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Maxillary sinus volumetric changes in jet aircraft pilots: A multislice computed tomography pilot study

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ABSTRACT

Purpose: This study evaluated maxillary sinus volume changes in military jet aircraft pilot candidates before and after the training program, in comparison with a control group, considering the effects of pressurization, altitude, and total flight hours, through multislice computed tomography.
Materials and Methods: Fifteen fighter pilots were evaluated before initiating the training program and after the final approval. The control group consisted of 41 young adults who had not flown during their military career. The volumes of each maxillary sinus were measured individually before and at the end of the training program.
Results: When comparing the initial and final volumes in the pilots, a statistically significant increase was observed both in the left and right maxillary sinuses. When evaluating the average total volume of the maxillary sinuses (i.e., the average volume of the right and left maxillary sinuses together), a significant increase in the volume of the maxillary sinuses was observed in the pilot group when compared to the control group.
Conclusion: The maxillary sinus volumes in aircraft pilot candidates increased after the 8-month training program. This may be explained by changes in the gravitational force, the expansion of gas, and positive pressure from oxygen masks. This unprecedented investigation among pilots might lead to other investigations considering paranasal sinus alterations in this singular population. ***(Imaging Sci Dent 2023; 53: 53-60)***

KEY WORDS: Multidetector Computed Tomography; Diagnostic Imaging; Maxillary Sinus; Aerospace Medicine; Aviation

Introduction

The maxillary sinuses are multifunctional pyramidal-shaped bone cavities. They secrete mucus to humidify the nasal cavity and moisten the inspired air. They also provide thermal insulation for this air, thereby contributing to facial growth, decreasing the weight of the skull, and absorbing impacts to the skull structures.[1] The maxillary sinuses are the first of the sinuses to develop,[2] beginning at the 17th week of the prenatal period and expanding rapidly after birth.[3] They grow simultaneously to other bones, and the shape and size are determined, but not restricted, by the perimeters of the surrounding bony structures.[3]

The maxillary sinus volume, together with the pneumatization of the maxillary alveolar bone,[2] increases until an individual is 12 years old and stabilizes after the last upper molar eruption. Approximately at the age of 20 years old, or around the period during which the third molars erupt, maxillary sinus pneumatization ends completely.[4]

Increases in the volumes of the maxillary sinuses have been observed after the removal of maxillary posterior teeth,

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especially if the second upper molar has been removed or multiple extractions have been performed.[2]

In contrast, pathologies, such as developmental sinus hypoplasia, silent sinus syndrome (as the result of sinus hypoventilation due to the ostium obstruction, resulting in the development of negative sinus pressure and retraction of the sinus walls),[5] systemic conditions (such as osteopetrosis), or even traumatic postsurgical and post-radiation events can decrease the volume of the maxillary sinus.

Military aircraft pilots are exposed to a wide variety of occupational stressors, such as hypoxia, high altitudes, and sudden movements,[6] on multiple flights with major changes in the gravitational force (Gz).[7] High-performance jet aircraft produce high sustained Gzs with rapid onset rates.[8] These stressors are compensated by adaptive physiological responses, such as cardiovascular abnormalities,[9] visual disturbances,[8] neck pain,[10] and increased respiratory and intrathoracic pressures.[9]

Furthermore, high-performance jet aircraft engage in considerable altitude changes. Therefore, pilots are exposed to huge barometric changes, which increase the incidence of aerosinusitis.[11] Aerosinusitis is defined as acute or chronic inflammation in the paranasal sinus, produced by a barometric pressure difference between the air or gas inside the sinus and the air or gas of the surrounding atmosphere.[12]

During a flight, the pressure of the gases in the atmosphere changes as the aircraft ascends and descends, affecting all of the body functions, including the respiratory and circulatory systems.[13] Despite this, the effects of Gz and the pressure of gases on facial structures, such as the maxillary sinus cavity, have not been studied in military jet aircraft pilots in comparison with a control group of non-pilots, with consideration of pressurization, altitude, and flight hours. The idea to develop this research was based on preceding observations on facial modifications in aircraft pilots throughout their careers from a Brazilian Air Force physician and imaging radiologist, who is also the first author of this study and has been working in the Brazilian Air Force for 13 years.

