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Original Article

Quantitative measurements of volumetric changes of maxillary sinus cavity after functional surgery

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Abstract: The aim of this study was to analyze the volumetric changes of maxillary sinus cavity after functional surgery of odontogenic cysts intruding into the maxillary sinus quantitatively and to explore the importance of sinus mucosa and bony wall preservation. Patients who underwent functional sinus surgery and had at least 1-year imaging follow-up were collected. The preoperative and postoperative volume (V_1, V_2, respectively) of the ipsilateral maxillary sinus and volume of the contralateral sinus (V_0) were measured using Mimics 18.0. Difference values of contralateral and ipsilateral sinus cavities were calculated ($\Delta V=V_0-V_1$, $\Delta V_1=V_2-V_1$, $\Delta V_2=V_0-V_2$). Paired t test was performed between V_1, V_2 and V_0, V_2. Difference of ΔV_1 in gender, age, V_1, follow-up period and ΔV were evaluated using independent t test or Spearman rank correlation. A total of 23 cases were enrolled in the study. The mean values of V_0, V_1 and V_2 were 18.35 ± 7.90 cm^3, 11.15 ± 9.79 cm^3 and 16.34 ± 9.43 cm^3. The mean volumetric change of the ipsilateral maxillary sinus was 5.19 ± 4.21 cm^3 (ΔV_1). V_2 was significantly increased than V_1 ($P<0.001$), but still there was significant difference between V_2 and V_0 ($P=0.006$). ΔV_1 was related to ΔV positively ($r=0.647$, $P<0.001$). The more the odontogenic cyst intruded into the ipsilateral maxillary sinus, the more postoperative volume increased. Preservation of maxillary sinus mucosa and bony wall can facilitate the recovery of maxillary sinus cavity volume.

Keywords: Maxillary sinus, functional surgery, quantitative measurement, Mimics

Introduction

Mucosal lining of maxillary sinus has important physiological function, which is determined by the ciliary activity, the volume and physical properties of mucus and periciliary fluid, and the efficiency of mucociliaryinteraction [1]. The complete stripping of sinus mucosa in the Caldwell-Luc procedure leads to regeneration of mucosa that bears dysmorphic and dyskinetic cilia [2]. Besides, changes can occur in the bony structures of the maxillary sinus and these mucosal and bone changes may cause reduction in maxillary sinus cavity volume and develop into short- and long-term complications, such as chronic sinusitis, facial deformity or paresthesia.

Since 1980s, it has been recognized that diseases involving sinuses secondarily are usually reversible when proper ventilation is reestablished [3]. It has been reported that immediate reclosure of the defect resulting from the surgical intervention can against the intrusion by soft tissue of the cheek into the maxillary sinus, together with mucosal restoration, the volume of the maxillary sinus cavity can recover to almost normal size [4, 5]. Our preliminary study also indicated that functional surgery of odontogenic cystic lesions intruding into the maxillary sinus led to less complications, no impairments to physiological function, and normal shape of the maxilla, also the volume of sinus cavity could recover in different degree [6]. Schneiderian membrane is the foundation of normal physiological function and appearance, which exhibits a remarkable capability for regeneration. However, the increase degree of the maxillary sinus cavity volume and whether it can return to normal size still need further quantitative measurements.

Due to the anatomic position of the maxillary sinus and its irregular shape, it is difficult to

