037 (0.010 to 0.087)	0.927
Percent volume reduction (%)	67.8 (57.7 to 78.9)	58.6 (17.3 to 77.9)	0.46
Percent area reduction (%)	62.5 (15.4 to 76.1)	57.6 (28.6 to 70)	0.76
Percent volume reduction rate (%/day)	0.40 (0.25 to 0.45)	0.33 (0.19 to 0.55)	0.49
Percent area reduction rate (%/day)	0.23 (0.08 to 0.38)	0.40 (0.25 to 0.6)	0.20

Data are shown as median (interquartile range), *$p < 0.05$.

Table 4 Correlation between decompression indices and patient characteristics in ameloblastoma by p values

	Volume reduction	Area reduction	Volume reduction rate	Area reduction rate	Percent volume reduction	Percent area reduction	Percent volume reduction rate	Percent area reduction rate
Age	0.366	0.537	0.436	0.409	0.169	0.0371* (0.560)	0.122	0.342
Sex	0.597	0.783	0.816	0.986	0.857	0.80	0.573	0.944
Initial volume	0.0492* (0.534)		0.102		0.725		0.605	
Initial area		$<$0.001* (0.793)		0.0041* (0.714)		0.0176* (0.622)		0.0274* (0.587)
Duration of decompression	0.594	0.493	0.563	0.553	0.034* (0.569)	0.383	0.039* (−0.556)	0.615
Unilocular or multilocular	0.357	0.488	0.232	0.580	0.272	0.991	0.50	0.882
Root resorption	0.813	0.338	0.797	0.253	0.666	0.500	0.984	0.238
Tooth displacement	0.748	0.805	0.876	0.969	0.410	0.876	0.726	0.909
Tooth involvement	0.817	0.703	0.809	0.780	0.695	0.575	0.742	0.999
Lesion site	0.396	0.974	0.292	0.634	0.319	0.562	0.854	0.924

Correlation coefficients are shown in brackets, *$p < 0.05$.

Table 5 Correlation between decompression indices and patient characteristics in odontogenic keratocysts by P values

	Volume reduction	Area reduction	Volume reduction rate	Area reduction rate	Percent volume reduction	Percent area reduction	Percent volume reduction rate	Percent area reduction rate
Age	0.567	0.625	0.463	0.822	0.970	0.459	0.333	0.391
Sex	0.794	0.838	0.693	0.720	0.532	0.738	0.724	0.888
Initial volume	0.0048* (0.7055)		0.0076* (0.679)		0.175		0.887	
Initial area		0.001* (0.815)		0.001* (0.811)		0.288		0.446
Duration of decompression	0.0949	0.185	0.164	0.737	0.215	0.159	0.714	0.446
Unilocular or multilocular	0.894	0.875	0.975	0.918	0.336	0.226	0.087	0.0535
Root resorption	0.519	0.271	0.342	0.489	0.745	0.629	0.796	0.941
Tooth displacement	0.675	0.502	0.933	0.400	0.585	0.339	0.962	0.376
Tooth involvement	0.960	0.947	0.712	0.789	0.465	0.732	0.122	0.742
Lesion site	0.0784	0.428	0.184	0.370	0.001* (0.862)	0.632	0.030* (0.535)	0.669

Correlation coefficient or correlation ratio is shown in brackets, $^*p<0.05$.

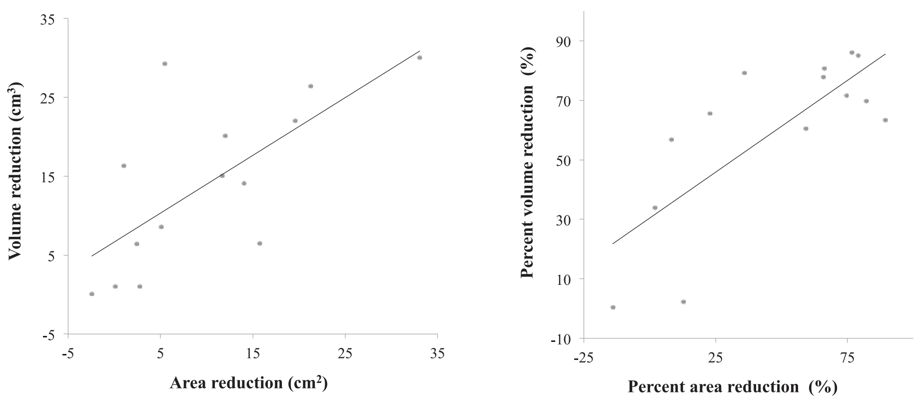

Fig. 1 Scatterplot and regression line (A) of volume reduction and area reduction in ameloblastoma, and (B) of percent volume reduction and percent area reduction.

ation of OKC, significant correlations were observed between volume reduction and initial volume (correlation coefficient 0.7055), between volume reduction rate and initial volume (correlation coefficient 0.679), between the percent volume reduction and lesion site (correlation coefficient 0.862), and between the percent volume reduction rate and lesion site (correlation coefficient 0.535). Among these parameters, significant correlations between area reduction and initial area (correlation coefficient 0.815) and between the area reduction rate and initial area (correlation coefficient 0.811) on PI matched those on CT. No other significant correlations were found between decompression indices and patient characteristics between CT and PI for either condition.

