THE CLINICAL ANATOMY OF CRICOTHYROID MEMBRANE – ITS RELEVANCE TO EMERGENT SUBGLOTTIC PROCEDURES

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CERTIFICATE

This is to certify that the dissertation on " **THE CLINICAL ANATOMY OF CRICOTHYROID MEMBRANE - ITS RELEVANCE TO EMERGENT SUBGLOTTIC PROCEDURES "** is the bonafide work done by **Dr.IVAN JAMES PRITHISHKUMAR,** in the Institute of Anatomy, Madras Medical College, Chennai - 600 003, during the year 2003 - 2006 under my supervision and guidance in partial fulfilment of the regulation laid down by the **Dr.M.G.R. Tamil Nadu Medical University,** for the degree M.S. Anatomy Branch V, Examination to be held in September 2006.

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<u>CHAPTER ONE - INTRODUCTION</u>

During their clinical training, medical students and residents perform a variety of invasive procedures. Such procedures – even simple needle procedures require a firm grounding in anatomy.

Graney (1996), states that invasive procedures that fail to achieve their objective, or that result in complications, can often be linked to a lack of understanding or misunderstanding of anatomy.

Various authors including the American Association of Clinical Anatomists (1999) have alluded to the crucial role of sound anatomical understanding underlying the safe performance of a clinical procedure.

The **purpose of the present paper** is to **describe one such life saving invasive procedure 'Cricothyroidotomy', in sufficient detail and to illustrate how anatomy forms the basis for its proper performance.**

Although the term '*cricothyroidotomy*' technically means 'vertically incising or splitting the cricoid and thyroid cartilages', and '*coniotomy*' means 'incising the cricothyroid (or conic) ligament' which runs from the cricoid to the thyroid cartilage, the term '*cricothyroidotomy*' is now commonly used to denote the latter procedure. **Cricothyroidotomy** is essentially 'making an opening' ventrally in the cricothyroid membrane as a means of entry into the subglottic larynx below the level of the vocal cords.

Puncture of the cricothyroid membrane is a component of several important clinical procedures; the most important being - **for emergency airway access**. The **other procedures done via the cricothyroid membrane** include giving botox injections into the vocal cord for patients with adductor spasmodic dysphonia, scintigraphic measurement of tracheal mucus velocity in patients with muco-ciliary dyskinesia, transcutaneous teflon and collagen injections into the vocal fold in patients with paralytic dysphonia, retrograde intubation of larynx, intra operative neuro-monitering of the recurrent laryngeal nerve during thyroid surgery, minitracheotomy for clearance of excess tracheobronchial secretions, tracheal ph monitoring in acid reflux associated asthma, and treatment of parkinsonian hypophonia with percutaneous collagen augmentation.

AIRWAY

The term **"airway"** in clinical practice, refers to the upper airway defined as the extra-pulmonary air passage consisting of the nasal and oral cavity, pharynx, larynx, trachea and bronchi.

THE DIFFICULT AIRWAY

Dash H.H(2001) defines the "difficult airway" as a clinical situation in which a conventionally trained anesthesiologist experiences difficulty with mask ventilation, difficulty in tracheal intubation or both. Failure to maintain the airway for more than a few minutes results in brain damage or death. Worldwide, 600 people are estimated to die each year of intubation related difficulties (Westhorpe RN, 1987).

Henderson et al (2004), reports that problems with tracheal intubation were the most frequent causes of anesthetic death in the published analyses of the UK medical defense societies.
A few common **causes difficult airways'** are given below. These include:

a) Severe maxillofacial trauma and midface fractures with distortion of anatomy in whom orotracheal and nasotracheal intubation will be impossible b) Suspected cervical spine injury- in whom cervical manipulation can cause further spinal cord insult. Cricothyroidotomy can be performed without any movement of the cervical spine. (Jorden,1988) c) Severe laryngeal edema of glottis and inlet of larynx e.g.- angioneurotic edema in anaphylaxis secondary to bee sting, snake bite, burns, toxic fumes inhalation injury. d) Upper airway obstruction by foreign body, oropharyngeal bleed, oropharyngeal tumour can make oral or nasal intubation unsuccessful. e) Masseter spasm- following succinyl choline injection during anesthesia

Airway problems may present as an acute life-threatening emergency or as part of the long term management of a chronically ill patient. Establishing an airway is a particularly important skill for emergency medicine clinicians, anesthetists, neonatologists and intensive care physicians. This skill is usually needed without warning as most airway conditions present suddenly and must be dealt with immediately. Failure to maintain the airway for more than a few minutes results in brain damage or death. Establishment of an airway and maintenance circulatory homeostasis are two of the most important goals of intensive care.

