



Morphometric analysis and clinical application of the working dimensions of cricothyroid membrane in south Indian adults: With special relevance to surgical cricothyroidotomy

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Abstract

- Objective:** To measure the working dimensions of the cricothyroid membrane in the adult south Indian population and to establish the association between the working dimensions and the appropriate endotracheal tube size for the purpose of cricothyroidotomy.
- Methods:** Cross-sectional evaluation of 50 fresh adult autopsy cases (35 men, 15 women) in a medical university teaching hospital in South India.
- Results:** Age ranged from 17.0 to 83.0 years. Working dimensions of the membrane in neutral position of neck, in men: width = 8.41 ± 2.11 mm, height = 6.57 ± 1.87 mm; in women: width = 6.30 ± 1.29 mm, height = 5.80 ± 1.56 mm. Depth of the subglottic larynx at the level of cricoid cartilage: men = 20.73 ± 1.97 mm, women = 15.62 ± 1.71 mm. Distance of the lower border of cricothyroid membrane from suprasternal notch in neutral position of neck, in men = 5.18 ± 1.76 cm, women = 4.72 ± 1.55 cm; in passively extended neck, men = 7.86 ± 1.25 cm, women = 8.05 ± 1.28 cm. Regression equations have been derived to determine endotracheal tube size for cricothyroidotomy, based on distance between sternal notch and chin, and height of the individual ($P < 0.05$).
- Conclusions:** Working dimensions are smaller in the Indian group compared with western publications. Endotracheal tubes ranging from size 3.0 to 6.0 might be used for cricothyroidotomy in the adult south Indian population.
- Key words:** *endotracheal tube, cricothyroidotomy, cricothyroid membrane, subglottic larynx, working dimension.*

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Introduction

Surgical cricothyroidotomy is a technique used to gain entry into the subglottic airway by creating an opening in the cricothyroid membrane followed by insertion of an endotracheal (ET) tube, which is then connected to an oxygen-delivering device. However, the position of the cricothyroid membrane is variable depending on the habitus and racial characteristics of the individual.¹ Information regarding the working dimensions of the membrane has been documented exclusively in the Caucasian race.^{2,3} Race, heredity, climate and nutritional status are known to affect the body size of a population. More knowledge regarding the cricothyroid membrane would facilitate optimal procedural guidelines for cricothyroidotomy and for choice of ET/tracheostomy tube size to be used in the procedure.

Study objective

The objectives of the present study were to measure the working dimensions of the cricothyroid membrane in the adult south Indian population and establish the association between the working dimensions and the appropriate ET tube size.

Methods

The study was performed on 50 fresh adult Indian autopsy specimens (35 men, 15 women) in a university teaching hospital – at the Institute of Forensic Medicine, Government Madras Medical College and Research Institute, Chennai. The study was approved by the institutional ethical committee and conforms to the provisions of the Declaration of Helsinki (as revised in Edinburgh 2000). Dissection was performed in less than 24 h from the time of death. The neck in all the subjects was normal and had no disfigurement or injury. The positions of easily palpable surface landmarks of neck (mandible, thyroid notch and cricoid cartilage) were noted and their distance from the suprasternal notch was measured (Fig. 1). An I-shaped skin incision in the infra-hyoid region of the neck exposed the vascular and soft-tissue structures, which were carefully dissected. The cricothyroid membrane was identified in the space between the thyroid and cricoid cartilages (Fig. 2), and its working dimensions measured using a vernier caliper. The ‘working dimensions’ of the cricothyroid