Previous studies regarding sinonasal cavities considered the presence of sinus disease[14] or barotraumas and allergy in commercial pilots,[15] but few studies have been dedicated exclusively to jet aircraft pilots and none of them have assessed facial structures, such as the maxillary sinuses, considering volumetric changes.

Thus, the objectives of this cross-sectional prospective study were to evaluate the maxillary sinus volume changes in military jet aircraft pilot candidates, before and after the training program, in comparison with healthy non-pilot volunteers in the same time interval, considering the effects of pressurization, altitude, and total flight hours, through multislice computed tomography (MSCT).

Materials and Methods

This cross-sectional prospective pilot study was conducted between March and November 2015 with an initial sample of 18 Brazilian aircraft pilot candidates. The sample size was determined by the number of military pilots selected for the jet aircraft training program that year. Additionally, 41 healthy volunteers of the same age and sex were included and considered as a control group for statistical comparison purposes.

This study followed the Declaration of Helsinki of 1975, which was revised in 2000, and it was approved by the Medical School ethics committee of São Paulo University (number 315/15). All pilots and healthy volunteers signed a written informed consent form before participating.

The maxillary sinus volumes and the presence of paranasal sinus diseases of the 18 jet aircraft pilot candidates, who comprised all the candidates approved for the military jet aircraft program (Joker Squad) at the Natal Air Base (Rio Grande do Norte, Brazil), in the year of the study (minimum age: 23; maximum age: 27), were evaluated before the candidates started the training program and after they completed it, with a time interval of 8 months between the first (initial) and second (final) evaluations. Only these 18 candidates were approved to join the program, but often about 18 to 20 pilots are approved every year, and all candidates were second lieutenants in the Brazilian Air Force. Based on the inclusion criteria specific to the training program, only healthy pilot candidates were admitted. They were tested to ensure their general health was satisfactory. This included the absence of cigarette and alcohol consumption. In addition, a history of sinonasal surgery and tooth removal before or during the training program were also considered exclusion criteria. Data on acute airway infections, headache episodes, and barotrauma during training were collected. The medical and imaging examinations performed and used in this research were part of a protocol applied regularly for candidates' program admission and final approval.

After the application of the inclusion and exclusion criteria, 3 pilots were excluded, and the final sample included 15 pilots. Thus, 30 maxillary sinuses were evaluated individually. The final sample included all the candidates admitted as candidates in the Brazilian Air Force in 2015 who could be considered after the application of the inclusion and exclusion criteria. The jet aircraft used in training was the A-29 (the Super Tucano version for the Brazilian Air Force), a single-engine, stepped-tandem, multi-purpose military turboprop aircraft.[16]

For comparison purposes, a control group was created with 41 non-pilot military personnel, with the same sex and age distribution (minimum age 23; maximum age 27), who volunteered to participate in this research. The inclusion criteria were similar to those of the pilots, except for the fact that the volunteers had not performed any flights during their military careers. The volunteers were also evaluated considering volumetric changes in maxillary sinuses and paranasal inflammatory diseases, similarly to the pilot group, using the same time interval for the first evaluation and the second evaluation.

The maxillary sinus evaluations were performed with non-contrast enhanced high-resolution MSCT with 16 slices (Toshiba Activion, Medical Systems Corporation, Otawara, Japan). The acquisition imaging parameters were 3-mm slice thickness, 4-mm spacing between slices, 180-mm field of view, 120 kVp, and 150 mA.

The volumes of each maxillary sinus were measured individually (in the control and pilot groups) using 3D Slicer version 4.6.0 (www.slicer.org) before and at the end of the training program. The maxillary sinuses' anatomy was determined using the automatic presets with further manual correction and detailing by the observers, utilizing axial, sagittal, and coronal slices. Then, the software calculated the entire volume. 3D Slicer is a free open-source medical imaging software package for measuring the volume of structures, available on multiple operating systems. The software platform includes registration and interactive segmentation, visualization, and volume rendering of multi-organ medical images.[17]

During the evaluations, the maxillary sinuses were first individually selected. Then, each maxillary sinus volume was manually quantitatively analyzed using axial, sagittal, and coronal volumes. The volumetric results were expressed in cubic centimeters. Each assessment was verified, and the results were interpreted based on the consensus of 3 experienced radiologists, who performed a blinded visual and volumetric assessment of pre- and post-training imaging status. Examples of the volumetric measurements performed using 3D Slicer are available in Figures 1 and 2.

