# Morphometry of human trachea in male and female using computerized tomography- a comparative study

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## Abstract

**Introduction:** Tracheal anatomy is useful for clinicians to select correct size of endotracheal tube. The study can be done by both invasive and non-invasive techniques like cadaveric dissection(CD), Computed Tomography (CT) scan. In present study we measured diameter, length, cross sectional area, volume of human trachea on CT scan images and the data was compared with that of the other studies.

**Method**: In this prospective study normal chest CT scan images of 110 cases (69 males and 41 females) were studied. Chest CT scans were performed on 64 slice CT scanner. Measurements were obtained using Digital Imaging and Communications in Medicine (DICOM) software. The minimum and maximum values in study population were established for each parameter. The relationship of all study parameters with height and weight was assessed using Pearson's correlation. The regression analysis of significantly correlating variables was done with height and weight as predictors.

**Results**:

**In males:** Height correlated significantly with A-P diameter and transverse diameter & Weight correlated significantly with A-P diameter and CSA.

The weight was found to be a weak predictor of A-P diameter, cross sectional area, and volume.

The height was found to be a weak predictor of length, and transverse diameter.

**In females:** None of the study parameter showed significant correlation with either height or weight. Neither height nor weight found to be the predictor of dependent variables.

**Conclusion**: Practical applications of the data may be useful in the configuration and design of tracheostomy tubes, endotracheal tubes.

**Keywords:** Ttrachea, diameters, Cross sectional area, Volume, Computerized tomography.

## Introduction

Tracheal anatomy is important from clinicians point of view. Knowledge of tracheal morphometry is useful to select correct size of endotracheal tube. Tracheal evaluation is fundamental part of chest imaging. The study can be done by both invasive and non-invasive techniques like cadaveric dissection, virtual bronchoscopy, Computed Tomography (CT) scan, Magnetic Resonance Imaging (MRI) scan.

CT adds a 3-Dimensional component to the understanding of tracheobronchial anatomy and enables calculations of intraluminal volume. It affords an unprecedented opportunity to determine tracheal diameters, cross-sectional area, length, and contained volume in vivo. In present study various parameters of human trachea were measured on CT scans of patients with no known respiratory disease and intra-thoracic pathology to establish normal ranges for diameter(antero-posterior, transverse), length, cross sectional area, volume in men and women. This study was undertaken to describe the morphometry of the normal human trachea on CT scans and to compare the data with that of the other studies.

## Material and Methods

In this prospective study of 18 months duration normal chest CT scan images of 110 adult individuals in the age group of 10-70 years of age (69 males and 41 females) were studied. The permission of the institutional ethics committee and the Head of Department of Radio-diagnosis was taken. Chest CT scan of these patients were performed on GE light-speed VCT multi slice (64 SLICE) multi detector spiral CT Scanner with a scan time of 2-4 seconds and slice thickness of 0.6 millimetres. Patients were given detailed information about the study and written informed consent was obtained from them for the use of their CT scan images for the purpose of this study. The CT scans were taken in supine position, at the end of full inspiration, with arms fully extended above the head[1,2].

**Diameters (antero-posterior and transverse)**: A-P and transverse diameters of the airway lumen were obtained by using electronic measuring tools available as a part of Digital Imaging And Communications in Medicine (DICOM) software in the radio- diagnosis department and were determined from each axial

section approximately at the level of body of vertebrae C6-T4 and averaged.**(Fig. 1)**

**Length of trachea:** The length of the trachea was measured from sagittal reformatted image correlating the upper end as the level of the first axial slice below the level of cricoid cartilage and the lower end as the axial slice showing the antero-posterior mucosal ridge of the carina **(Fig. 2)**.

**Cross-sectional area (CSA)**: was measured at 10 different axial slices cranio-caudally along the length of the trachea and then averaged. The cross-sectional area of the airway (in square millimetres) was obtained by hand tracing the inner wall of the airway with an electronic tracing tool of the DICOM software **(Fig. 3)**.

