

Methods for measuring the volume of the maxillary sinus in living man

R. Aust and G. Helmius, Uppsala, Sweden

SUMMARY

Two methods for measuring the volume of the maxillary sinus in living man are described. The first method is roentgenographic and based on an experimental study on dry skulls. These studies show that the maxillary sinus schematically has the form of a triangular prisma with a pyramid cut off at its dorsal end. The volume can be calculated from the measurements on two roentgenograms taken of the sinus frontally and laterally as shown in the paper. The product of the measurements on the roentgenograms are multiplied with a correction factor yielded in the experimental study.

The second method is manometric and based on calculation with Boyles' law on experiments with an equipment which contains a manometer and a syringe for expansion of the air in the sinus. In this method the ostium of the sinus has to be obstructed, either spontaneously or experimentally. The measuring manometer and the syringe are connected to the sinus through a cannula introduced into the antrum through the lower nasal meatus.

The volume of 56 persons was investigated roentgenographically and 5 of these were also measured manometrically. Good correlation between the two methods was obtained.

The mean volume of the maxillary sinus was 15.8 ml in men and 13.3 ml in women. The difference was not significant.

THE origin, shape and size of the paranasal sinuses in man have been the subject of many investigations both on dissected specimens and cadavers. Proetz (1953) has described the development of the paranasal sinus from the foetal stage to adult age and described their total volume in relation to the volume of the nasal cavity. According to his investigations, the total volume of the paranasal sinuses in adults varies from 37.1 to 59.6 ml and the average nasal volume was found to be 34.2 ml. Boyd (1958) has reported dimensions of the maxillary sinus from the age of 8 days to 21 years. For the 8 day to 1 year old period, he reported a vertical (cranio-caudal) diameter of the maxillary sinus of 5.7 mm, a medio-lateral diameter of 4.6 mm and an antero-posterior diameter of 13.3 mm, while the corresponding dimensions at 21 years were 26.5 mm, 20 mm and 32 mm,

respectively. According to Wagemann (1964) the adult male maxillary sinus has a mean volume of 18 ml and the adult female sinus, a mean volume of 12 ml. The volume varied from 2 ml to 30 ml. Flottes et al (1960) have performed measurements on maxillary sinuses of cadavers and reported volumes from 6 ml tot 22 ml with an average volume of 10 ml.