Entry into the airway can be made at various points such as through the nasal aperture, mouth or oral cavity, through the cricothyroid membrane or trachea. As such, establishment of an airway is of many types and is based on the need and availability of the situation. This includes **non-surgical airway** procedures such as oro-tracheal or nasotracheal intubation, oro-pharyngeal or nasopharyngeal intubation, and invasive or **surgical airway** procedures such as cricothyroidotomy or tracheostomy.

Orotracheal intubation is the commonest route of airway access in most general surgical procedures, emergency and intensive care management. Using a laryngoscope, the endotracheal tube is advanced into the trachea via the oral route. Oral intubation requires some degree of cervical hyperextension for glottic visualization. Bucholz et al (1979), says that, "…In performing airway maneuvers after acute trauma, one must always consider the possibility of injury to the cervical spine". There can be an occult dislocation, or an unstable fracture that has yet to produce injury to the spinal cord, or an incomplete spinal cord lesion that can be aggravated by uncontrolled manipulation of the neck. This route can also be difficult or contraindicated in patients with maxillo-facial and mandibular fractures, laryngeal fracture, massive oropharyngeal hemorrhage obstructing vision, tumour obstructing the oropharynx, or inhalation of toxic fumes and gases causing laryngeal edema.

Nasotracheal intubation, popularized by Magill (1930) is done by passing an endotracheal tube via the nasal aperture into the trachea. Nasotracheal intubation can be achieved with the head in neutral position. It has several advantages in trauma, requiring no cervical manipulation. It is contra indicated in maxillofacial trauma with instability of the midface severe intranasal disease, suspected fracture of the cribriform plate where a misdirected endotracheal tube may enter the frontal cranial fossa, or a suspected skull base fracture with leak of cerebrospinal fluid leak. Disadvantages of nasal intubation include trauma to the nasal mucosa, nasal septum or turbinates, and retropharyngeal perforation.

SURGICAL AIRWAY ACCESS

Inability to intubate the trachea is a clear indication for creating a surgical airway.

Surgical airway access can be created in the patient by either:

- **A Cricothyroidotomy**
- **A Tracheostomy**

'CRICOTHYROIDOTOMY' - Cricothyroidotomy is a technique used to gain emergency access to the airway by creating an opening ventrally at the level of the cricothyroid membrane.

TYPES OF CRICOTHYROIDOTOMY

Cricothyroidotomy is of two types:

- Needle cricothyroidotomy
- Surgical cricothyroidotomy

Surgical (or stab) cricothyroidotomy is done by a "stab" incision (using a surgical scalpel blade) passing through the skin, subcutaneous tissue and cricothyroid membrane followed by introduction of a larger endotracheal tube or tracheostomy tube into the subglottic larynx.

Needle cricothyroidotomy is done percutaneously by passing a needle through the skin and cricothyroid membrane, followed by introduction of an *'over the needle'* cannula or sheath connected to an oxygen delivering device to maintain ventilation.

Needle cricothyroidotomy is deemed as the only type of surgical airway that is indicated in children younger than 10-12 years simply because the dimensions of the larynx and the cricothyroid membrane are smaller in children. A 12 –or 14 gauge catheter over a needle will support ventilation and oxygenation in a child until a tracheostomy is performed in the operating room.

When compared with tracheostomy, it is faster, simpler, less invasive and less likely to cause hemorrhage. The procedure relies on easily visible landmarks, requires elementary technical skills, a few basic instruments, needs less neck extension than tracheostomy and can be carried out safely outside the operating room in contrast to a tracheostomy that should always be carried out under a controlled environment such as an operating theatre.