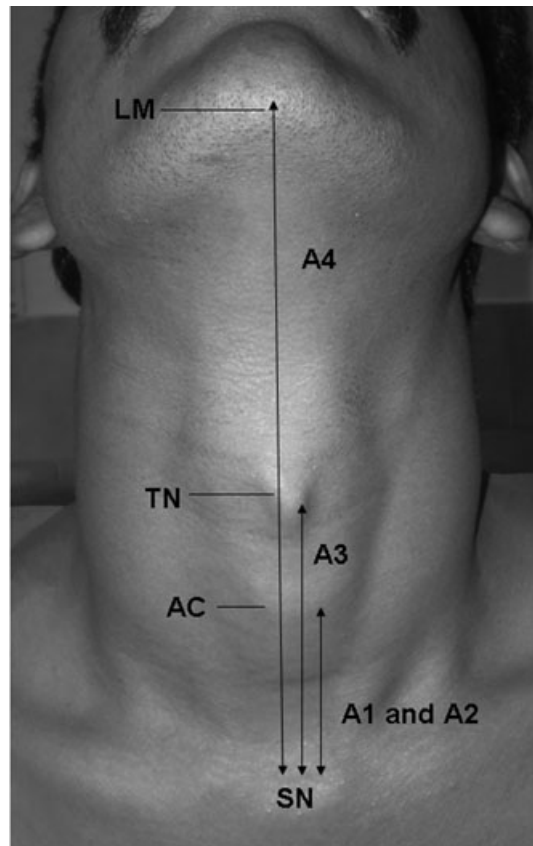


Figure 1. Surface landmarks of neck and their distances from the sternal notch. A1, distance between suprasternal notch and upper border of cricoid cartilage in neutral position of neck; A2, distance between suprasternal notch and upper border of cricoid in passively extended position of neck; A3, distance between suprasternal notch and thyroid notch in passively extended position of neck; A4, distance between the suprasternal notch and lower border of mandible in passively extended position of neck; AC, anterior arch of cricoid; LM, lower border of mandible; SN, sternal notch; TN, thyroid notch.

membrane is defined as the area exposed between the medial borders of the two cricothyroid muscles extending between the thyroid cartilage above and the cricoid cartilage below² (Fig. 3). It is through this space that the tube is inserted in surgical cricothyroidotomy. As the exposed portion of the membrane is trapezoidal in shape, wider above than below, measurements included width at three levels (Fig. 3). The height of the membrane was measured in both neutral and passively extended positions of neck. The cricothyroid membrane was cut and removed from the body and its thickness measured using a vernier caliper. The depth of the sub-

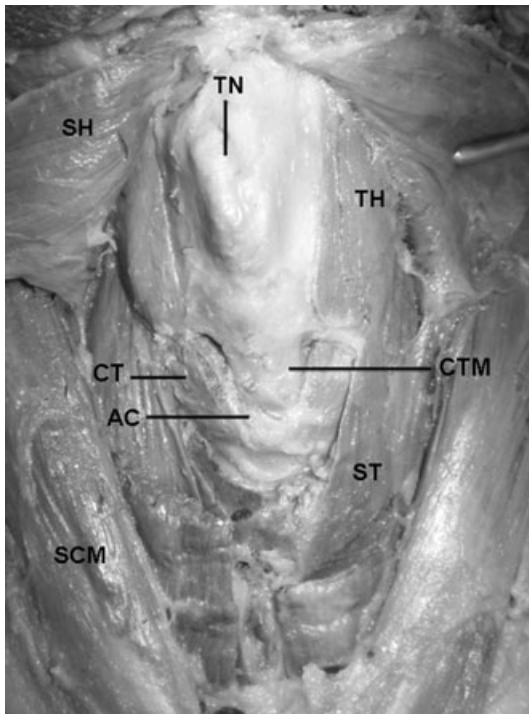


Figure 2. Dissection showing the cricothyroid membrane. AC, anterior arch of cricoid; CT, cricothyroid muscle; CTM, cricothyroid membrane; SCM, sternocleidomastoid; SH, sternohyoid muscle reflected; ST, sternothyroid; TH, thyrohyoid; TN, thyroid notch.

glottic larynx was measured at the level of the upper border of cricoid cartilage from its outer rim to the posterior wall of larynx.

Statistical analysis was done using SPSS version 16 (SPSS, Chicago, IL, USA). The mean measurement in male and female subjects was compared by Student's *t*-test. The working dimensions of the membrane in relation to sex, height of the individual and neck parameters were analysed for correlation using Pearson correlation coefficient. Linear regression equations were derived to estimate the optimal size of the ET tube in cricothyroidotomy.

Results

The baseline results are listed in Table 1. The working widths of the membrane are denoted in the 'W' series. The working width demonstrated variation at three levels and was different based on the sex of the subject. W1 and W2 are significantly more in men ($P=0.001$).