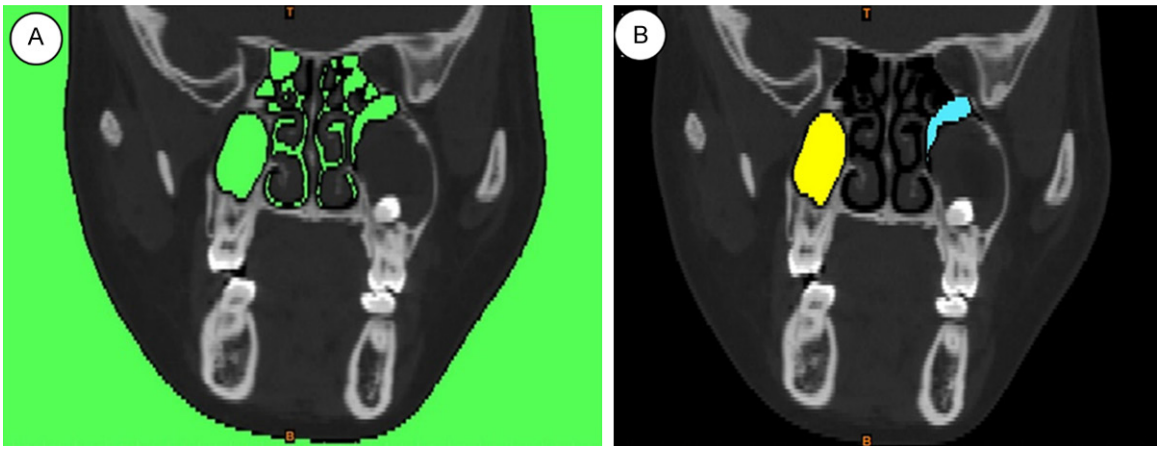

Figure 1. Procedure of 3-dimensional reconstruction. A. Green mask including paranasal sinuses, nasal cavity and oropharyngeal cavity; B. Yellow mask showed the maxillary sinus cavity of normal side and blue mask showed maxillary sinus cavity of affected side.

measure its volume. Several techniques were proposed to analyze the sinus cavity. Although panoramic radiographs were proposed to quantify vertical alterations of the sinus cavity, no volumetric investigations can be achieved from two-dimensional data and superimposition or distortion of images would affect the accuracy of measurements [7]. Computer tomography (CT) and cone beam CT (CBCT) were also used to analyze sinus cavity volume. Briefly, the maxillary sinus area was measured in each slide manually or automatically, multiplied by slice thickness, then the total volume of the sinus was calculated. Obviously, there remained difference between the calculated volume and the actual volume, but the thinner the slice thickness was, the smaller the difference would be. In addition, measuring area of every slice was quite time consuming and labor intensive. With the assistance of a software for image analysis may help to bypass these disadvantages [8].

The current study evaluated the volumetric changes of the ipsilateral maxillary sinus cavity quantitatively compared with the contralateral side using CT data and Mimics 18.0 (Materialise®, Belgium), aiming to estimate whether or not the functional surgery could facilitate the expanding of the sinus cavity.

Materials and methods

Subjects

A retrospective study was designed and implemented, of which the study population was composed of patients who underwent a functional surgery [6] performed by the same senior surgeon of Department of Oral Surgery, Shanghai Ninth People's Hospital from January 2012 to December 2014. To be included in the study sample, the patient must present with odontogenic cystic lesions intruding into maxillary sinus, and had both presurgical CT and follow-up CT at least 1 year after surgery.

The institutional review board of the Ninth People's Hospital (Shanghai, China) approved this study. The retrospective study followed the tenets of the Declaration of Helsinki for research involving human subjects, informed consent was obtained from all participants.

Three-dimensional reconstruction

The data of thin-slice (slice thickness, .625 mm) CT scan were written into a disc as Digital Imaging Communications in Medicine (DICOM) files. Then the data were elaborated using Mimics 18.0 (Materialise®, Belgium). The software was set on standard parameters with air density at -1,000 Hounsfield units (HU) and water at 0 HU [9, 10]. To isolate the maxillary sinus, the raters chose preset masks to individuate it on specific radio density of tissues.

The Green mask (-1,000-0 HU) was selected to include all air cavities, then Yellow mask and Cyan mask were achieved from editing and region growing of the Green mask. After the raters set the Yellow mask and the Cyan mask, the software calculated the corresponding volume automatically (**Figure 1**).