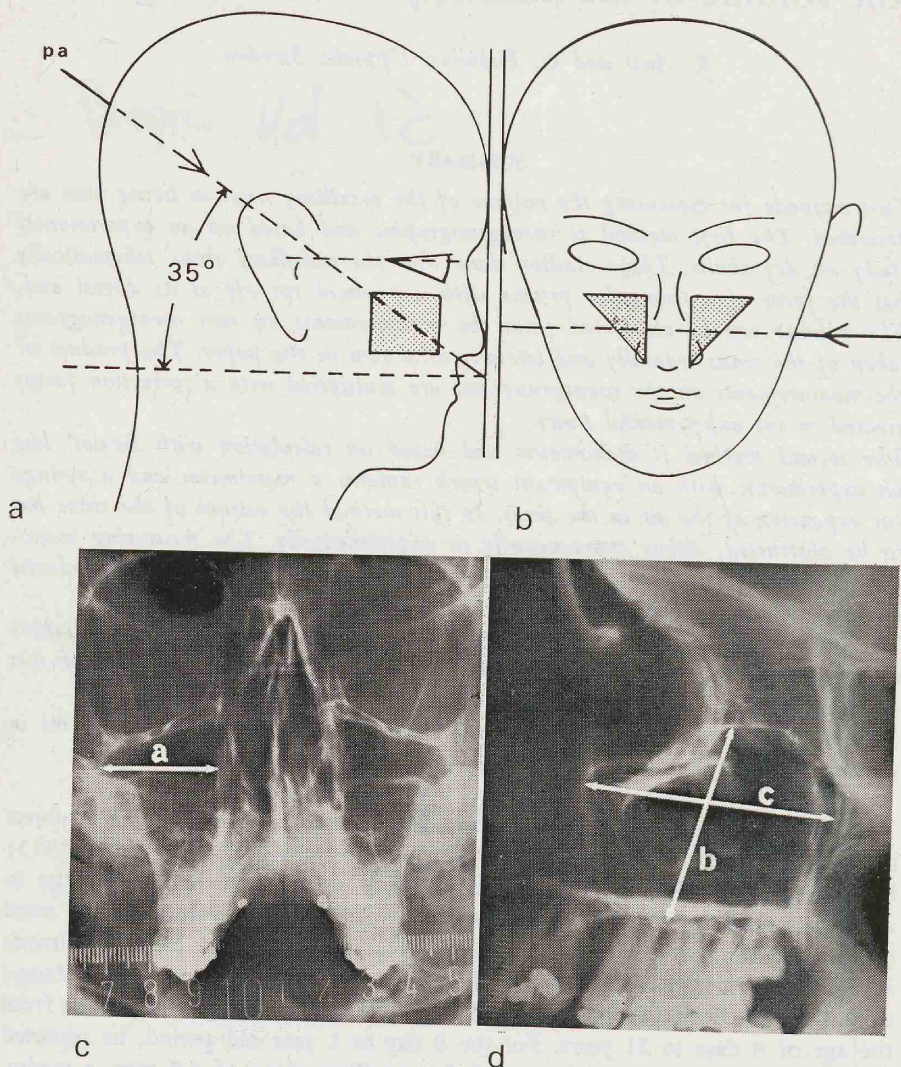


Figure 1. Schematic drawing of the positioning of
 a. the antero-posterior view
 b. the lateral view at the roentgen examination.
 Roentgenograms in
 c. antero-posterior projection
 d. lateral projection with ruler.

However, no study has been reported giving any measurements of the volume of the maxillary or other paranasal sinuses in living humans. Physiological studies of the gas exchange in the maxillary sinuses have made it necessary for us to find reliable methods for such measurements. Furthermore, such studies present an opportunity to correlate antral disorders with variations in the volume of the maxillary sinus.

Two methods have been used in our investigation. The first method is based on measurements on roentgenograms of the bony maxillary sinus. The bony contours of the maxillary sinus can be used as the real limits since the normal antral mucosa is $125\ \mu$ thick in healthy persons (Loring et al., 1973) and can thus be neglected.

The second is a manometrical method which can be used in maxillary sinuses with obstructed ostia.

1. *Roentgenographic method* (Experimental roentgen study)

The maxillary sinuses of 20 dry skulls were examined roentgenographically in frontal and lateral projection. The preferable projections were found to be as shown in figs 1 a and b.

1 a. The postero-anterior projection which is taken with the tube angled 35° cranially from the orbito meatal line with the central ray passing through the anterior nasal spine.

1 b. The lateral projection which is taken with the central ray passing through the center of the maxillary sinus.

For both frontal and lateral projections the roentgenograms were taken with a ruler¹⁾ placed in the same plane as the examined sinus and the scale on the ruler was used to calculate the actual dimensions, thus avoiding magnification errors. From these roentgenograms calculations were performed according to figures 1 c and 1 d, where a is the widest medio-lateral measure on the postero-anterior projection, b the cranio-caudal measure along the posterior contour of the zygomatic process of the maxilla and c the longest anterior-posterior measure of the sinus on the lateral roentgenogram.

Afterwards each examined sinus was filled with an x-ray contrast medium of suitable consistence (Mixobar Oesophagus ASTRA mixed with wheat flour in proportions 3 : 1) and the sinus was controlled roentgenographically to avoid filling defects. The volume of the contrast needed to fill the sinus was measured and that volume was divided by the product of $a \times b \times c$ and the resulting quotient was the correction factor we used for the calculation of the volume of the maxillary sinus. Table I shows the results of the measurements on the 20 skulls. The results of these measurements has yielded the factor 0.39.

