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ORIGINAL ARTICLE

Volume reduction of cystic lesions after surgical decompression: a computerised three-dimensional computed tomographic evaluation

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Abstract

Objectives This study was performed to evaluate the three-dimensional radiographic variation in mandibular odontogenic cystic lesions after decompression.

Materials and methods Pre- and post-decompression computed tomography (CT) evaluations in 20 patients affected by keratocysts (n=10), dentigerous cysts (n=9) and ameloblastoma (n=1) were analysed using software designed for three-dimensional measurement of volumes; the results were correlated with treatment duration, age, sex and histological type.

Results The mean (range) decompression time was 5.70 (3–12) months. The mean (SD) pre- and post-decompression volumes were 9.50 (7.74) and 4.65 (4.34) cm^3, respectively ($P<0.001$), with a mean (SD) reduction of 49.86 % (19.34 %). The volume reduction was positively correlated with the duration of decompression ($P<0.001$), whereas no correlations with other variables were found ($P=0.2357$). The median monthly reduction in cyst volume was 11.34 % (mean, 13.52 %; range, 4.45–30.43 %) ($P<0.001$).

Conclusions This three-dimensional CT investigation demonstrated the effectiveness of decompression in the treatment of mandibular odontogenic cystic lesions and showed a positive correlation between the duration of treatment and volume reduction.

Clinical relevance Decompression treatment, which is simple to perform and generally well-accepted by patients, is a reliable method to considerably reduce the volume of mandibular odontogenic cystic lesions before surgical removal. Extended decompression time seems to improve results of the reduction process.

Keywords Decompression · Three-dimensional CT evaluation

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Introduction

The release of intraluminal pressure allows the bone cavity of a cystic lesion to progressively decrease in volume, with the gradual growth of surrounding bone. This treatment modality aims to preserve the pulp vitality and periodontal integrity of teeth close to the lesion, to prevent damage to the inferior alveolar nerve, maxillary sinus, nasal cavity and developing teeth, and to avoid bone fracture [1, 2]. Two methods have been described in previous reports, although the distinction between them is often not precise [3, 4]. Marsupialisation, as described by Partsch [5, 6], creates a pouch connecting the oral and cystic cavities after suturing the cyst wall to the oral mucosa [7, 8]. Decompression, proposed by Thoma [9], requires a device, such as a tube or a stent [10], which is sutured in situ for constant drainage, creating a connection between the cyst and the oral environment until an epithelial slit forms. The decompression procedure may be easier to perform and more conservative than marsupialisation, sparing more soft and hard tissue, and is particularly indicated in children [1, 11–13]. This method is also better accepted by patients, even though they have to tolerate having a device in the mouth for several weeks and must perform daily irrigation to avoid infection and wound closure [11]. Marsupialisation may be considered a resolutive treatment, not to be followed by enucleation, whereas decompression alone without subsequent enucleation is rarely indicated [8].

The effectiveness of decompression/marsupialisation in the primary [3, 14, 15] or definitive [3, 16] treatment of large odontogenic cysts has been widely reported. Moreover, this procedure may reduce the risk of recurrence of aggressive lesions, such as keratocysts [17–19].

Nevertheless, many points remain to be clarified. To date, there has been no standardisation of the parameters of volume reduction [1], and consequently, the actual percentage of volume decrease is unclear. Furthermore, the possible relationships between this parameter and the duration of decompression or other variables, including sex, age and the histological type, size and location of the cysts, have not been determined.

Different approximate methods of measurement have been applied in attempts to estimate the shrinkage of lesions after decompression, but all previous reports used two-dimensional (2D) radiographic examinations (OPT) [1, 2, 14, 18]. These evaluations do not allow meta-analysis to calculate the actual duration of reduction and to establish the minimal duration of decompression that may be considered effective. Furthermore, it is controversial whether marsupialisation/decompression should be considered a resolutive treatment or must be followed by enucleation [3, 14–16, 20, 21].