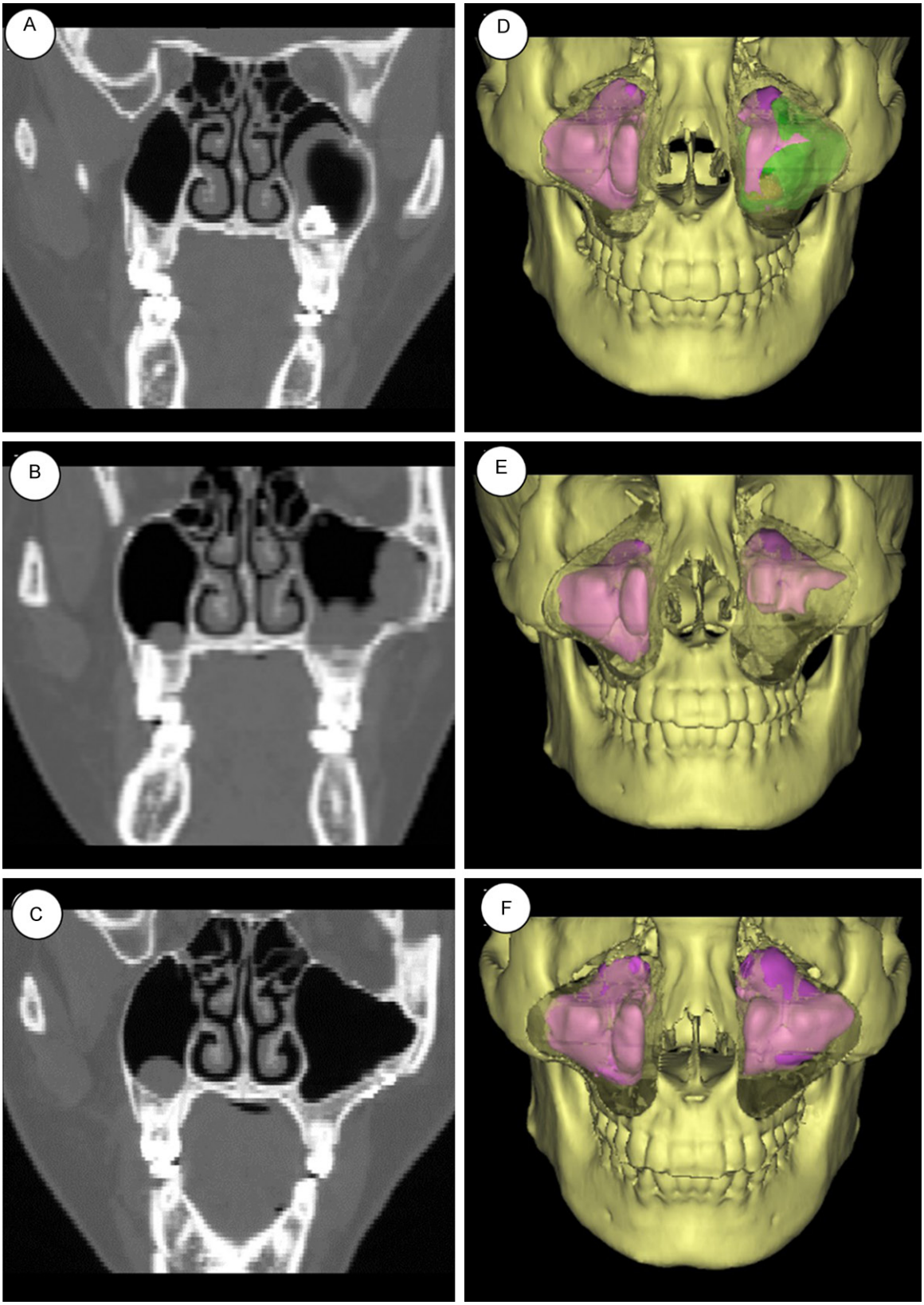

Figure 2. Coronal CT images and 3D reconstruction images by Mimics. A, D. Before operation, volume of normal maxillary sinus was 17.48 cm^3 while affected side was 1.53 cm^3 (purple mask showed the residual maxillary sinus cavity and light green mask showed the cyst); B, E. 1 month postoperatively, affected side expanded to 9.87 cm^3; C, F. 21 months postoperatively, affected side expanded to 15.64 cm^3.