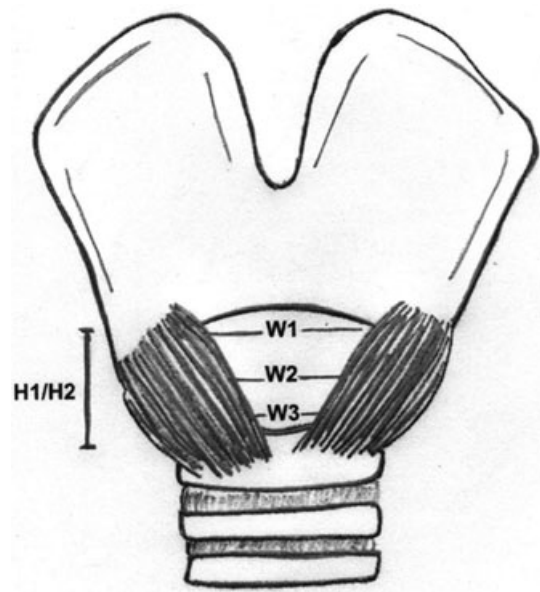


Figure 3. The working dimensions of cricothyroid membrane. H1, height of the exposed membrane in neutral position of neck; H2, height of the exposed membrane in extended position of neck; W1, upper transverse width of the exposed cricothyroid membrane along the lower border of thyroid cartilage; W2, middle transverse width of membrane; W3, lower transverse width along the superior border of the cricoid cartilage.

However, W3 showed no significant difference. Though the height of the cricothyroid membrane in neutral position, H1 showed no significant gender difference, whereas H2 was more in men than women ($P=0.049$). The height of the membrane increased significantly on extending the neck, thereby exposing a larger working area for cricothyroidotomy.

Thickness of the cricothyroid membrane (TM) ranged from 1.4 to 9.0 mm; mean was 3.54 ± 1.24 mm in men and 2.70 ± 0.71 mm in women. Thickness of the membrane was significantly more in men ($P=0.019$).

The depth of the subglottic larynx at the level of upper border of cricoid cartilage (DL) ranged from 13.0 to 25.3 mm; mean was 20.73 ± 1.97 mm in men and 15.62 ± 1.71 mm in women. Depth of larynx was significantly more in men ($P=0.000$).

The stab incision in surgical cricothyroidotomy is preferably performed along the lower border of the cricothyroid membrane, to avoid the transverse cricothyroid artery, which runs close to the lower border of the thyroid cartilage.³ Hence, it is useful to have information about the expected distance for safe approach in clinical conditions where palpation of the cricoid cartilage

Table 1. Baseline results of all measured parameters

Neck parameters	Men (n = 35)			Women (n = 15)			P-value
	Range	Mean	SD	Range	Mean	SD	
Age (years)	17–83	38.54	15.92	17–75	46.2	18.22	0.142
Stature (cm)	145–179	159.97	7.41	135–159	146.4	6.59	0.0001
A1 (cm)	2.0–8.0	5.18	1.76	2.5–7.0	4.72	1.55	0.461
A2 (cm)	5.5–10.0	7.86	1.25	6.0–11.0	8.05	1.28	0.842
A3 (cm)	9.0–13.0	10.87	1.28	8.0–14.0	9.93	1.68	0.036
A4 (cm)	13.0–20.0	16.61	1.71	12.5–20.5	15.63	2.29	0.101
P1 (cm)	10.0–18.0	13.50	1.80	6.0–17.0	13.03	2.34	0.449
NC (cm)	29.0–43.0	34.47	3.22	26.0–35.0	30.10	2.76	0.0001
W1 (mm)	5.0–17.0	11.49	2.67	6.0–11.0	8.78	1.43	0.001
W2 (mm)	3.0–12.0	8.41	2.11	3.0–8.0	6.30	1.29	0.001
W3 (mm)	0.0–8.0	3.73	1.86	0.0–7.0	3.05	1.87	0.243
H1 (mm)	3.0–10.0	6.57	1.87	3.0–8.4	5.80	1.56	0.170
H2 (mm)	4.0–13.0	8.76	1.93	5.0–10.4	7.57	1.81	0.049
TM (mm)	2.0–9.0	3.54	1.24	1.4–4.0	2.70	0.71	0.019
DL (mm)	14.3–25.3	20.73	1.97	13.0–19.3	15.62	1.71	0.0001

Working dimensions of the cricothyroid membrane are depicted in bold print.