Three-dimensional (3D) computed tomography (CT) is more reliable and precise than two-dimensional CT [2, 22] and has been used successfully in oral surgery [23–26]. In particular, CT with multiplanar reconstructions is superb for defining cystic borders, cortical integrity, tooth displacement and the proximity of vital organs and important anatomic structures [1, 27]. The usefulness of CT investigation after the decompression protocol was underlined by Bodner and Bar-Ziv [28], who performed CT with multiplanar reconstruction on 23 marsupialised cysts, and by a subsequent paper on cystic lesions of the jaw in children [27]. Nevertheless, these studies evaluated only morphological and linear variations in the treated lesions.

The aim of this retrospective study was to assess the effectiveness of the preliminary decompression protocol in terms of reduction in cyst volume, analysing the CT images acquired pre- and post-decompression with image-processing software. Furthermore, the study examined whether volume reduction was correlated with the duration of treatment, age and sex of patients and the histological type of lesions.

Materials and methods

Patient selection and study design

The medical records of all patients who underwent decompression for a mandibular cystic lesion from 2007 to 2011 at the Oral and Maxillofacial Surgery Unit, Department of Oral and Dental Sciences, University of Bologna, Italy, were reviewed.

The inclusion criteria for patients undergoing decompression were (1) a large radiolucent area radiologically showing involvement of the alveolar bundle, dental structures and lingual cortical layer; and (2) a histologically confirmed diagnosis of the cystic lesion (e.g., a dentigerous cyst, keratocyst or ameloblastoma).

Twenty subjects (15 males, five females; mean age, 44.3 (range, 17–73) years) with a total of 20 mandibular lesions consisting of keratocysts ($n=10$), dentigerous cysts ($n=9$) and an ameloblastoma ($n=1$) were selected. These patients underwent CT before and after surgical decompression. A second CT exam was following decompression, at an interval ranging from 3 to 12 months. In these cases, the second CT was performed because a two-dimensional radiological exam (panoramic), taken in every case following decompression, did not provide sufficient detail or information regarding the healing process for use in planning subsequent enucleation surgery.

The panoramic X-ray was considered insufficient when (1) the margins of the lesion were unclear; (2) it was necessary to establish which teeth were involved in the lesion and which were to be treated endodontically before surgical enucleation; and (3) it was necessary to clarify the involvement of the lesion with the lingual cortex.

When possible (four cases), it was preferable to perform cone-beam CT (CBCT) examinations to reduce the patient burden.

Descriptive data are presented in Table 1.

All decompression approaches were performed under local anaesthesia and involved mobilisation of a vestibular full-thickness flap, exposure of the cyst lining after limited osteoplasty of the buccal bone plate, removal of a portion of the cyst wall with a scalpel, placement of a rubber drainage tube fitted so as to avoid interfering with occlusion or oral function and fixed to the oral mucosa with non-absorbable sutures and suturing of the flap. The cyst-wall specimens were sent for histological analysis. After surgery, the patients received oral antibiotic therapy (amoxicillin 2 g loading dose, then 2 g/day for 10 days beginning 1 day after surgery), and a non-steroidal analgesic drug was also recommended as needed. The patients were instructed to

Table 1 Descriptive data of patients

	Mean	Standard deviation	Range
Age (in years)	44.35	18.30	17–73
Time (in months)	5.70	2.02	3–12
Volume pre (in cm^3)	9.50	7.74	1.45–36.01
Volume post (in cm^3)	4.65	4.34	0.12–16.30
Reduction (in percentage)	49.86	19.34	0.36–98.71
Monthly volume reduction rate (in percentage)	13.52 (median 11.34)	7.35	4.45–30.43

adhere to a soft diet for 2 weeks and to maintain appropriate oral hygiene, which included twice daily rinsing with 0.2 % chlorhexidine mouthwash and two to three daily saline irrigations of the buccal cavity through the rubber tube using a syringe for about 4 months after surgery. The rubber tubes were removed as soon as epithelial slit formation was complete, at least 2 weeks after surgery.