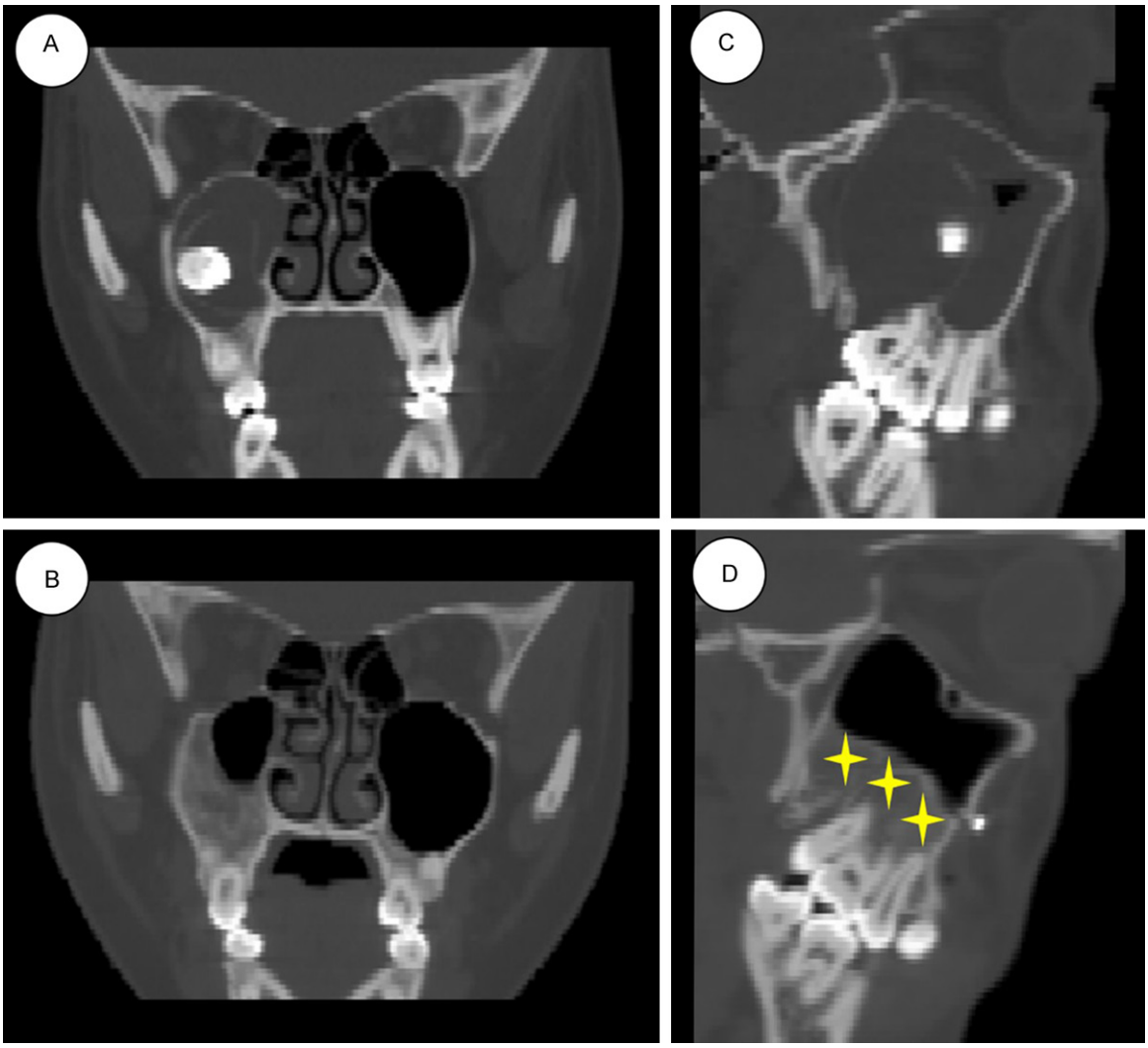

Figure 3. A large number of new bone formation on the inferior wall of the sinus postoperatively. A, C. The cyst before operation; B, D. 29 months after operation (the stars showed new bone).

Outcome variables and assessment

The volume (mean ± SD) of contralateral sinus cavity (V_0), preoperative ipsilateral sinus cavity (V_1), postoperative ipsilateral sinus cavity (V_2), andthe deduction of V_0 and V_1 (ΔV), total volume change by subtracting V_1 from V_2 (ΔV_1), as well as the deduction of V_0 and V_2 (ΔV_2) were calculated.

Two series of measurements were performed on V_0, V_1 and V_2 by two senior oral and maxillofacial surgeons independently. All measurements were performed twice and in the interval of 2 weeks for intra- and inter-reliability estimate.

Data analysis

The statistics were analyzed by standard statistical software packages (SPSS, version 20.0; IBM Corporation, Armonk, NY, USA). For each value, the mean and standard deviation (SD) were computed.

Paired t test was performed between V_1-V_2 and V_0-V_2 to test whether there was significant volume change of the ipsilateral maxillary sinus cavity and the difference between contralateral and postoperative ipsilateral maxillary sinus cavities. Independent t test was used to study the difference between gender and ΔV_1, while association between age, V_1, ΔV and ΔV_1 were assessed by Spearman rank correlation analysis. *P* value less than .05 was taken to indicate a significant difference.