The systematic step by step outline of the performance of a needle and surgical cricothyroidotomy by Boon et al (2004) in a 'Clinical anatomy review of cricothyroidotomy' is given below.

NEEDLE CRICOTHYROIDOTOMY

1. Place the patient in supine position
2. Assemble a 12 or 14 gauge over the needle catheter attached to a 5 ml syringe.
3. Surgically prepare the neck using antiseptic swabs.
4. Identify the cricothyroid membrane, between the cricoid cartilage and the thyroid cartilage. Stabilize the trachea with the thumb and forefinger.
5. Puncture the skin in the midline with the needle attached to the syringe, directly over the cricothyroid membrane. Carefully insert the needle through the lower half of the cricothyroid membrane close to the upper border of the cricoid cartilage.
6. Direct the needle at a 45 degree angle inferiorly to avoid injury to the vocal cords, while applying negative pressure to the syringe.
7. Aspiration of air signifies entry into the tracheal lumen.
8. Remove the syringe and advance the catheter while withdrawing the needle, being careful not to injure and perforate the posterior wall of the trachea.
9. Attach the oxygen tubing over the catheter needle hub.

10. Connect to PercutaneousTrans laryngeal Jet ventilation (PTJV).

SURGICAL CRICOTHYROIDOTOMY

1. Place the patient in supine position with the neck in neutral position.
2. Note the anatomical landmarks- palpate the thyroid notch, cricoid cartilage, cricothyroid membrane, sternal notch, and hyoid bone for orientation.
3. Surgically prepare the neck using antiseptic swabs and anaesthetize the area if there is time.
4. Stabilize the thyroid and keep the skin taut in order not to lose the anatomical landmarks.
5. Make a vertical skin incision (2cms) over the cricothyroid space.
6. Locate the cricothyroid membrane and then incise horizontally 1.5 cms (McGill et al., 1982), through the lower half of the cricothyroid membrane in order to avoid the cricothyroid arteries. Make sure only the tip of the scalpel blade enters the airway, to avoid injury to the posterior wall of larynx.
7. Insert the scalpel handle into the incision and rotate it 90 degrees to open the airway. Extend the incision laterally for 1 cm if necessary on each side of the midline.
8. Insert an appropriately sized, cuffed endotracheal tube or tracheostomy tube into the cricothyroid space, directing the tube distally into the trachea. Aim the tube downwards to avoid injury to the vocal cords above. Inflate the cuff in tube.
9. Fix the tube by anchoring sutures to the skin.
10. Connect the tube to an oxygen source and ventilate the patient.
11. Observe bilateral air entry into the lungs by auscultation.

David M.Anderson (1998) states that cricothyroidotomy, whether achieved by the surgical or percutaneous technique is a relatively rapid and safe procedure to obtain an emergency airway in patients, when other methods are contraindicated or impossible to perform. A cricothyroidotomy can be converted to a tracheostomy or to oral endotracheal placement after the acute situation is controlled.

The advantages of a cricothyroidotomy are the speed with which the procedure can be carried out and its safety outside the operating room in contrast to a tracheostomy that should always be carried out under the controlled environment of an operation room.
Mace (1988) states that cricothyroidotomy remains the quickest, safest, and easiest way to obtain an airway where intubation is difficult and is a lifesaving skill where the oral and nasal route of intubation is either impossible or contraindicated. The procedure also requires elementary technical skills, a few basic instruments, and can be performed rapidly (Dover et al., 1996).

There are various anatomical pitfalls and complications of a cricothyroidotomy. A sound visualization of the underlying anatomy is therefore necessary to perform the procedure correctly.

The purpose of the present paper is to present a morphometric analysis of the location and ‘working dimensions’ of the human cricothyroid membrane and to study the various possible ‘structures at risk’ during the performance of a cricothyroidotomy. This study focuses in a systematic way on the various pitfalls and complications of a cricothyroidotomy, linking these to their indispensable anatomical framework.