Correlation between volume and area for reduction and percent reduction in each condition

In AME, volume was significantly correlated with the area of reduction and percent reduction. The following regression equations were obtained.

Volume reduction＝6.7＋area reduction×0.7

Percent volume reduction＝30.4＋percent area reduction×0.6

No significant correlation was found for OKC. Figure 1 shows the scatterplot and regression line.

DISCUSSION

Significant lesion reduction due to decompression of AME and OKC was confirmed on both CT and PI. To our knowledge no reports have statistically evaluated correlations of volume with area using the same patient's data before and after decompression of AME or OKC. Our results demonstrate the reliability of PI as a modality for follow-up examination after decompression. Regarding 3D evaluation, Asutay *et al.* performed combined analysis of AME and OKC using CT and indicated that lesion volume was significantly decreased by decompression.[11] Lizio *et al.* also reported that the volumes before and after decompression were significantly different. However, that study involved patients with not only OKC and AME, but also other cystic lesions.[19] Shudou *et al.* used CT to evaluate the volume of OKC after decompression, and calculated it as volume after decompression = initial volume $\times e^{(-0.0029 \times \text{duration of decompression})}$.[13] Using this equation, the volume of OKC after decompression as calculated in our study was 4.7 cm^3. The median volume in our study was 3.0 cm^3 (IQR 1.9 to 6.3), and the obtained value of 4.7 cm^3 was within the IQR, which was considered to be in good agreement. Anavi *et al.* reported the area before and after decompression from 2D evaluation of 22 patients with OKC with other cysts using the area calculated as maximum vertical length × maximum horizontal length.[10] Although that method was simple and useful, it lacked accuracy.

Significant differences were observed in decompression indices between AME and OKC, with both volume reduction and volume reduction rate being greater in AME. In the present study, however, volume reduction (both AME and OKC) and volume reduction rate (OKC only) were correlated with initial volume, and initial volume was significantly larger in AME than in OKC. Because of the larger initial lesion size of AME, the lesion may show faster and greater size reduction compared with OKC. Therefore, it could not be said that there were significant differences in these indices based on this study alone, indicating the necessity for further study that incorporates the initial volume of both lesions. For these reasons, at present, we believe that there are no differences in the decompression indices between AME and OKC based on CT and PI evaluation. Although there is no report comparing volume reduction in both conditions, Song *et al.* reported numerical values of 23 cm^3 with an initial volume of 37 cm^3 for AME and 10.2 cm^3 with an initial volume of 16.5 cm^3 for OKC.[8] Although these volume reductions were greater than ours, this is thought to be due to the initial volume being greater than ours. To our knowledge, there has been no report directly comparing the volume reduction rate between AME and OKC. In both of these conditions, correlations between lesion reduction (volume or area) and initial lesion size (volume or area) were observed on both CT and PI.

From this perspective, it can be suggested that the actual amount of lesion reduction in AME and OKC could be increased when the area at the initial examination is large as deduced by PI evaluation. Also, there has been no previous report on correlations between lesion reduction and patient characteristics in AME and OKC. We also observed a correlation between the lesion reduction rate (volume or area) and initial lesion size (volume or area) in both CT and PI evaluations in OKC only. Therefore, even if the initial lesion area is large in PI, the required duration of decompression may not be long because the actual reduction rate is high. Song *et al.* reported that the volume reduction rate in OKC was 0.043 cm^3/day from an initial volume of 10.2 cm^3, which correlated with the initial volume.[8] Although the volume reduction rate in their report was about twice that of ours, their initial volume was also greater than ours, making them consistent. According to Park *et al,* the area reduction rate in OKC was 0.035 cm^2/day, from an initial area of 23.56 cm^2, which also correlates with the initial area.[7] Although their value of the area reduction rate was almost the same as ours, our initial area was smaller. This is possibly because in the evaluation by PI, the area reduction rate might not increase beyond a certain value. Further study with a large number of cases is needed.

No report has described the optimal timing of CT scanning to confirm lesion reduction during follow-up with PI. To clarify this, we examined the correlation between CT and PI evaluation regarding lesion reduction and percent lesion reduction. In AME, both lesion reduction and percent lesion reduction were correlated, and a regression line and regression equation were obtained. These conversion formulas can be used as a reference to determine the necessity and timing of CT scanning. For example, if the attending physician has planned enucleation with curettage as secondary intervention when the lesion is reduced to 50% of its initial volume and the course is being followed by PI, if a reduction of about 33% is detected on PI, it would be advisable to perform CT to confirm the actual percent reduction. On the other hand, for OKC, no correlation was found between the two evaluation modalities, suggesting that the actual reduction may not be reflected even when the reduction and the percent reduction are evaluated using PI.

This paper has some limitations. First, the number of cases was small. Second, we did not perform detailed examination according to histopathological subtype of AME because of the small number of cases. We would like to overcome these limitations in a future study. The associations between PI evaluation and CT evaluation were observed and the utility of PI was verified for estimating lesion reduction from initial lesion size in AME, and estimating lesion reduction and lesion reduction rate from initial lesion size in OKC. For AME, regression equations were obtained with which PI results can be used to estimate lesion reduction and percent lesion reduction on CT.

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