**Tracheal volume**: was calculated by multiplying length by mean cross-sectional area. The mean corrected cross-sectional area, derived from all slices except those showing the lateral flare just above the tracheal bifurcation and those through the region of variable narrowing just below the cords, was multiplied by the corrected length of the trachea[3].
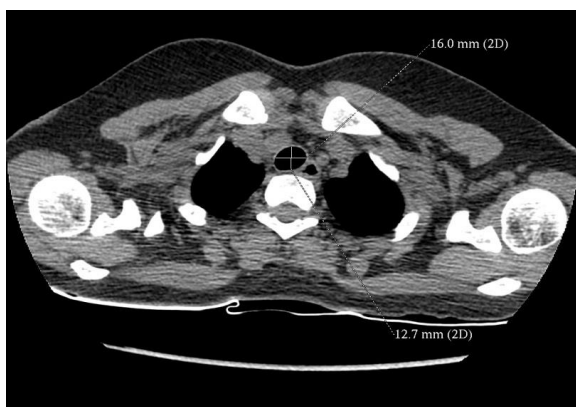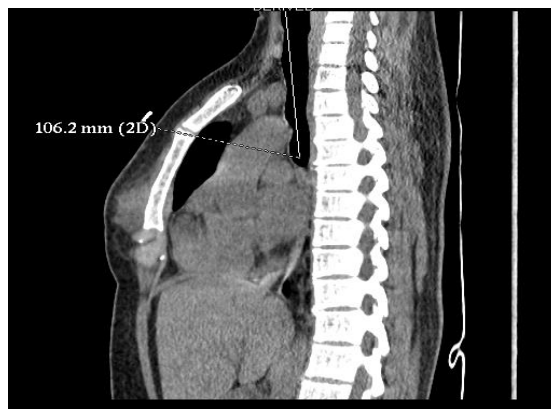


**Fig. 2: Measurement of length of the trachea**



**Fig. 3: Measurement of cross sectional area of the trachea**

**Statistical analysis:** Quantitative variables were expressed as mean ± 2 standard deviation (2SD) of the mean. The minimum and maximum values in study population were established for each parameter. The relationship of all study parameters i.e. A-P and Transverse diameter of trachea, length of trachea, cross sectional area and volume of trachea with height and weight of patient was assessed using Pearson's correlation. The regression analysis of significantly correlating variables was done with height and weight as predictors. The $R^2$ values were calculated and significance was taken at 'p' < 0.05. The null hypothesis of no difference in each of the study parameter between male and female population was tested using 't' test. Statistical significance was defined as 'p' value < 0.05. Statistical Package for Social Sciences (SPSS) 16 was used for statistical analysis.



**Fig. 1: Measurement of the A-P & transverse diameter**

## Observation and Result

**Table 1: Measurements of Trachea in Male and Female population with mean height and weight**

| Parameters | Mean | | ±S.D. | | Minimum | | Maximum | |
|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female | Male | Female |
| A-P Diameter (mm) | 18.82 | 13.25 | 2.37 | 1.68 | 10.15 | 10.72 | 22.92 | 17.25 |
| Transverse Diameter | 16.30 | 14.92 | 1.65 | 1.50 | 11.02 | 10.57 | 19.98 | 17.22 |

| (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Length(mm) | 116.21 | 105.67 | 9.99 | 5.34 | 73.1 | 92.90 | 118.9 | 121.30 |
| CSA(mm$^2$) | 288.42 | 175.54 | 50.20 | 40.16 | 100.36 | 127.34 | 367.59 | 270.27 |
| Volume (cm$^3$) | 33.70 | 18.54 | 6.88 | 4.30 | 7.34 | 13.78 | 43.71 | 28.32 |
| Height (mtr) | 1.65 | 1.59 | 0.052 | 0.040 | 1.35 | 1.50 | 1.74 | 1.66 |
| Weight (Kg) | 67.11 | 57.12 | 8.74 | 8.97 | 25 | 42 | 87 | 75 |

**Correlations with Height and Weight in Male population:** The Pearson's correlation coefficient (r) was calculated for each study parameter to see whether there was any correlation between study parameters and height and weight of cases. Significance was taken at 'p'<0.05. Height correlated significantly with A-P diameter ('r' =0.397, 'p'<0.01) and transverse diameter ('r' =0.344, 'p'<0.05). Weight correlated significantly with A-P diameter ('r' =0.376, 'p'<0.01) only and not with transverse diameter. There was a weak correlation between length of trachea and height ('r' =0.275, 'p'<0.05) and weight ('r' =0.277, 'p'<0.05). There was a significant correlation between weight and volume of trachea ('r' =0.330, 'p'<0.01). but no correlation was found between height and volume. The height did not correlate with cross sectional area but weight significantly correlated with cross sectional area ('r' =0.342, 'p'<0.01).