A1, distance between suprasternal notch and upper border of cricoid cartilage in neutral position of neck; A2, distance between suprasternal notch and upper border of cricoid in passively extended position of neck; A3, distance between suprasternal notch and thyroid notch in passively extended position of neck; A4, distance between the suprasternal notch and lower border of mandible in passively extended position of neck; DL, depth of subglottic larynx from the outer rim of upper border of cricoid arch to the posterior wall of larynx; H1, height of the exposed membrane in neutral position of neck; H2, height of the exposed membrane in extended position of neck; NC, circumference of neck measured at the level of thyroid notch; P1, distance between external occipital protuberance and seventh cervical spine in neutral position of neck; TM, thickness of the cricothyroid membrane; W1, upper transverse width of the exposed cricothyroid membrane along the lower border of thyroid cartilage; W2, middle transverse width of membrane; W3, lower transverse width along the superior border of the cricoid cartilage.

becomes impossible because of subcutaneous oedema of the neck. Measurement of distance of the lower border of cricothyroid membrane from suprasternal notch as observed in Table 1 denoted a mean of 4.72 ± 1.55 cm with the neck in neutral position and 7.86 ± 1.25 cm when the neck is passively extended. There was no significant sex difference ($P = 0.461$).

The working dimensions of the membrane were correlated with age, stature and neck parameters of the individual using Pearson's bivariate correlation coefficient (Table 2). Working widths of the membrane (W1, W2 and W3) correlate positively with each other and with the working heights of the membrane (H1 and H2) at the 0.01 level. As height of the membrane increased, there is a concomitant increase in its width. Working width (W1 and W2) correlates positively with the depth of subglottic larynx at the 0.01 level. H1 correlates positively with H2, W1, W2 and W3 at the 0.01 levels and A4, which is distance between the suprasternal notch and lower border of mandible in passively extended position of neck, is at the 0.05 level. H2 correlates with A4 at the 0.01 level. Height of

the individual correlates positively with the width of the membrane (W1, W2 and W3) and depth of the larynx at the 0.01 level and with the height of the membrane (H1 and H2) and A4 at the 0.05 level. Neck circumference correlates positively with the depth of subglottic larynx at the 0.01 level. Neck circumference, however, does not correlate with the width of the membrane. Thickness of the membrane correlates positively with age, height of the individual and length of anterior neck A3 and A4.

Regression analysis of the width and height of the cricothyroid membrane against stature of the individual and neck parameters is shown in Table 3. Using the regression coefficient ET tube sizes have been generated.

ET tube size calculation for cricothyroidotomy in south Indian adults

H1 and W2 are relevant working parameters to calculate ET tube size in cricothyroidotomy. From the regression analysis in Table 3, the best variables to

Table 2. Correlation of measured parameters with width, height, thickness of the cricothyroid membrane and depth of subglottic larynx

	W1	W2	W3	H1	H2	TM	DL
Age	0.018	0.008	0.046	0.085	-0.064	-0.284*	-0.158
Height	0.515**	0.436**	0.373**	0.319*	0.294*	0.343*	0.620**
A1	-0.064	0.083	0.146	0.313	0.360*	0.141	0.014
A2	-0.041	0.016	-0.018	0.125	0.237	0.212	-0.162
A3	0.192	0.220	0.114	0.192	0.301*	0.280*	0.080
A4	0.260	0.319*	0.212	0.325*	0.384**	0.311*	-0.009
P1	0.224	0.207	0.263	0.248	0.252	-0.020	0.078
NC	0.220	0.139	0.057	-0.174	-0.149	0.137	0.608**
W1	1	0.930**	0.680**	0.512**	0.491**	0.103	0.461**
W2	0.930**	1	0.692**	0.610**	0.592**	0.096	0.407**
W3	0.680**	0.692**	1	0.388**	0.441**	0.032	0.149
H1	0.512**	0.610**	0.388**	1	0.882**	0.068	0.118
H2	0.491**	0.592**	0.441**	0.882**	1	0.156	0.071
TM	0.103	0.096	0.032	0.068	0.156	1	0.113
DL	0.461**	0.407**	0.149	0.118	0.071	0.113	1

*Correlation is significant at the 0.05 level (two-tailed).