From the series of roentgen investigations on the maxillary sinus we have found that the maxillary sinus schematically can be described as a triangular prisma with a pyramid cut off its dorsal end. Figure 2.

¹⁾ Medical Products Octagon P.O. Box 13020, S - 750 13 Uppsala, Sweden.

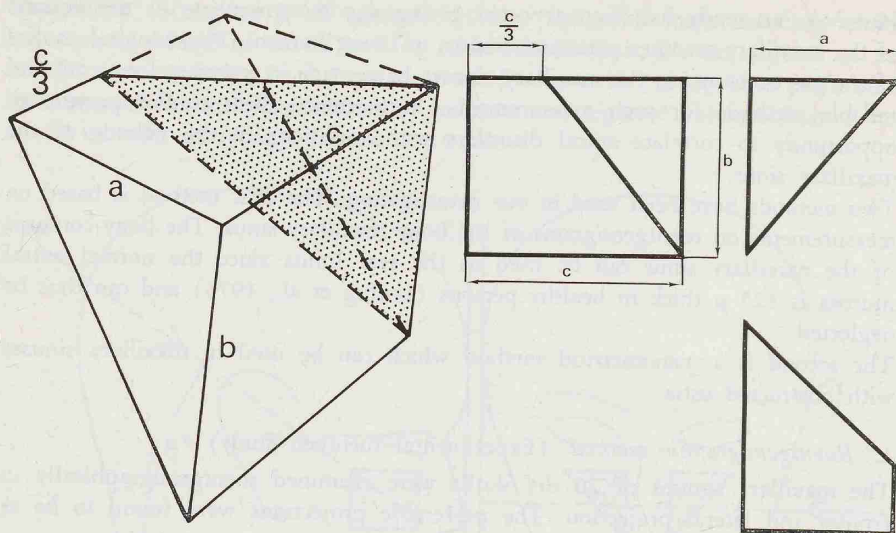


Figure 2. The schematic shape of the maxillary sinus in different views.

The volume of this prisma is

$$V = \frac{a \times b \times c}{2} \times \frac{2c}{3} = \frac{a \times b}{2} \times \frac{2c}{3}$$

$$V = \frac{7 abc}{18} = 0,39 \times a \times b \times c$$

The surface area of the prisma shaped sinus is

Surface =

$$\frac{3 ab + 6 bc + 4 ac + 4 c \sqrt{a^2 + b^2} + 3 b \sqrt{a^2 + \left(\frac{2c}{3}\right)^2}}{6}$$

This gives us a possibility to calculate the mucosal surface in the investigated sinus.

CLINICAL ROENTGEN STUDY

The volume of the maxillary sinus was calculated roentgenographically in 56 persons. The postero-anterior roentgenograms were taken in an erect position with the tube angled 35° cranially from the orbito-meatal line and the central ray passing through the anterior nasal spine, instead of 30° angulation and central ray through the nose tip as in the classical roentgenograms of the sinus (sinus I) (Lysholm, 1931).

Table I. Measuring of the maxillary sinus volume in dry skulls.

	Contrast volume CV	a x b x c	CV/abc
1.	7.9 ml	19.64	0.40
2.	8.3	25.35	0.33
3.	15.0	33.68	0.44
4.	10.2	24.10	0.42
5.	16.0	40.57	0.39
6.	11.6	30.96	0.37
7.	10.5	24.23	0.43
8.	13.2	31.72	0.42
9.	12.2	29.71	0.41
10.	12.0	30.87	0.39
11.	22.2	58.25	0.38
12.	11.2	31.80	0.35
13.	9.1	26.67	0.34
14.	14.5	34.40	0.42
15.	11.0	32.29	0.34
16.	8.3	20.02	0.41
17.	9.0	23.76	0.38
18.	6.0	14.45	0.41
19.	7.0	16.29	0.43
20.	23.0	50.74	0.44

Mean CV/abc 0.39. SD = 0.0346. SD% = 8.9%.