Multi-slice CT was taken in 16 cases before and after the surgical decompression using the same CT system, a helical multi-detector CT scanner (LightSpeed VCT; GE Medical Systems). The scanning parameters were 120 kV, 130 mA, 0.65-mm slice thickness, pitch 1 and gantry tilt 0°. Multiplanar image reformatting and 3D post-processing were performed on an Advantage Windows 4.5 workstation (GE Medical Systems). The patient data were reconstructed with a 0.3-mm slice thickness and saved in the Digital Imaging and Communication in Medicine (DICOM) file format. The data were transferred to a Mac Pro Quad 2.66-GHz workstation (Apple Corp., Cupertino, CA, USA) and were visualised and analysed using open-source OsiriX medical imaging software. To minimise measurement errors, the data orientation was standardised using a plane parallel to the inferior border of the mandible.

Cone-beam CT was taken in four cases using the same scanner, the 3D Accuitomo® MST-1, Ex-2, RH 202 (Morita, Kyoto, Japan), both before and after the surgical decompression. This apparatus was used for an exposure time of 17 s at 75 kV and 5 mA. The imaging area (field of view) of the 3D Accuitomo is a cylinder with a height of 30 mm (240 voxels) with diameter of 40 mm (320 voxels), resulting in an isotropic cubic voxel with 0.125-mm sides. Contiguous cross-sectional images were reconstructed from the projection data with a slice width of 0.5 mm, in three directions: parallel to the dental arch, perpendicular to the dental arch and horizontal. Viewing the contiguous sectional images using dedicated software (I-Dixel 3 DX®, Morita), we analysed the images in each section on a cathode ray tube monitor. The data were transferred to a workstation (Mac Pro Quad 2.66 GHz; Apple Corp.) and were visualised and analysed using open-source OsiriX medical imaging software. To minimise measurement errors, the data orientation was standardised according to a plane parallel to the inferior border of the mandible.

The pre- and post-decompression volumes of the lesions were calculated with OsiriX® (Pixmeo, Geneva, Switzerland) software, which was designed to process digital images obtained from radiological machines in *dicom (.dcm)* format. Each exam was evaluated by two assessors (GL and SR) who were trained in radiological diagnosis and measurement detection. The assessors selected the cystic area based on the differences in greyscale density between the chromatic representations of totally or partially mineralised bone and the lesion; this selection was performed manually in all coronal slices taken at 1-mm intervals, completing the sequence using the function “Multiple ROI” available in OsiriX. These 2D measures were subsequently combined using the appropriate function to obtain a 3D model.

The two assessors were totally blinded regarding the timing of the CT exam and patient identity, and they independently evaluated the images. The inter-observer discrepancy was minimal (<0.5 cm^3) in every case, and the mean value of the two measurements was included in the dataset.

The volumetric reduction of the cysts was calculated by subtracting the post-decompression volume from the pre-decompression volume.

A case involving a keratocyst is shown in Figs. 1, 2, 3 and 4.

Statistical analysis

To determine the statistical significance of reduction in volume before and after treatment, we performed the *t* test for paired data.

The monthly percentage reduction was computed for each patient using the following formula: $[1 - (\text{volume after}/\text{volume before})/\text{time}] \times 100$. The result was assessed using a one-sample *t* test to evaluate whether the observed value was statistically different from zero.

A linear regression model was fitted, with reduction percentage as a dependent variable and controlling for all other independent variables, i.e. histological type of lesion, sex, age and duration of decompression. In the linear regression, the dependent variable was the monthly reduction, and the results were not statistically significant.

Results

The postoperative period was uneventful in all patients. The mean duration of decompression was 5.70 (range, 3–12) months.

Fig. 1 Keratocyst in the right mandible. A panoramic X-ray taken before surgical decompression

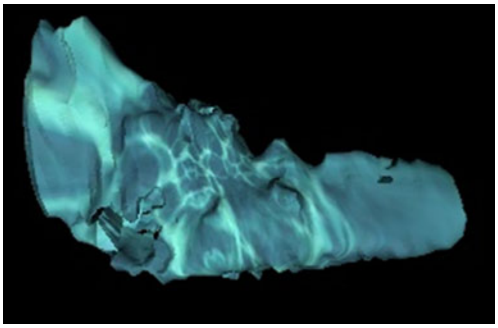

Fig. 2 Computerised 3D reconstruction of the lesion in Fig. 1

Eighteen patients underwent subsequent surgical enucleation of the lesion, and in cases with dentigerous lesions, wisdom tooth extraction was also performed. One keratocyst showed a 98.71 % reduction after 12 months and did not require further treatment, probably due to the long follow-up. In one case with prolongation of decompression for concomitant bisphosphonate drug treatment (alendronic acid), surgical enucleation was not performed.