**Correlation is significant at the 0.01 level (two-tailed).

For definitions, please refer to the footnote of Table 1.

measure the working height of the membrane in neutral position of neck (H1) and the middle transverse width of membrane (W2) are height of the individual and A4, which is the distance between the suprasternal notch and lower border of mandible in passively extended position of neck ($P < 0.05$). Using the regression formula $Y = bX + a$, tube sizes have been generated for known values of A4 and height of the individual (Tables 4 and 5). In summary, for A4 values < 16 cm, an ET tube size 3.0 can be used; for A4 of 16–18 cm, ET size 4.0 is used; for A4 between 19 and 21 cm, ET size 5.0 is used; and for A4 > 21 cm, ET size 6.0 can be used. For height of the individual < 135 cm size 2.0 can be used; between 135 and 149 cm size 3.0 can be used; between 150 and 169 cm size 4.0 can be used; 170–184 cm size 5.0 can be used; for height > 185 cm size 6.0 can be used.

Discussion

In massive neck swelling caused by subcutaneous oedema or haematoma, emergency cricothyroidotomy is very difficult as normal anatomical landmarks are obliterated.¹ Blind attempts have often caused damage to the thyroid cartilage, inadvertent puncture of thyrohyoid membrane or tracheal insertion of the airway.³ Puncture of the posterior wall of larynx and oesophagus are also reported complications following cricothyroidotomy.³

Insertion of oversized tubes results in fracture of the laryngeal cartilage and subsequently dysphonia and subglottic stenosis.^{2,4,5} It is therefore imperative that sound knowledge of the working dimensions of the cricothyroid membrane is available especially in relevance to the population we serve. The present study on 50 fresh adult autopsy cases (35 male and 15 female) is the largest study thus far and focuses exclusively on the Indian race.

Table 6 compares the working dimensions in the subjects of the present study with the landmark article by Dover *et al.*³ that dealt with Caucasian subjects. It is observed that the working dimensions are consistently smaller in the adult south Indian population compared with their Caucasian counterparts. Hence, tube sizes recommended in earlier studies might not be applicable to other racial groups. The height of the membrane increased significantly on extending the neck, thereby exposing a larger working area for cricothyroidotomy (Table 1). This could be attributed to the fibroelastic nature of the membrane,⁶ as well as the mobility of the synovial cricothyroid joint.²

The American Association of Clinical Anatomists suggested that a cannula of outer diameter 8 mm and internal diameter of at least 5 mm be used in cricothyroidotomy.⁷ Smaller cannulas are easier to insert, but narrower the internal diameter more is the resistance to airflow. According to Poiseuille's law, flow is directly

Table 3. Regression of height of the individual and neck parameters with working dimensions of the membrane