For the pilot group, data on flight features, such as median altitude, aircraft pressure, and total training hours, were also collected for each pilot during the program.

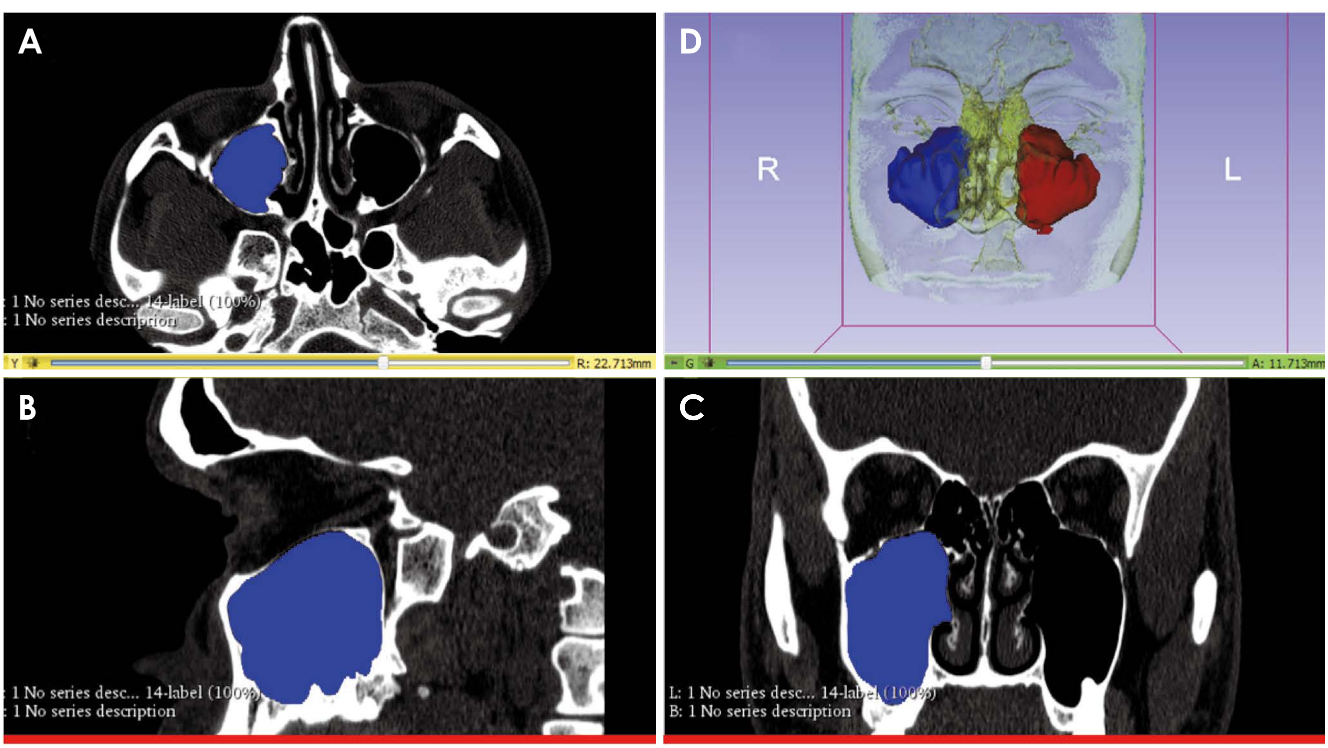

Fig. 1. Images from the sample of the present study taken using 3D Slicer software. A: Computed tomography shows the maxillary sinus in an axial slice. B: Computed tomography shows the maxillary sinus in a sagittal slice. C: Computed tomography shows the maxillary sinus in a frontal slice. D: 3D reconstruction presents the right maxillary sinus in blue and the left maxillary sinus in red.