The histological diagnosis at the time of surgical decompression was confirmed in all cases by the second histological analysis after enucleation. The mean pre- and post-decompression volumes of the lesions were 9.50 and 4.65 cm^3, respectively. The *t* test showed a significant difference in volume before compared with after treatment ($t=5.06$; $P<0.001$; CI95% (2.84, 6.84)).

The mean percentage reduction of volume was 49.86 %.

The median monthly reduction was 11.34 % (mean, 13.52 %; range, 4.45–30.43 %), and the difference was significant ($t=8.129$; $P<0.001$; 95 % CI 0.07–16.95; one-sample *t* test).

The linear regression model revealed that only the duration of decompression was significantly associated with volume reduction.

Table 2 shows the linear regression estimates.

We compared this model with an alternative model that added histological type of lesion as a variable. The one ameloblastoma was placed in the dentigerous cysts group. No additional significant associations were observed ($F=0.126$, $P=0.727$).

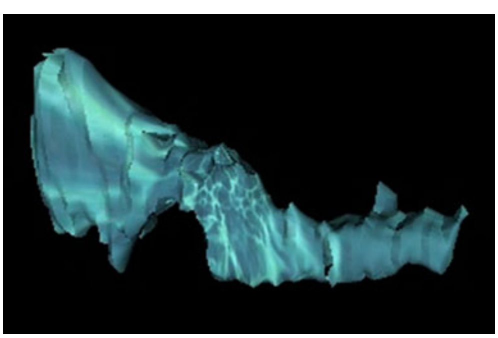

Fig. 3 The panoramic examination of the keratocyst in Figs. 1 and 2, taken 5 months after decompression

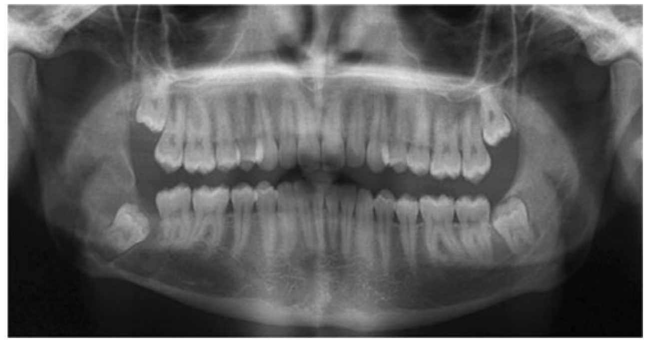

Fig. 4 Computerised 3D reconstruction of the lesion in the previous figures, at 5 months after decompression

The model assumptions were checked graphically, controlling for the Gaussian distribution of residuals.

Figure 5 shows a Q-plot of lesion volume percentage reduction correlated with duration of treatment in months.

Discussion

Marsupialisation and decompression are widely used techniques for primary or definitive treatment of extended odontogenic cysts, preventing damage to important anatomical structures and reducing the surgical trauma with no necessity for grafting. This is particularly useful in younger, elderly or high-risk patients with local or general diseases [3, 20, 29] or who are undergoing pharmacological treatment. In particular, for keratocysts, it was reported that marsupialisation/decompression before enucleation resulted in a lower recurrence rate compared with enucleation alone [4, 14, 17, 30–32]. Drawbacks of these procedures are the need for patients' cooperation, as they must irrigate the cystic cavity for several weeks and undergo frequent follow-up visits [3, 11], as well as the possibility of a missed diagnosis: Possible malignant transformation may progress undetected without incisional biopsy of part of the lining during the prolonged decompression period [8, 14, 33, 34].