This alteration insured separation of the petrous bone from the lateral border of the maxillary sinus. The lateral roentgenograms were taken with the central ray passing through the centrum of the maxillary sinus to avoid parallax errors. The ruler was used in the same way as in the experimental study. In the postero-anterior projection it was easy for the person to hold the ruler in the open mouth close to the upper teeth 5+. +5), i.e. the same plane as in the experimental study. The results are presented in Table II.

Table II. The volume of the maxillary sinus of 56 persons measured roentgenographically.

Sex	Nr.	Max. volume	Min. volume	Mean volume	SD
Female	32	21.5 ml	6.9 ml	13.3 ml	4.0
Male	24	23.1 ml	8.4 ml	15.8 ml	5.0

2. Manometrical method

The second method, the manometrical, can be used for measuring the volume of maxillary sinuses with obstructed ostia. The ostium can be obstructed either by a swollen mucosa or experimentally with a tampon. In our experiments we have used a tampon moistened with otogutte Terracortril cum polymyxin B^R (Pfizer).

The measurements were performed with an apparatus consisting of a cannula for sinus punctures, connected to an electromanometer Elema-Schönander EMT 33 and a recorder, Mingograph 34. An airtight syringe was also connected to the apparatus (Hamilton with total volume, 25 ul). For the measurements the cannula was introduced into the maxillary sinus through the inferior meatus of the nose. With the manometer the patency was checked by letting the patient breath, sniff and blow through his nose. If the ostia was obstructed a known volume was aspirated into the syringe and the reduction in the air pressure in the sinus and measuring system was registered.

By using Boyles law,

$$\frac{P \times V}{T} = \frac{P^1 \times V^1}{T}$$

where P is pressure, V is volume and T is temperature (K), the volume of the sinus and the measuring system can be calculated. The volume of the measuring system was calculated from similar experiments, substituting a rubber cork for the sinus. The difference between the first and the second volumes gives the volume of the maxillary sinus.

This method has been used by Ingelstedt et al. (1967) for determination of the volume in the tympanic cavity and they found that the error caused by the volume displacement in the electromanometer and by the swelling of the mucosa on aspiration of air in the syringe was negligible.

Tables III. The volume of the maxillary sinus of five persons measured roentgenographically and manometrically.

Sex	Age	Aspirated volume	Pressure reduction	Volume manometer	Volume roentgen	Diff %
Male	25	10 ul	4.9 mm H ₂ O	15.8 ml	15.2 ml	— 3.8
Female	43	10 ul	8.8 mm H ₂ O	6.3 ml	6.9 ml	+ 9.5
Female	53	10 ul	5.2 mm H ₂ O	14.6 ml	14.2 ml	— 2.7
Female	38	10 ul	5.1 mm H ₂ O	15.0 ml	13.8 ml	— 8.7
Male	27	10 ul	5.25 mm H ₂ O	14.7 ml	15.4 ml	+ 4.8

M diff = 0.18.

Clinical study

On 5 normal persons the volume of the right maxillary sinus was measured with the two methods. The results are presented in Table III. The pressure reduction in the manometric method was recorded 3 times in each patient and the mean volume is given in the table.

The maxillary volume of 11 patients with recurrent sinusitis was compared with that of 45 healthy persons and no difference was found.

For all the measurements presented, the measuring system for the manometric method had a volume of 5.0 ml.

DISCUSSION

The results from the present measurements showed that there is a good correlation between the two methods.