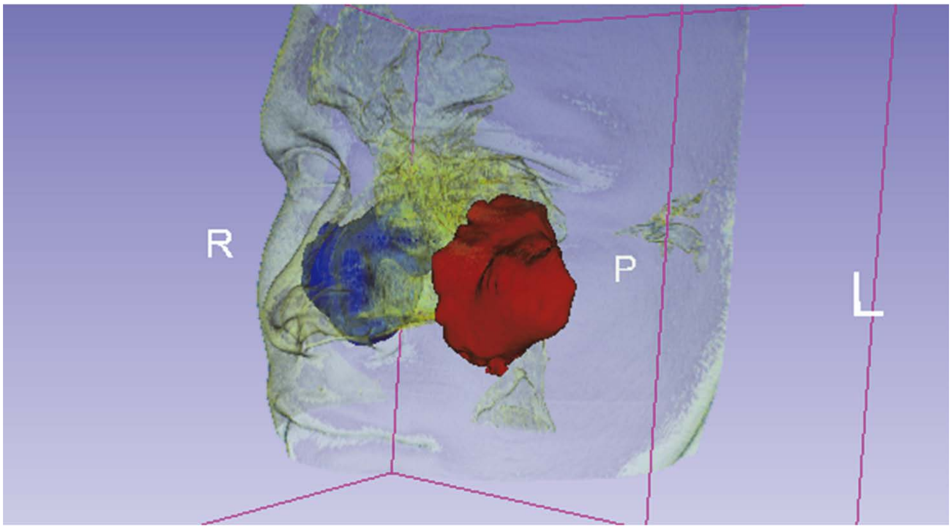

Fig. 2. An image from the sample of the present study taken using the 3D Slicer software for maxillary sinus computed tomography with 3D reconstruction shows the right maxillary sinus in blue and the left maxillary sinus in red.

Data for continuous quantitative variables that did not meet the condition of normality were subjected to a logarithmic transformation. Qualitative variables were described as absolute numbers and quantitative variables as mean and standard deviation. Interobserver agreement for assessments was evaluated using intraclass correlation coefficients (ICCs), and assessment between observers was further evaluated using the paired Student t-test.

First, the volumetric changes in maxillary sinuses from the initial measurement to the final measurement in pilots and controls were assessed for the left and right sides individually using the paired Student t-test. Then, the mean values for volumetric changes of the left and right maxillary sinuses together from the pilots and controls were compared using analysis of covariance. The Pearson correlation test was applied to verify the correlations between flight variables and volumetric changes in jet aircraft pilots. The data were analyzed with the computer program Stata/SE v.14.1 (Stata CorpLP, College Station, TX, USA), and the results were considered statistically significant if $P<0.05$.

Results

Volumetric changes were assessed in 30 maxillary sinuses of 15 military jet aircraft pilots and 82 maxillary sinuses of 41 non-pilots, which constituted a total of 112 MSCT examinations evaluated. Three pilots were excluded during the evaluations due to a history of sinonasal surgery or tooth removal.

Medical alterations of the paranasal sinuses were also assessed in pilots and in the control group. A few episodes of barotrauma, headache and acute airway infections were identified in the pilots during the training program, as shown in Table 1.

Table 1. Number of aircraft pilots symptomatic during the training program

Characteristic assessed	Numerical data
Number of jet pilots evaluated	15
Episodes of headaches during training	2
Episodes of acute airway infections	3
Episodes of barotrauma	2

Table 2. Agreement between observers evaluated using intraclass correlation coefficients

Volume	Control	Pilots
Initial (right side)	0.9996	0.9997
Initial (left side)	0.9979	0.9999
Final (right side)	0.9983	0.9997
Final (left side)	0.9989	0.9999

To assess the agreement between pairs of observers, initially, ICCs were estimated separately for the pilot group and the control group. Table 2 shows the values of the ICCs. Then, for each measure, the null hypothesis was tested that the average difference between the measures of the 2 observers is equal to zero (i.e., the means of the measures would be equal), versus the alternative hypothesis that the average differences would be significantly different from zero (i.e., the means of the measurements would be different from zero).