**Linear regression with Height and Weight in Male population:** The weight was found to be a weak predictor of A-P diameter ($R^2$=0.141), cross sectional area($R^2$=0.104), and volume($R^2$=0.109) ('p' <0.05).The height was found to be a weak predictor of length ($R^2$=0.063), and transverse diameter ($R^2$=0.105) ('p' <0.05).

**Correlations with Height and Weight in Female population:** None of the study parameter showed significant correlation with either height or weight.

**Linear regression with Height and Weight in Female population:** In female population neither height nor weight found to be the predictor of dependent variables.

**Table 2: Statistical analysis of differences between male and female population**

| Parameters | Mean difference | 95% C.I. | 'p' value |
|---|---|---|---|
| A-P Diameter (mm) | 5.57 | 4.73 to 6.41 | <0.01 |
| Transverse Diameter (mm) | 1.37 | 0.75 to 2.0 | <0.01 |
| Length(mm) | 10.53 | 7.18 to13.89 | <0.01 |
| CSA(mm$^2$) | 112.87 | 94.61to131.14 | <0.01 |
| Volume (cm$^3$) | 15.16 | 12.79 to 17.52 | <0.01 |

## Discussion

The human trachea is a dynamic distensible organ of continuously varying size, shape. Standard measurements of various parameters of tracheo-bronchial tree are essential to estimate correct size of endotracheal tube. CT area calculation may be useful in demonstrating and quantifying tracheal obstruction and to localize the lesion.

CT allows considerable precision of measurement. These measurements should be useful in the detection of tracheal abnormalities, in problems in respiratory physiology, and in endotracheal intubation, endoscopy, and tracheostomy.

Reed J.M. et al. (1996)[4] studied the tracheal diameter with MRI scan and stated that, practical applications of these data may be useful in the configuration and design of tracheotomy tubes. Brodsky J.B. et al. (1996)[5] found that direct measurement of tracheal width could be used as a guide to predict which left double lumen tube (DLT) to be selected for each patient. Randestad A. et al. (2000)[6] stated that, knowledge of morphometry of trachea was important clinically. Sakuraba S. et al (2010)[7] concluded that, assessments of tracheal diameter (TD) were important to select proper endotracheal tubes. Vock P. et al. (1984)[8] stated that, non-invasive CT area calculation may be useful in staging mediastinal neoplasms. Shamberger R.S. et al (1991)[9] showed that, cross sectional area could be a guide to surgical and anaesthetic management of children with anterior mediastinal masses.

**Comparison of mean values of the study parameters with that of previous studies:**

**Table 3: A-P diameter of trachea(mm)**

| S. No | Author (year) | Method | n | A-P diameter(mm) | |
|---|---|---|---|---|---|
| | | | | Male | Female |
| 1 | Oon C.L. (1964) | R | 150 | 19.2±1.8 | 14.5±1.3 |
| 2 | Greene R. (1978) | R | 60 | 22.5± 2.4 | - |
| 3 | Breatnach E. et al. (1984) | R | 808 | 10-27 | 10-23 |

| | | | | | |
|---|---|---|---|---|---|
| 4 | Olivier P. et al. (2006) | CT | 206 | 19.7± 3.7 | 16.0± 2.2 |
| 5 | Kamel K.S. et al. (2009) | CT | 60 | 22.6±2.9 | 19.2±2.6 |
| | | CD | 10 | 20.8±2.9 | 15.5±1.1 |
| 6 | Present study (2011) | CT | 110 | 18.82±2.37 | 13.25±1.68 |

**R**= radiograph, **CT**= Computed tomography **CD**= cadaveric dissection, **n**= study sample

The A-P diameter was greater in males than females. Thus the A-P diameter of trachea in present study correspond reasonably well to those with Oon C.L. (1964), Griscom N.T. et al. (1986), Leader J. K. et al. (2004), Olivier P. et al. (2006), Boiselle P.M. et al. (2009). The values given by Kamel K.S. et al. (2009) were greater than those of present study which may reflect a role of racial factor on measurements. The values given by Reed J.M. et al. (1996) were lower than the present study because of the differences in age distribution of the study population in both the studies.