We found that the roentgenologic method is the easiest for measuring the volume of the sinus of healthy persons. The manometrical method can be used for measurements on both normal and infected sinuses and is to be preferred in sinuses with swollen mucosa which can change the shape of the antrum from prismatic to a more spherical form. In healthy persons the manometrical method has the disadvantage that the maxillary ostium must be blocked which in many cases is difficult to achieve but makes the method suitable in cases with spontaneous ostial obstruction. The two methods have therefore different fields of application: the roentgenologic method principally in normal subjects and the manometric, principally in patients with sinusitis or related diseases.

ZUSAMMENFASSUNG

Zwei Methoden zur Messung des Kieferhöhlenvolumens bei Menschen in vivo wird beschrieben. Die erste Methode ist eine röntgenographische und basiert auf einer experimentellen Studie an Kranien. Diese Studie zeigt, dass die Kieferhöhle schematisch die Form eines triangulären Prismas hat, dem am hinteren Ende eine Pyramide abgechnitten wurde. Das Volumen kann anhand der Messungen zweier Röntgenogramme berechnet werden, die frontal und lateral vom Sinus gemacht wurden. Das Produkt der röntgenographischen Messungen wird mit einem korrigierenden Faktor multipliziert, den man bei der experimentellen Studie erhält.

Die zweite Methode ist eine manometrische und basiert auf Berechnungen von Versuchen unter Anwendung des Boyle'schen Gesetzes. Zur Durchführung der Versuche werden ein Manometer und eine Spritze zur Aspiration benötigt. Bei dieser Methode muss das Ostium des Sinus entweder verschlossen sein oder tamponiert werden. Das messende Manometer und die Spritze sind durch eine durch den unteren Nasengang in den Sinus eingeführte Kanüle mit der Kieferhöhle verbunden.

Das Volumen von 56 Personen wurde röntgenographisch erforscht. Bei 5 von diesen wurde das Volumen auch noch manometrisch bestimmt. Eine gute Übereinstimmung wurde beobachtet.

Das durchschnittliche Kieferhöhlenvolumen war 15.8 ml bei Männern und 13.3 ml bei Frauen. Dieser Unterschied war nicht signifikant.

REFERENCES

1. Boyd, E., 1958: Diameter of sinuses: Man. In Handbook of respiration. National Academy of Sciences. Saunders & Co. London and Philadelphia, 19.
2. Flottes, L., Clerk, P., Riu, R. and Devilla, F., 1960: La physiologie des sinus. Librairie Arnette, Paris.
3. Handbook of respiration, 1958: National Academy of Sciences. Saunders & Co. London and Philadelphia.
4. Ingelstedt, S., Ivarsson, A. and Jonsson, B., 1967: Mechanics of the human middle ear. Acta otolaryng. (Stockh.) Suppl. 228.

5. Kolmodin, C. G., 1968: Kodak Röntgenhandbook - Röntgenundersökning av skelettet. Kodak AB.
6. Loring, S. H. and Tenney, S. M. 1973: Gas absorption from frontal sinuses. Arch. Otolaryng. 97, 470.
7. Lusted, L. B. and Keats, T. E., 1972: Atlas of roentgenographic measurement. 3. Edition. Year Book Medical Publishers. Inc. Chicago.
8. Lysholm, E., 1931: Apparatus and technique for roentgen examination of the skull. Acta Radiol., Suppl. 12.
9. Proetz, A. W., 1953: Applied physiology of the nose. Annals Publishing Company.
10. Takahashi, R., 1971: Ear, Nose and Throat Studies. Department of Otolaryngology, Jikei University, School of Medicine. Kyoya Co. Ltd., Tokyo, Japan.
11. Wagemann, W., 1964: Anatomie, Physiologie und Untersuchungen der Nase und der Nasenhöhlen. In Hals-Nasen-Ohrenheilkunde, Band 1 (Ed. Berendes, J., Link, R. und Zöllner, F.) Georg Thieme Verlag, Stuttgart.

R. Aust and G. Helmius,
Department of Otolaryngology and the
Department of Diagnostic Radiology,
University Hospital,
Uppsala, Sweden.