Table 3 presents descriptive statistics of the volume mea-

Table 3. Interobserver analysis of the volumes of the maxillary sinuses of the pilot and control groups

Group	Variables	Observer	Volume (cc)	Mean difference (2-1)	*P*
Pilot (n = 15)	Initial (right side)	1	20.49 ± 5.27	−0.014	0.712
		2	20.48 ± 5.29		
	Initial (left side)	1	20.74 ± 5.91	−0.021	0.306
		2	20.72 ± 5.94		
	Final (right side)	1	20.86 ± 5.32	−0.050	0.137
		2	20.81 ± 5.32		
	Final (left side)	1	21.06 ± 5.88	0.016	0.461
		2	21.08 ± 5.88		
Control (n = 41)	Initial (right side)	1	19.96 ± 5.83	0.017	0.482
		2	19.97 ± 5.81		
	Initial (left side)	1	20.05 ± 5.65	−0.034	0.557
		2	20.02 ± 5.63		
	Final (right side)	1	19.95 ± 5.81	0.055	0.306
		2	20.01 ± 5.86		
	Final (left side)	1	20.07 ± 5.57	0.003	0.947
		2	20.07 ± 5.60		

Table 4. Volumetric changes in the right and left maxillary sinuses separately. comparing the initial to final measurements (unit: cc)

Group		Right	Left
Pilots	Initial volume	20.48 ± 5.28	20.73 ± 5.93
	Final volume	20.83 ± 5.32*	21.07 ± 5.88*
Controls	Initial volume	19.96 ± 5.82	20.03 ± 5.64
	Final volume	19.98 ± 5.83	20.07 ± 5.58

*: $P < 0.05$ compared with the initial volume

sures and the *P*-values of the statistical tests, separately for the pilot and control groups. Comparisons between the mean volumes measured by each observer demonstrated no statistically significant differences between observations.

When comparing the initial and final volumes, considering the left and right sides separately, an increase in pilots' volume was observed for both sides, with a mean initial volume of 20.73 cc and a mean final volume of 21.07 cc on the left side ($P = 0.002$); and a mean initial volume of 20.48 cc and a mean final volume of 20.83 cc on the right side ($P = 0.008$). The control group did not present any volume increase on either side, as exhibited in Table 4.

When comparing the initial and final volumes of the left and right maxillary sinuses in the pilots and controls, a statistically significant difference was found ($P = 0.014$) for the final volume measurements of pilots, who experienced an increase in volume, as shown in Table 5.

A description of the flight variables, including the altitude and number of flight hours (during the 8-month training), are available in Table 6. No correlations were found between any flight variables and the volumetric assessments in jet aircraft pilots ($P > 0.05$).

Table 5. Mean volume of both maxillary sinuses in pilots and controls

	Pilots (n = 15)	Controls (n = 41)
Initial	20.61 ± 5.57	20.00 ± 5.59*
Final	20.95 ± 5.55	20.03 ± 5.56*

*: $P < 0.05$ compared with pilots (by ANCOVA test)

Table 6. Average cabin altitude, average altitude, and total flight hours during the entire training program of the pilot group

Variants	Values
Average cabin altitude in feet	6,576 ± 800 (range 5,683-8,455)
Average altitude in feet	8,142 ± 892 (range 6,157-9,204)
Total flight hours in hours	93 ± 15 (range 72-132)

Discussion

The main observation of the present study was an increase in the volume of the maxillary sinuses of military jet aircraft pilots after the completion of an 8-month training program in comparison with a control group, with the same age distribution and sex, that did not engage in any kind of flight task.

This is the first study to assess the volumes of the maxillary sinuses of military jet aircraft pilots; thus, no data are available in the literature for a direct comparison of the results. Although the maxillary sinus volumetric increase was slight, considering the mean values reported, this increase was not expected due to the fact that it is well known that the volume of the maxillary sinuses stops increasing near 20 years of age.[18] The presence of a control group, with a higher number of military volunteers who did not participate in any kind of flight task and did not show any volumetric changes in the maxillary sinuses, reinforces the results revealed by this research.

Further volumetric changes occur only in the presence of pathologies, such as lesions of distinct histologic natures, or following the removal of the upper superior posterior teeth. However, the occupational risks inherent in flying, to which military jet aircraft pilots are exposed, should be considered.