CHAPTER TWO - AIM AND OBJECTIVES

Aim

The aim of the present study was to determine the location and working dimensions of the cricothyroid membrane in the South Indian subjects and to study the various vascular and soft-tissue structures that could be encountered opposite the cricothyroid membrane (and possibly at risk) during the performance of a cricothyroidotomy.

Objectives

The objectives of the study were to:

1) To determine the average location of the cricothyroid membrane from the suprasternal notch, so that even a blind puncture could be attempted when normal surface landmarks of the neck become impalpable in the presence of a large subcutaneous edema or hematoma of the anterior neck.

2) Determine the average height and width of the cricothyroid membrane between the two cricothyroid muscles.

3) Determine the depth of the subglottic larynx at the level of the upper border of cricoid cartilage, so that posterior penetration of laryngeal wall could be avoided during puncture of the cricothyroid membrane.

4) Determine vascular and soft-tissue structures commonly encountered in the cricothyroid space (opposite the cricothyroid membrane) that are possibly at risk during a cricothyroidotomy.

5) Determine neck parameters such as: lengths of the anterior midline region of neck from sternum to other palpable landmarks such as cricoid cartilage, thyroid notch and

mandible; determine the length of the posterior region of neck from external occipital protuberance to seventh cervical spine; and the circumference of the neck.

6) Determine whether the sex of the individual, stature height, and neck parameters such as lengths of the anterior region of neck, neck circumference and length of posterior region of neck had any statistically significant correlation with the dimensions of the cricothyroid membrane.

7) Draw simple regression equations between the correlated parameters.

8) Suggest a suitable size of a cricothyroidotomy tube for emergency subglottic intubation of larynx in our south Indian population and racial group.

9) Study the histology of the cricothyroid membrane.

CHAPTER THREE – REVIEW OF LITERATURE

ANATOMY OF THE CRICOTHYROID MEMBRANE

The cricothyroid ligament has several alternative names, including cricovocal membrane (International Anatomical Nomenclature committee, 1983, 1989), Conus elasticus (Williams et al.,1989; Sorokin,1988), and Cricothyroid membrane (Williams et al.,1989)

The term "conus", describes this structure when viewed from its front as it resembles an 'inverted cone'. The varied nomenclature is a result of its location and pathway, but the diversity sometimes causes confusion (John Scandalakis, 2004).

Though various authors have mentioned the presence of the cricothyroid membrane in the larynx, the precise attachments to these cartilages, especially to the cricoid, are controversially discussed. Pernkof (1952), states that the membrane is attached by separate layers both to the medial and to the lateral edge of the cricoid; Lanz and Wachsmuth (1955) even deny any attachment of the Conus Elasticus to the cricoid cartilage. They describe the Conus Elasticus as a submucous elastic membrane not connected to the cricoid cartilage. Braus and Elze (1956) state that the conus elasticus is anchored to the entire superior rim of the cricoid cartilage. All the authors mentioned above however agree in that the thickened cranial edge of the lateral part of the Conus Elasticus constitute the vocal cords, extending between the vocal process of each arytenoid cartilage and the thyroid cartilage.

G.M.Wyburn (1964), states that the cricothyroid membrane is an intrinsic ligament beneath the mucous membrane of the larynx. It is a thick band of elastic tissue that connects the thyroid, cricoid and arytenoid cartilages. The anterior part of this membrane is the cricothyroid ligament and the lateral part, lined with the mucous membrane of the larynx is the conus elasticus, directed upwards and medially from the superior margin of the cricoid cartilage. On each side the conus elasticus has a thickened upper free margin – the vocal ligament.