With regard to the operative technique, we applied the decompression protocol in all cases to be more conservative and to limit intraoperative and postoperative patient discomfort [11]. This procedure was easily and rapidly performed

Table 2 Linear regression estimates

	Coefficient estimates	*P* value
Age	–0.11	0.64
Time	5.06	0.02
Sex	4.37	0.66

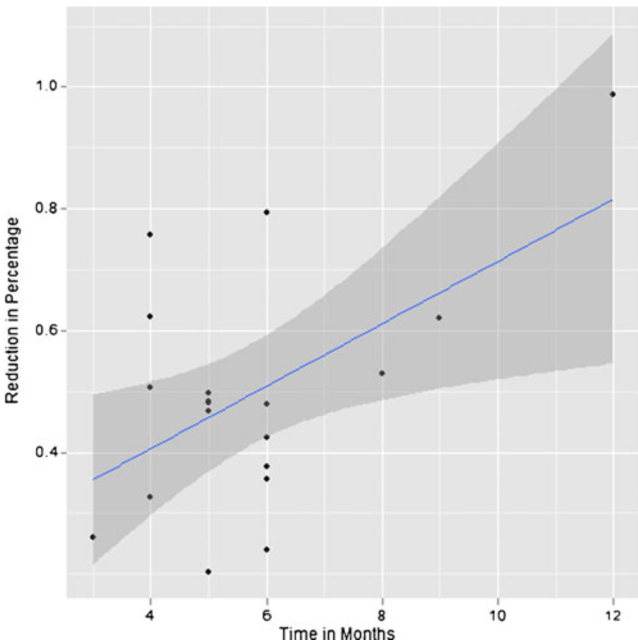

Fig. 5 Q-plot of the time in months versus cystic volume reduction after decompression. The linear regression line is shown

in a dental office under local anaesthesia, and the immediate post-operative period was painless and had minimal swelling. A number of authors have reported application of a small-diameter polyethylene tube cut to various lengths and maintained in situ until completion of epithelial slit formation [10, 18, 27, 35]. Although it required remarkable cooperation to accurately perform daily irrigation to prevent the risk of infection or closure of the slit, all patients managed the post-surgical wound correctly and had no complaints or particular problems.

To date, there have been no reports regarding the methods and parameters for evaluating the effectiveness of marsupialisation/decompression.

The volumetric variations in keratocysts have been quantified in millilitres by injection of saline solution into the cyst cavity. Volume reductions of 22.42 %, 46.07 % and 64.69 % were observed 1, 3 and 6 months after marsupialisation, respectively [2].

Radiography is the most commonly used method for detecting bone formation in healing osseous defects [2, 28, 36]. Some authors measured two-dimensional images (OPT) by simply calculating the area of the lesion [20, 31, 32, 37]. Yoshikawa et al. performed 3D evaluations of posterior–anterior and lateral radiographs [38]. Two studies involved measurement on computerised scanned panoramic images: Nakamura et al. quantified pixel numbers in the lesion areas before and after decompression and reported a percentage >50 % reduction in the lesion in 96.3 % of treated cases in a mean period of 23.5 months [14], and Zhao et al. calculated the variation in bone density using a 254-tone greyscale image, obtaining mean increases in bone density of the cystic area of about 22.42 %, 46.07 % and 64.69 % at 1, 3 and 6 months after marsupialisation, respectively [2].

A 3D exam, such as CT, is considered superior in showing cystic lesions of the jaw, in planning the correct surgical approach, and in evaluating bone regeneration after decompression [2, 13, 22, 27–29, 39]. In particular, Bodner et al. [27] demonstrated that CT-based reconstruction programs, either multiplanar reconstruction (MPR) or 3D, can better determine the topography of the cystic lesion, the integrity/discontinuity of the bony margins, the proximity to vital structures and the displacement of teeth.