Y	X	b	SE (b)	a	SE (a)	r ²	p
W1	Height of the individual	0.143	0.034	-11.66	5.379	0.265	0.000
W1	A1	-0.102	0.289	10.667	1.527	0.004	0.726
W1	A2	-0.086	0.307	11.369	2.488	0.002	0.780
W1	A3	0.350	0.259	6.970	2.768	0.037	0.183
W1	A4	0.359	0.193	4.820	3.166	0.067	0.068
W1	P1	0.303	0.191	6.626	2.576	0.050	0.118
W1	NC	0.160	0.102	5.362	3.419	0.049	0.124
W2	Height of the individual	0.096	0.029	-7.268	4.495	0.190	0.002
W2	A1	0.115	0.253	6.908	1.336	0.007	0.652
W2	A2	0.027	0.245	7.565	1.982	0.000	0.913
W2	A3	0.320	0.205	4.392	2.190	0.048	0.125
W2	A4	0.350	0.151	2.060	2.473	0.101	0.024
W2	P1	0.223	0.152	4.799	2.058	0.043	0.150
W2	NC	0.081	0.083	5.100	2.762	0.019	0.334
W3	Height of the individual	0.073	0.026	-7.819	4.086	0.139	0.008
W3	A1	0.169	0.209	2.580	1.101	0.021	0.424
W3	A2	-0.027	0.216	3.749	1.747	0.000	0.900
W3	A3	0.146	0.184	1.985	1.966	0.013	0.431
W3	A4	0.205	0.137	0.180	2.248	0.045	0.140
W3	P1	0.250	0.133	0.188	1.789	0.069	0.065
W3	NC	0.029	0.074	2.558	2.455	0.003	0.692
H1	Height of the individual	0.060	0.026	-2.999	4.018	0.101	0.024
H1	A1	0.343	0.190	4.520	1.004	0.098	0.082
H1	A2	0.181	0.206	4.896	1.669	0.016	0.386
H1	A3	0.237	0.175	3.829	1.870	0.037	0.182
H1	A4	0.303	0.127	1.391	2.094	0.105	0.021
H1	P1	0.227	0.128	3.305	1.729	0.061	0.083
H1	NC	-0.086	0.070	9.178	2.331	0.030	0.227
H2	Height of the individual	0.060	0.028	-0.951	4.398	0.086	0.038
H2	A1	0.428	0.203	6.289	1.071	0.129	0.043
H2	A2	0.370	0.219	5.448	1.774	0.056	0.098
H2	A3	0.404	0.184	4.129	1.972	0.091	0.033
H2	A4	0.389	0.135	2.056	2.220	0.147	0.006
H2	P1	0.251	0.139	5.055	1.875	0.064	0.077
H2	NC	-0.079	0.076	11.039	2.541	0.022	0.303

For definitions, please refer to the footnote of Table 1.

a, intercept (constant); b, coefficient of regression; P, level of significance; r², square of coefficient of correlation known as coefficient of determination; X, independent variable; Y, dependent variable, such as height and width of the cricothyroid membrane.

proportional to the fourth power of the internal radius, thus indicating that a minimal increase in cannula size would result in significant variation in airflow dynamics. Although it is quicker to insert a smaller diameter cannula, earlier and more reliable increases in PaO₂ were achieved only with larger cannulas.⁸ Number 6 tracheostomy tube (which has an internal diameter of 6 mm and an outer diameter of 8 mm) had been suggested by Narrod *et al.*⁴ Larger cannulas might fracture the thyroid or cricoid cartilage and also cause subglottic stenosis.^{2,4,5}

Recommended ET tube size for cricothyroidotomy in south Indian adults

Using the regression formula $Y = bX + a$, tube sizes have been generated for known values of A4 and height of the individual (Table 4). Summarizing Table 4, for A4 values <16 cm, an ET tube size 3.0 can be used; for A4 of 16–18 cm, ET size 4.0 is used; for A4 between 19 and 21 cm, ET size 5.0 is used; and for A4 >21 cm, ET size 6.0 can be used. For height of the individual <135 cm, size 2.0 can be used; between 135 and 149 cm size 3.0

Table 4. Recommended endotracheal (ET) tube size for cricothyroidotomy based on A4

A4 (cm)	H1 (mm)	W2 (mm)	Working area = $\pi(H1/2)^2$ (mm ²)	Maximum outer diameter of tube (mm)	Recommended ET tube size
12	5.027	6.26	19.79	5.0	3.0
13	5.33	6.61	22.31	5.0	3.0
14	5.633	6.96	25.71	5.5	3.0
15	5.936	7.31	27.67	5.5	3.0
16	6.239	7.66	30.56	6.0	4.0
17	6.542	8.01	33.59	6.5	4.0
18	6.845	8.36	36.74	6.5	4.0
19	7.148	8.71	40.12	7.0	5.0
20	7.451	9.06	43.59	7.0	5.0
21	7.754	9.41	47.22	7.5	5.0
22	8.057	9.76	50.76	8.0	6.0

A4, distance between the suprasternal notch and lower border of mandible in passively extended position of neck; H1, height of the exposed membrane in neutral position of neck; W2, middle transverse width of membrane between the cricothyroid muscles.