W. Henry Hollinshead, (1968) in his textbook ‘Anatomy for Surgeons’ writes, “ The conus elasticus is a strongly developed layer of elastic tissue arising from the upper border of the arch of the cricoid cartilage sweeping upward and medially. In the anterior midline, a part of this ligament can be seen attaching to the lower border of the thyroid cartilage, and this part alone has been called the cricothyroid or the middle cricothyroid ligament. Most of the cricothyroid ligament, however, projects upward deep to the thyroid cartilage to form the conus elasticus. Posteriorly, the conus attaches to the movable arytenoid cartilage and its vocal processes on each side. Between the thyroid cartilage and the tips of the vocal processes, the conus forms the vocal ligaments. The thyroid and cricoid cartilage are united to each other by the synovial cricothyroid joint. The rotatory action possible at the cricothyroid joint allows to increase or decrease the distance between the thyroid and the upper border of the cricoid cartilage. The posterior portion of the cricothyroid ligament is overlapped externally by the cricothyroid muscle, but anterolaterally it is subcutaneous, and emergent tracheostomies have been made through it.

According to John V. and Charles E., (1984) the cricothyroid membrane is an elastic triangular membrane that arises from the upper border of the cricoid cartilage. The midline portion of the cricothyroid membrane is called the cricothyroid ligament and is sometimes penetrated in a tracheostomy to create an airway below the level of the vocal ligament.

Williams et al (1989) states that the membrane is attached only to the medial edge of the superior rim of cricoid inferiorly.

According to Dover et al (1996) the cricothyroid membrane, or ligament, is seen as a trapezoidal, tough band of tissue extending in the midline from the cricoid cartilage below to the thyroid cartilage above. It should be referred to more specifically as the median cricothyroid ligament, for it is the superficial, thickened anteromedial part of the conus elasticus which lies beneath the laryngeal mucosa. This membrane arises from the arch of the cricoid cartilage and attaches superiorly to the thyroid and arytenoid cartilages. Its free superior margin forms the vocal ligament or cord.

Bennett et al (1996) describes the **'Working dimensions'** of the cricothyroid membrane as the area of the cricothyroid membrane exposed between the medial borders of the two cricothyroid muscles extending in the midline from the cricoid cartilage below to the thyroid cartilage above. This area has also been termed as the cricothyroid space (CS) and is important for several subglottic procedures, including emergent subglottic airway intubation.

Reidenbach (1996) studied the attachment of the cricothyroid membrane in detail making use of histological techniques from plastinated sections of larynx. According to Reidenbach, the conus elasticus as a whole consists of an anterior, and right and left lateral parts, which unite to form a coherent anatomical structure. The anterior midline part is separately defined as the anterior or median cricothyroid ligament and can be seen attaching to the lower border of the thyroid cartilage. This median Cricothyroid ligament (MCL) is attached caudally to the perichondrium of the cricoid arch both at its ventral and dorsal surface. Cranially the ventral fibres of the MCL are anchored to the perichondrium at the ventral edge of the caudal thyroid rim. The dorsal fibres of the ligament join the dorsal perichondrium of the thyroid cartilage upto the insertion of the thyroarytenoid muscle to the thyroid cartilage. The lateral part of the Conus Elasticus is formed by the joining of two separate collagenous layers taking attachment from the perichondrium of the cricoid arch and lamina. The medial fibre layer is continous as the sub-mucous fibroelastic sheet. Between the two sheets is a space of connective tissue, containing conspicuous blood vessels, before they join and form one coherent fibrous sheet. Both the right and left lateral parts reveal a thickened cranial margin each. These cranial edges represent the right and left “vocal ligament” or “vocal cord” (International Anatomical Nomenclature Committee, 1983, 1989; Williams et al., 1989) that extends between the vocal process of each arytenoid cartilage and the thyroid cartilage. The membrane may be pierced by small blood vessels, usually situated at its attachments to the thyroid and cricoid cartilages. The area in front of the cricothyroid membrane has been termed as the cricothyroid space by Reidenbach and is important with regard to surgical procedures, the spread of laryngeal cancer and traumatic lesions of the larynx.

John Scandalakis (2004) in his textbook ‘Surgical anatomy - The embryological and Anatomical basis of modern surgery’ refers to the cricothyroid membrane as a subcutaneous tough band covering the laryngeal mucosa, extending from the cricoid cartilage to the thyroid cartilage and to the vocal processes of the arytenoid cartilage. Its free border forms the vocal ligament. Anteriorly, it is thickened to form the median cricothyroid ligament, the frequent site for establishing an emergency airway.