To assess bone regeneration following marsupialisation, a previous study compared the CT with MPR performed preoperatively and at 3–4 months after marsupialisation in 23 patients with cysts of the jaw. The 3D outline of the cyst showed partial reduction in volume. Furthermore, the distance between the cyst and adjacent structures (vital teeth, maxillary sinus, nasal cavity and mandibular canal) appeared to be increased; the integrity of the cortex and mandibular canal was recovered, and the new bone formed in the periphery of the cyst showed a ground glass appearance and radial bone spicules [28]. In another study, the cystic area was defined on computed tomograms using a digital pen to take five measurements. This method documented 81 % shrinkage after a mean decompression period of 446 days [18].

The methods used in previous studies for evaluating the reduction rate on radiographs appear questionable. Imaging studies represent the 3D reality on a flat plane, with obvious distortions and deformities. Calculating the area of a lesion as a regular ellipsoid is an approximation that does not take into consideration the frequent morphological irregularities of these lesions, especially keratocysts, and the presence of collateral cavities and scalloped contours. The software used in the present study allows evaluation with a high level of precision of all types of lesion from different projections; it is able to measure every slice obtained on a CT exam taken at constant intervals, combining the areas obtained in a 3D model and calculating its volume.

Several reports have featured the use of OsiriX software in clinical medicine and research [40–44]. Melissano et al. [40] performed a precise analysis of the artery of Adamkiewicz by reconstructing data from MD-CT angiography with OsiriX. The reliability of the software used in the present study has been investigated in neurology, comparing OsiriX with certified commercial medical software. When the images were reconstructed and compared in volume rendering and MPR modes, no significant difference was noted [41]. Matsumoto et al. [42] did not find marked differences in 3D reconstructed images of blood vessels between OsiriX and two other two software programs. In maxillofacial surgery, Sicurezza et al. used the same protocol as we did to evaluate the increment in orbital volume after rapid maxillary expansion [43]; another study compared surgical findings with the 3D reconstructions using OsiriX software in patients with facial fractures and found that the OsiriX images were consistent with the surgical findings in 96.5 % of the cases [44]. The *Journal of Digital Imaging* recently published a paper that certified the accuracy and reliability of length measurements from 3D CT using OsiriX, finding no significant differences between OsiriX and actual measurements [45]. As in that study [45], we found that, even when the margin of error of the volumetric reconstruction using OsiriX is not validated with extreme precision, a minimal error margin in length measurements (0.3 mm) in the evaluation of intra-bone lesions can be tolerated.

OsiriX offers several advantages: It is a free DICOM software program, is simple for clinicians and clinical researchers to use and has excellent reproducibility [45].

We decided to include the CBCT data in our evaluation to augment the sample size, because two recent studies used OsiriX software to manage CBCT images. The first study [46] demonstrated the reliability of CBCT volumetry in the assessment of the osseous consolidation in defects created in the tibias of 16 mini-pigs, correlating the obtained values with a histomorphometric reference standard; a positive correlation between histologically visible newly formed bone and the extent of bone regeneration on CBCT volumetry was identified. The authors concluded that the CBCT volumetry tool in OsiriX allows for reliable, non-invasive, quantitative monitoring of bone defect healing. The second was an in vitro study [47] that found a positive linear correlation between the CBCT voxel value and the hyaluronic acid content in rod samples, considered as reference multi-slice CT data.

Even when a homogeneous sample of CT exams might have been better, some studies have shown that the 3D models obtained from CBCT deviated just slightly from those obtained from CT images, with both showing small deviations from the gold standard [48, 49]. The most important parameter considered in this study, the percentage of volumetric reduction, was not influenced by the differences between the types of examination used for each patient.

Although widely used, decompression protocols are not standardised, with several variations in the surgical technique and different treatment durations reported to date.

Dimensional reduction seems to be strictly correlated with the duration of treatment. The rate of reduction in cyst dimensions reported in previous studies ranged from 65 % after 8.4 months [16] to 81 % after 17.5 months [18]. With a decompression time <6 months, keratocysts showed shrinkage of 19.05 % and 55.62 % at 1 and 3 months, respectively [2]. Zhao et al. reported a 50–60 % reduction 3–7 months after marsupialisation [32].