Previous studies have reported a number of frequent and distinct physiopathological changes in military aircrews, such as bruxism, which is associated with signals of chronic stress and is observed mainly in pilots.[19] Back pain was also reported, mainly in the cervical region, in fighter pilots,[20] and it was associated with uncomfortable neck postures during flights.[7] Adaptive heart changes in retired fighter pilots have been documented through echocardiograms.[21] In addition, hypercoagulable states have been identified after flight, as well as visual disturbances.[8]

Acquired progressive nasal deformities have been reported in F-16 pilots, such as growth in the dorsal hump and bony exostoses, because of the pressure on their noses from the oxygen masks worn during flights.[22] The masks must be airtight to prevent air leakage and to supply an adequate percentage of oxygen. The flight length, sustained Gz, and use of night vision goggles may also increase the pressure of the mask on the face.[22]

The increases in the volumes of the maxillary sinuses found in the present study might be explained by alternative hypotheses, even though no correlations were found between the investigated variables and the increased volumes of the maxillary sinuses. One explanation is that the volume changes might be associated with the pilots' exposure to repeated Gz changes. It has been previously noted that repeated changes in Gz result in adaptive physiological responses, such as increases in the mean resting arterial pressure and heart rate[23] and activation of the sympathetic nervous system.[24]

Furthermore, the increase in the gas volume in the paranasal sinuses during flights, must also be considered. The pressure and volume of a gas are inversely related at a constant temperature.[25] When there is a decrease in ambient pressure, as upon the ascent of an aircraft, the air expands.[26] This may lead to an increase in the intrasinusal pressure, resulting in sinus bone wall remodeling and, consequently, increases in the volume of the sinuses because of continual exposure to this condition, as occurred in the training program.

Another hypothesis is related to the oxygen mask worn during flights. The Brazilian pilots' oxygen masks used to prevent hypoxemia (MBU 12/P, Gentex Corporation, Zeeland, MI, USA) provide a positive pressure of oxygen inside the nasal cavity and, consequently, in the maxillary sinus to prevent hypoxemia during high-G maneuvers, which may result in the expansion of the maxillary sinuses.

As comparisons with other studies related to aircraft pilots were not possible, information was scrutinized regarding other professionals or sportsmen/women who deal with strong variations in atmospheric pressure that could affect the paranasal sinuses, such as scuba divers. Although they experience the same alterations as pilots (e.g., barotrauma, barosinusitis, and sinus squeeze), no data on volume changes of the paranasal sinuses are available. Nonetheless, volume changes of the paranasal sinuses might also occur in scuba divers due to their similarities to jet aircraft pilots.[27]

The limitations of the present study are its small sample size and the short period of time between the first and second assessments. However, the strength of this study is the presence of a control group, with a high number of control group participants to perform comparisons between the military aircraft jet pilots and the non-pilot participants to reinforce the results obtained in the pilot group.

Conducting studies focusing particularly on military jet aircraft pilots may be difficult due to the small number of pilots who are selected every year, especially among Brazilian aircraft pilots, which was the population evaluated in this investigation; likewise, it may be difficult to recruit healthy volunteers with the same features as the studied group to perform comparisons and validate the results. In the Brazilian aircraft program, only a few pilots (18 to 20) are selected every year and their participation in research needs special authorization from the Brazilian Area Force military high command, as well as the agreement of the pilot himself, which is extremely challenging to achieve. For the aforementioned reasons, no preceding investigations considering military jet aircraft pilots have been carried out, either in Brazil or elsewhere in the world. Further larger-sample studies in other countries should be conducted among jet aircraft pilots to detect volumetric alterations in the maxillary sinuses.

Hence, it was concluded that the maxillary sinus volumes in aircraft pilot candidates might have increased after the training program. This might be explained by changes in the Gzs, the expansion of gas, and the positive pressure of the oxygen masks. As a subtle but statistically significant difference was noted in military jet aircraft pilot candidates during a short period of time (8 months), and Brazilian military aircraft pilots retire after approximately 20 years of service, it is recommended to conduct studies among pilots over a longer time frame, as well as further periodical sinonasal examinations to detect the volumetric alterations observed in this investigation. This pioneering investigation of pilots may lead to further studies in distinct aircraft crews, with larger sample sizes.

This is an unprecedented investigation in Brazil and in the entire world, and the authors are confident that other researchers worldwide could quantify and qualify the alterations in maxillary sinuses and in paranasal sinuses of this unique population with distinct occupational characteristics.

Conflicts of Interest: None

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