Table 5. Recommended endotracheal (ET) tube size for cricothyroidotomy based on height of the individual

Height of individual (cm)	H1 (mm)	W2 (mm)	Working area = $\pi(H1/2)^2$ (mm ²)	Maximum outer diameter of tube (mm)	Recommended ET tube size
130	4.81	5.212	18.09	4.5	2.0
135	5.11	5.692	20.50	5.0	3.0
140	5.41	6.172	22.90	5.0	3.0
145	5.71	6.652	25.51	5.5	3.0
150	6.01	7.132	28.27	6.0	4.0
155	6.31	7.612	31.29	6.0	4.0
160	6.61	8.092	34.21	6.5	4.0
165	6.91	8.572	37.39	6.5	4.0
170	7.21	9.052	40.71	7.0	5.0
175	7.51	9.532	44.17	7.5	5.0
180	7.81	10.012	47.90	7.5	5.0
185	8.11	10.49	51.52	8.0	6.0

H1, height of the exposed membrane in neutral position of neck; W2, middle transverse width of membrane between the cricothyroid muscles.

can be used; between 150 and 169 cm size 4.0 can be used; 170–184 cm size 5.0 can be used; for height >185 cm size 6.0 can be used.

Injury to posterior wall of larynx

Puncture of the posterior wall of larynx and oesophagus are reported complications following cricothyroidotomy resulting in the formation of tracheo-oesophageal fistulae.^{3,9} The study showed that depth of subglottic larynx ranged from 13.0 to 25.3 mm; mean was 20.73 ± 1.97 mm in men and 15.62 ± 1.71 mm in women ($P=0.000$). Care should be taken not to incise too deeply while entering the subglottic larynx.

Table 6. Comparison of working dimensions (present Indian study vs. western studies)

Working dimensions	Dover <i>et al</i> ⁸		Present study	
	Male	Female	Male	Female
W1 (mm)	11.6	9.5	11.38	8.66
W2 (mm)	8.8	6.9	8.36	6.11
W3 (mm)	4.5	3.5	3.69	2.83
Hm (mm)	10.9	9.5	6.53	5.74

Hm, height of the exposed membrane in neutral position; W1, upper transverse width of the exposed cricothyroid membrane along the lower border of thyroid cartilage; W2, middle transverse width of membrane; W3, lower transverse width along the superior border of the cricoid cartilage.

Recommended site of procedure

The stab incision is usually made along the lower border of the cricothyroid membrane.³ In massive neck swelling caused by subcutaneous oedema or haematoma, emergency cricothyroidotomy can become very difficult as normal anatomical landmarks get obliterated.¹ Placement of the horizontal skin incision too cephalad or caudad might lead to inadvertent puncture of the thyrohyoid membrane, damage to the thyroid cartilage or tracheal insertion of the airway.³ The present study showed that the distance of the lower border of cricothyroid membrane from sternal notch in neutral position of neck is 5.18 ± 1.76 cm from the sternal notch in men and 4.57 ± 1.55 cm in women ($P=0.461$). In extended neck it is 7.86 ± 1.25 cm from the sternal notch in men and 8.05 ± 1.28 cm in women ($P=0.842$). In the total group, however, the average distance of the cricothyroid membrane from the sternum is about 7.9 cm in extended neck and 5.0 cm in neutral position of neck. The cricothyroid membrane is situated about 1/2 the distance between chin and sternum in neutral position of neck and 1/3 of the distance in extended position of neck. These values become significant when normal anatomical landmarks of neck are impalpable and a blind attempt is warranted to save life.

Conclusions

As working dimension of the cricothyroid membrane is smaller in the south Indian population, ET tubes ranging from size 3.0 to 6.0 have been suggested for use here. Insertion of oversized tubes is known to cause dysphonia, laryngeal damage and subglottic stenosis.^{2,5,10,11} There is scope for further research to validate these findings and observe if there is any variation in size in other ethnic races in Asia.

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Competing interests

There is no competing interest between authors that might pose conflict.

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