Although the period of decompression is traditionally about 6–14 months [1, 2, 4, 18, 20, 31, 32, 37, 47], the range reported in the literature is from 2 [1] to 80 months [14]. A decompression time ≥12 months was necessary for Marker et al. [20] to obtain a reduction of ≥50–60 %, and Anavi et al. [1] suggested times to obtain effective decompression of up to 33 and 22 months for maxilla and mandible, respectively. Other authors considered 3 months sufficient for significant cyst volume reduction [2] and the minimum waiting time to safely proceed with enucleation [28]. Pogrel and Jordan [3] reported a period ranging from 7 to 19 months for significant cyst volume reduction.

We obtained a radiographically estimated volume reduction of 49.86 % with a mean decompression period of 5.70 (range, 3–2)months.

One study examined the correlations between variations in keratocyst dimensions and four variables [2]. The first was the duration of treatment, and the volume measures were taken at different times; the decrease in cyst volume was more significant during the first than during the second 3 months. The results further indicated that the changes were negatively related to increased bone density in the cyst area and were not significantly correlated with the pre-operative cyst diameter or patient age. Anavi et al. [1] reported that lesion reduction occurred significantly faster in smaller (<10 cm^2) than in larger cysts (>20 cm^2), that there were no differences in rate of reduction according to pathological type (12 %, 10 % and 13 % for dentigerous cysts, keratocysts and radicular cysts, respectively) and that younger patients (≤18 years old) had a rate of reduction of 14 % compared with 9 % in older patients (>18 years); the mean decompression time was 9.2± 5.2 months. Nakamura et al. [14] reported that the results in keratocysts of the mandibular body were greater than in those of the mandibular ramus.

Since Brondum and Jensen applied the decompression protocol in 44 keratocysts [37], the majority of articles on marsupialisation in the literature have concerned this type of lesion. It was suggested that keratocysts may respond more rapidly and predictably to marsupialisation than do other forms of odontogenic cysts [3] and that the growth characteristics of these lesions becomes less aggressive during decompression, with a lower risk for recurrence [14]. This may be due to metaplasia into the normal mucosa or to creeping substitution [3] and transformation into a thickened hyperplastic tissue with inflammatory changes [31, 48]. In fact, some cases of complete keratocyst resolution with decompression only have been reported, with no recurrence after a mean of 2.8 years [3, 8]. We observed one almost complete resolution of a keratocyst (98.71 % reduction) after the longest decompression period (12 months). In this case, we decided not to surgically remove the residual lesion because of its very small size after decompression (0.12 cm^3), considering the possibility of histological transformation of the lining wall in inflammatory tissue or normal mucosa [3, 31, 48]. The patient has been followed closely.

Anavi et al. [1] reported a slightly greater reduction in less aggressive odontogenic cysts than in keratocysts.

Our retrospective evaluation indicated a positive correlation between the duration of decompression and cystic lesion shrinkage, whereas patient age and sex and the histological type of the lesion had no influence. The results in the single case of unicystic ameloblastoma were comparable to those of the other cystic lesions from both clinical and radiographic viewpoints.

The power of our study was the method used for evaluation, as it allowed us to confirm the validity of the surgical procedure and to consider the duration of the protocol as a positive element influencing healing of these lesions. However, our study was limited by the small number of cases, which reduced the statistical power of each individual variable, and by the differing times of CT exams for each patient, which precluded establishing boundaries for efficient treatment duration. A prospective study, with at least two post-operative CT exams after the pre-operative examination for each patient and with larger numbers of subjects, would provide further insights regarding this protocol. However, performing three or more CT exams may be inappropriate from an ethical viewpoint; we prescribed CT exams only when it was mandatory for correct evaluation in a particular case.

Conclusions

Three-dimensional CT evaluation with dedicated software confirmed that the decompression protocol, which is very simple to perform and is generally well-accepted by patients, is very useful for reducing the size of mandibular odontogenic cystic lesions. The duration of treatment seems to be positively correlated with dimensional reduction of these lesions.

Conflicts of interest The authors report no conflicts of interest related to this study.

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