The 39th British edition of Grays Anatomy (2005) describes the conus elasticus as an intrinsic ligament of the larynx connecting the thyroid, cricoid, and arytenoid cartilages.

DIMENSIONS OF THE CRICOTHYROID MEMBRANE

DIMENSIONS OF CRICOTHYROID MEMBRANE IN ADULTS

Kress and Balasubramaniam (1982) studied the membrane in adult subjects and found that the size of the membrane varies in adults between 22-33 mm wide (beyond the cricothyroid muscles) and 9-10 mm high. This is the total height and total width of the membrane and not it’s working dimensions.

Dover K, Howdieshell TR, Colbora GL (1996) studied the **working dimensions** and vascular anatomy of the cricothyroid membrane in 15 cadaveric specimens. All of them were adult subjects. Nine of the specimens were male (60%) and six were female (40%), with ages ranging from 70 to 92 years.

The results of his study are shown in the **Tables 19A and 19B**:
The average width of the cricothyroid membrane between the two cricothyroid muscles in their study was 8.2 mm at W2 and the average height 10.4 mm in the total group. The average width and height were consistently smaller in females (Females: 6.9mm width and 9.5mm height; Males: 8.8mm width and 10.9mm height).

Bennet JD, Guha SC, and Sankar (1996) studied the anatomy of the cricothyroid membrane in 13 adult fresh cadavers preserved at 45 degree F and examined at 70 degree F. The sex of the subjects was not mentioned. The working dimensions of the cricothyroid membrane were measured for emergency cricothyroidotomy and placement of an airway tube. The vertical measurement ranged from 8-19mm (mean 13.69 +/- SE 0.96mm) and the maximal width between the cricothyroid muscles ranged from 9-19mm (mean12.38 +/- SE 0.52mm).

DIMENSIONS OF CRICOTHYROID MEMBRANE IN CHILDREN

Though cricothyroidotomy is done in children with smaller tubes than in adults, data of dimensions of the cricothyroid membrane has not been documented in children.

David R.Gens (2004), states that needle cricothyroidotomy is deemed as the only type of emergency surgical airway in children younger than 10-12 years simply because the dimensions of the larynx and the cricothyroid membrane is smaller in children. A 12 –or 14 gauge catheter over a needle will support ventilation and oxygenation in a child until a tracheostomy is performed in the operating room. However in adults and children over 10-12 years of age, a surgical cricothyroidotomy is preferred because of larger dimensions.

DIMENSIONS OF CRICOTHYROID MEMBRANE IN NEONATES

Airway management of the neonate remains a cornerstone in neonatal care, which in most cases involves tracheal intubation. However difficult intubations do occur.

Navsa N, Tossel G and Boon JM (2005), department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria, South Africa, studied the dimensions of the neonatal cricothyroid membrane in 27 neonatal cadavers. They said that "Cricothyroidotomy is recognized as an entry point below the vocal cord. This procedure becomes increasingly difficult in young children and is not recommended in children under the age of 5 years". They also said that "Little is known about the anatomy of the neonatal airway, especially the cricothyroid membrane". To remedy this they conducted a study to determine the dimensions of the cricothyroid membrane in neonates.

Twenty seven neonatal cadavers were carefully dissected and the dimensions of the cricothyroid membrane measured with a digital caliper (accuracy 0.01mm). They found that the mean height of the membrane is 2.61 mm (standard deviation: 0.71) and width of 3.03 mm (standard deviation: 0.63). These findings indicate that the dimensions of the cricothyroid membrane is too small for passing a tracheal tube, as dimensions of the tube exceed the dimensions of the membrane. This could fracture the cartilages of the larynx. The researchers concluded that the performance of a surgical cricothyroidotomy with passing of a tracheal tube should be strongly discouraged in neonatal patients.

SURFACE LANDMARKS FOR LOCATION OF CRICOTHYROID MEMBRANE

Mc Gill et al (1982) stress that identification of anatomical landmarks for successful placement of a tube in the cricothyroid space includes the cricoid cartilage, thyroid cartilage, cricothyroid membrane and hyoid bone.