Intra-observer and inter-observer reliability was evaluated using the intra-class correlation coefficient (ICC). An ICC value <.40 was considered

Table 1. Volumetric change of the ipsilateral maxillary sinus

	Volume (cm^3) (Mean ± SD)	t	*P*
V_1	11.15 ± 9.79	-5.91	<0.001*
V_2	16.34 ± 9.43		
ΔV_1	5.19 ± 4.21		

*Significant difference between V_1 and V_2.

Table 2. Difference between the contralateral and the postoperative ipsilateral maxillary sinus

	Volume (Mean ± SD) (cm^3)	t	*P*
V_0	18.35 ± 7.90	3.05	0.006*
V_2	16.34 ± 9.43		
ΔV_2	2.01 ± 3.17		

*Significant difference between V_0 and V_2.

Table 3. Analysis contributing factors for ΔV_1

	r	*P*
Gender		0.221
Age		0.581
V_1		0.117
Follow-up period		0.152
ΔV	0.647	0.001*

*Significant correlation between ΔV and ΔV_1.

poor agreement, .40-.60 was fair agreement, .61-.80 was good agreement and > .80 was excellent agreement.

Results

In total, there were 23 cases, including 10 males and 13 females, aged from 17 to 66 years (mean age of 39.65 years). The follow-up period ranged from 15 to 41 months, with a mean of 26.22 months.

The ICCs for inter-observer agreement was between .86 and .88, demonstrating a good reliability between the observers. The range of ICCs for intra-observer agreement was between .91 and .93, indicating an excellent reliability within the raters.

Assessment of volumetric changes

The mean of V_0 was 18.35 ± 7.90 cm^3, of V_1 was 11.15 ± 9.79 cm^3, and of V_2 was 16.34 ± 9.43 cm^3. The mean volumetric change of the ipsilateral maxillary sinus resulted in 5.19 ± 4.21 cm^3 (ΔV_1), and all cases demonstrated volume enlargement (**Figure 2**) except for 1 case showing a mass of bone formation on sinus floor, leading to a decrease in volume by the size of 1.90 cm^3 (**Figure 3**). The difference value of the contralateral and the preoperative ipsilateral maxillary sinus resulted in 7.20 ± 4.06 cm^3 (ΔV), and the difference value of the contralateral and the postoperative ipsilateral maxillary sinus resulted in 2.01 ± 3.17 cm^3 (ΔV_2).

Significant difference was found when V_1 and V_2 was compared (**Table 1**), showing that the volume of the ipsilateral maxillary sinus increased remarkably after functional surgery. V_2 was larger than V_0 in 8 out of 23 cases, however, the volume of the contralateral maxillary sinus was still significant larger than postoperative ipsilateral side (**Table 2**).

Analysis contributing factors for ΔV_1

There was a positive correlation between ΔV_1 and ΔV (r=00.647, *P*<0.001), indicating that the greater the difference between the contralateral and the preoperative ipsilateral sides, in other words, the more the odontogeniccyst intruded into the ipsilateral maxillary sinus, the more the sinus cavity expanded after surgery. But there was a bone plate between the odontogenic cyst and the sinus cavity in 1 case, resulting in small volume increase, despite of great invasion of the lesion preoperatively. On the other hand, gender, age, follow-up period and V_1 had no evident relation with ΔV_1 (**Table 3**).

Discussion

Criticism of traditional Caldwell-Luc method has concentrated on the complete stripping of the mucosa and remaining permanent bone defect, leading to granulation tissue arising from the wound in the soft tissue of the cheek growing through the defect. The larger this bone defect is, the more the volume of the maxillary sinus will be reduced due to the inward collapse of the soft tissue of the cheek [5]. Moreover, following radical maxillary sinus surgery, bone changes may develop into chronic sinusitis and osteomyelitis, also appositional bone formation adjacent to the infected sinus, followed by intramembranous bone remodeling, can be observed [11, 12], which may be another reason causing volume reduction of

the maxillary sinus cavity. Consequently, sinus mucosal preservation and integral bone structure are essential to the volume of maxillary sinus cavity. The aim of this study was to evaluate the volume changes occurring in the maxillary sinus cavity quantitatively after functional surgery. The authors hypothesized that if both the sinus mucosa and the lateral bony wall were preserved, the volume of the maxillary sinus cavity should increase appreciably and return to normal size.