**Table 4: Transverse diameter of trachea (mm)**

| Sr. No | Author (year) | Method | n | Transverse diameter(mm) | |
|---|---|---|---|---|---|
| | | | | Male | Female |
| 1 | Greene R.(1978) | R | 60 | 19.7± 2.0 | - |
| 2 | Breatnach E.et  al. (1984) | R | 808 | 13 –25 | 13 -21 |
| 3 | Olivier P.et al. (2006) | CT | 206 | 17.1±3.6 | 15.7±2.1 |
| 4 | Kamel K.S.et al. (2009) | CT | 60 | 27.1±3.4 | 22.9±2.6 |
| | | CD | 10 | 21.4±1.6 | 17.8±1.5 |
| 5 | Sakuraba S.et al (2010) | CT | 146 | 17.4± 1.7 | 14.8±1.8 |
| | | R | 146 | 17.7± 2.0 | 15.8±1.8 |
| 6 | Munguía-Canales D.A. et al  (2011) | CD | 44 | 19± 2 | 17±3 |
| 7 | Present study(2011) | CT | 110 | 16.30±1.65 | 14.92±1.50 |

**R**= radiograph, **CT**= Computed tomography, **CD**= cadaveric dissection, **n**= study sample

The mean transverse diameter in present study was smaller than the means provided by previous studies which used CT imaging for measurements. The transverse diameter of trachea did not correlate with height, weight like that of a previous study (Sakuraba S. et al. (2010)[7]. In present study the height was found to be a weak predictor of transverse diameter with $R^2$=0.105 (mild association) while the Al Mazrou et al (2009)[19] found the height to be a predictor of the transverse diameter with $R^2$=0.5928 (moderate association). From Table 3 and 4 it was observed that in the previous studies the A-P diameter was greater than the transverse diameter[2,11,12,14,15]. In present study when total study population(n=110) was considered the mean A-P diameter (16.75±3.44 mm) was found to be more than the mean transverse diameter (15.79±1.73 mm), so was also true in the male population [mean A-P diameter (18.82±2.37 mm) and the mean transverse diameter (16.30±1.65 mm)]. But in female population the mean transverse diameter (14.92±1.50 mm) was greater than the mean A-P diameter (13.25±1.68 mm).

**Table 5: Length of trachea (mm)**

| Sr. No | Author (year) | Method | n | Length of trachea (mm) | |
|---|---|---|---|---|---|
| | | | | Male | Female |
| 1 | Kamel K.S.et al. (2009) | CT | 60 | 105.1±9.8 | 98.3±8.7 |
| | | CD | 10 | 103 | 96 |
| 2 | Munguia-Canales D.A. et al (2011) | CD | 44 | 91± 9 | 86± 5 |
| 3 | Present study(2011) | CT | 110 | 116.21±9.99 | 105.67±5.34 |

**CT**= Computed tomography, **CD**= cadaveric dissection, **n**= study sample

The length of trachea was greater in males than females. The values for length of trachea correspond with those provided by Kamel K.S. et al. (2009) (CT). The length of trachea reported in present study was greater than those found in cadaveric studies[16]. This showed that the difference may be due to the use of different methods of study and also the values may differ in living subjects and cadavers.

### Table 6: Cross sectional area (mm²)

| Sr. No | Author (year) | Method | n | Cross sectional area (mm²) | |
|---|---|---|---|---|---|
| | | | | **Male** | **Female** |
| 1 | Vock P. et al (1984) | CT | 50 | 272±33 | 194±35 |
| 2 | Present study(2011) | CT | 110 | 288.42±50.20 | 175.54±40.16 |

**CT**= Computed tomography, **n**= study sample

The cross sectional area of trachea was greater in males than females. Measurements of cross sectional area of present study correspond well to those reported by Vock P. et al (1984).

### Table 7: Tracheal volume (cm³)

| Sr. No | Author (year) | Method | n | Tracheal Volume (cm³) | |
|---|---|---|---|---|---|
| | | | | **Male** | **Female** |
| 1 | Kamel K.S.et al. (2009) | CT | 60 | 35.6±6.8 | 24.7±6.1 |
| 2 | Present study(2011) | CT | 110 | 33.70±6.88 | 18.54±4.30 |

**CT**= Computed tomography, **n**= study sample

The tracheal volume was greater in males than females. The mean tracheal volume in present study was within the range provided by Kamel K.S.et al. (2009)

### Conclusion

The purpose of present study was to define the normal range of tracheal dimensions with computerized tomography using standardized technique. The mean values for the study parameters were measured using CT.

Practical applications of these data may be useful in the configuration and design of tracheostomy tubes, endotracheal tubes and also when tracheal intubation, endoscopy and transplantation are to be performed.

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