Walls RM (1988), says that knowledge of anatomy of the anterior neck and a specific sequence for performing a cricothyroidotomy will result in a good success rate and acceptable rate of complications.

David M.Anderson (1988) while describing the procedure of cricothyroidotomy says that the cricothyroid membrane is located between the thyroid cartilage and the cricoid cartilage. The cricothyroid membrane can be identified by stabilizing the thyroid cartilage with the thumb and third finger, and then palpating inferiorly approximately 2 cm with the index finger until an indentation is felt. The cricothyroid membrane lies just beneath the skin. The cricoid cartilage is located in the midline, approximately 2 to 3 cm inferior to the thyroid cartilage and is the only circumferential ring in the upper airway.

Piotrowski and Moore (1988), state that the cricothyroid membrane is situated more cephalad in children compared to adults. Because of difficulty in palpating the anatomical landmarks it is better to do a formal tracheostomy in children less than 5 years of age.

Suzanne and Brenda (1992), on describing the puncture of the cricothyroid membrane, say that with the patient in supine position, extend the neck by placing towels beneath the shoulders, and then identify the prominent thyroid cartilage (Adam's apple). Allow the finger to descend in the midline to the depression between the lower border of the thyroid cartilage and the upper border of the cricoid cartilage. This depression represents the cricothyroid membrane. A needle or any sharp instrument is then inserted at a 10- to 20-degree caudal direction in the midline just above the upper part of the cricoid cartilage.

David M.Anderson (1998), states that in children the landmarks are different because the thyroid cartilage does not fuse completely until adolescence. Hence the laryngeal prominence is difficult to palpate. This makes identification of the cricothyroid membrane more difficult but not impossible.

David R.Gens (2004) states that the cricothyroid membrane is located between the thyroid and cricoid cartilages. Both structures are easily palpated. The cricothyroid membrane can be found approximately 1/3rd of the distance from the manubrium to the chin in the midline in a patient with a normal habitus. In a patient with a short, obese neck, the membrane may be hidden at the level of the manubrium. In a patient with a thin, long neck, it may be midway between the chin and the manubrium.

Boon et al (2004) on presenting a clinical anatomy review on Cricothyroidotomy says the anterior midline structures of the neck from superior to inferior are the mandible, floor of the mouth, hyoid bone, thyrohyoid membrane, thyroid cartilage, cricothyroid membrane and cricoid cartilage. The cricothyroid membrane forms the first indentation inferior to the thyroid cartilage. These structures are not always easily palpable but the thyroid notch can be palpated in most patients. The index finger can be slid down on the thyroid cartilage to identify the cricothyroid membrane just inferior to the thyroid cartilage.

William Jay et al (2004) studied a new technique for localizing the cricothyroid space during cricothyroidotomy. The traditional method for locating the cricothyroid membrane is digital palpation. However, in some patients identification of the membrane with digital palpation is difficult. A study was done to investigate the utility of a handheld ultrasonography device to locate the level of the cricothyroid membrane on fresh cadavers and confirm this level with surgical dissection. Handheld ultrasonography (SonoSite 180) was performed on 16 fresh non-embalmed cadavers and a 10-mghz probe was placed on the anterior aspect of the neck, in the midline, just below the mandible. The handheld ultrasonography technique accurately identified the level of the cricothyroid membrane in 11 of 14 (79%) cadavers. The results of this pilot study suggested that ultrasonography may be useful for the identification of the level of the cricothyroid membrane.

STRUCTURES AT RISK DURING CRICOTHYROIDOTOMY

1. **ARTERIES**

E.W.Walls (1964) in the Cunningham textbook of anatomy describes the cricothyroid artery as a branch of the thyroid artery given in the muscular triangle. The cricothyroid branch passes forwards across the cricothyroid muscle to anastomose in front of the cricothyroid ligament with its fellow of the opposite side.

Safer and Penninckx (1967), report a case of bleeding from the cricothyroid artery during an attempt at cricothyroidotomy.