To our knowledge, it is the first time that the volumetric changes of the maxillary sinus cavity after functional surgery was measured quantitatively. According to this study: ① the ipsilateral maxillary sinus cavity volume increased significantly after operation; ② significant difference still existed between volumes of postoperative ipsilateral and contralateral maxillary sinus cavity, although V_2 was even larger than V_0 in 8 cases; ③ the increased degree of volume of the ipsilateral maxillary sinus was related to the extent of intrasinusal invasion of odontogenic cysts, and the more the cyst intruded into the sinus, the more the sinus cavity expanded after surgery.

Previous studies evaluated volume of maxillary sinus manually based on CT scans. Briefly, in each selected slide, sinus cavity was manually plotted and the volume was calculated. This method presented noteworthy bias, for sinus anatomy is extremely variable [13], let alone the time it consumed. Based on thin-slice CT scan and together with the use of Mimics, it was possible to calculate the sinus cavity accurately and quickly. The mean values of the maxillary sinus volume have been reported in previous researches to range from 11.1 ± 4.5 cm^3 to 23.7 ± 6.7 cm^3 [14]. The result of our study showed contralateral maxillary sinus volume was 15.75 ± 7.74 cm^3, being consistent with previous reports. The volume of intrasinusal invasion of odontogenic cysts varying in size, along with the anatomical variability of the sinus, may explain the high SD of V_0, V_1 and V_2 reported in our study.

Since there was no statistically significant correlation between the volumes of the maxillary sinuses with side [15], the contralateral side was chosen to serve as the control, analyzing volumetric changes of the ipsilateral side. The volume of ipsilateral side by comparison between pre- and post-operation had statistical significance (P<.01), providing support for our hypothesis that preserving sinus mucosa and lateral bony wall was in favor of volume expansion of the maxillary sinus cavity. However, there was statistical significance between contralateral and postoperative ipsilateral sides (P<.01), and this might be caused by small sample. According to quantitatively measurements, the deviations were less than 2 cm^3 in 15 out of 23 cases, besides, the volume of the ipsilateral side was even larger than the contralateral side in 8 of them. Therefore, postoperative maxillary sinus cavity had the potential of returning to normal size.

Pedicledbuccal fat pad (BFP) was applied to fill the gap after clearing the lesion during the operation. It has the advantages of simplicity, versatility, excellent blood supply, minimal to donor site morbidity and good rate of epithelialization [16, 17]. As it showed in the study, BFP would not prevent sinus volume increase. Reposition of the bone lid can prevent soft tissue from collapsing into sinus cavity, on the other hand, air pressure associated with respiration is present in the maxillary sinus, so that Schneiderian membrane can be driven by this pressure to reattach to bony wall. Sinus cavity expansion may be induced by these reasons, and it may explain why bone plate between the cyst and maxillary sinus would hinder the ability of the sinus cavity to enlarge.

Recently, several researchers have reported that Schneiderian membrane has the potential to stimulate bone formation [18, 19]. In sinus lifting procedure, blood clot is allowed to form in the submembrane space to act as a scaffold for new bone formation [20]. The case who presented massive bone formation in our study probably is owing to substantial blood clots and young age.

The increased degree of volume of the ipsilateral maxillary sinus was related to the extent of intrasinusal invasion of odontogenic cysts, and the more the cyst intruded into the sinus, the more the sinus cavity expanded after surgery. This result showed great capability of sinus mucosa to regenerate. Furthermore, ΔV_1 being not related to age indicated that its regeneration ability was not restricted by age. Thus, the

sinus mucosa should be preserved no matter what age.

Our study merely evaluated volumetric changes after functional surgery, and comparison between functional surgery and radical surgery should be addressed in a further study. Moreover, large sample size is required for further analysis, such as whether disease entity could influence sinus cavity expansion or not, and for more stable and reliable results. Nevertheless, it is still safe to say that sinus mucosa and bony wall preservation have benefits for the sinus cavity to restore its volume.

Conclusions

From the results of the study, it can be concluded that the ipsilateral maxillary sinus cavity volume increased significantly after operation, even larger than normal side; the more the cyst intruded into the sinus, the more the sinus cavity increased after surgery. Functional surgery is recommended for odontogenic sinus diseases.

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Disclosure of conflict of interest

None.

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