Donald and Bernstein (1975) present a case in which a patient experienced an acute, brisk, endolaryngeal hemorrhage following an attempt at translaryngeal aspiration of tracheobronchial secretions though the cricothyroid membrane. The bleeding was probably due to injury of one of the vessels running in the submucosal area of the larynx in the region of the cricothyroid membrane. The endolaryngeal arteries in the submucosa of the larynx anastomose with the cricothyroid arteries via a perforating branch. The bleeding was probably due to injury of the perforating branch of the cricothyroid artery or vein.

Fatal airway hemorrhage has also been reported by Unger and Moser (1973) following trans-tracheal needle aspiration and cricothyroidotomy. The cricothyroid artery was lacerated with its freely bleeding transected ends forced into the lumen of the airway resulting in endobronchial hemorrhage and asphyxsia.

Fatal airway hemorrhage after cricothyroidotomy has also been reported by Schillaci et al (1976), with laceration of the cricothyroid artery with resultant endobronchial bleeding and asphyxia. Autopsy showed that this patient had a larger than normal cricothyroid artery coursing horizontally across the mid-portion of the membrane.

McGill et al (1982), refers to a case of fatal airway hemorrhage followed by aspiration when the cricothyroid artery was disrupted.

Lippert et al (1985) says that the cricothyroid artery usually arises from the superior laryngeal branch of the superior thyroid artery and commonly has rich anastomoses with the superior laryngeal artery deep to the thyroid lamina. In 5% of cases, the cricothyroid artery may totally replace the superior laryngeal artery.

Little et al (1986) dissected 34 adult cadavers and studied the vasculature of the area anterior to the cricothyroid ligament. They reported that twenty seven cadavers (79%) had vascular structures within this area and twenty one (62%) had vertically oriented arteries or veins that would be at risk during cricothyroidotomy.

Bergmann et al (1988) also states that the cricothyroid artery usually arises from the superior laryngeal branch of the superior thyroid artery.

Walls (1988) states that since the cricothyroid artery courses through the upper part of the membrane (closer to the thyroid cartilage) it is recommended to make the incision in the lower half of the cricothyroid membrane along the superior border of the cricoid cartilage. The incision should not be made alongside the inferior border of the thyroid cartilage.

Williams et al (1989) in the British edition of Gray's Anatomy state that the cricothyroid artery crosses the superior portion of the median cricothyroid ligament.

Dover et al (1996) in his landmark study of the cricothyroid membrane reports on the cricothyroid artery arising from the superior thyroid artery in 93% of 15 cases studied. Latex injection of the carotid artery demonstrated a transverse cricothyroid artery arising from the superior thyroid artery in 93% of cases. In 13 of the 15 cadavers (87%), the superior thyroid artery originated from the external carotid artery. In two cadavers, both male, the superior thyroid artery originated from the common carotid artery. A transverse cricothyroid artery was identified in 14 cadavers (93%), originating from the superior thyroid artery. The cricothyroid artery coursed across the upper one-third of the cricothyroid membrane in 13 specimens (93%) and across the lower portion in one cadaver. Unilateral superior thyroid artery injection demonstrated anastomoses between right and left cricothyroid arteries. Occasionally, two enlarged cricothyroid arteries anastomosed in the midline giving origin to a median descending artery supplying a pyramidal thyroid lobe. Several branches of the cricothyroid artery supplied the strap muscles, while others penetrated the cricothyroid membrane and ascended along the undersurface of the thyroid cartilage to supply the laryngeal mucosa. The cricothyroid artery usually crosses the upper half of the ligament. In performing a cricothyroidotomy, this small artery can be lacerated inadvertently and hence it is preferable to enter the airway through the lower part.

Bennett et al (1996), in his study of 15 subjects reported eight subjects (62%) who had an artery running transversely across the cricothyroid membrane.

Reidenbach (1996) studied the histology of the cricothyroid membrane and found that the membrane may be pierced by small blood vessels, usually situated at its attachments to the thyroid and cricoid cartilages.

David M. Anderson (1998), states that there are no major vascular or neural structures in the area of the cricothyroid membrane. He says that the left and right cricothyroid arteries arise from the left and right superior thyroid arteries. They anastomose to form the arterial supply to the area across the superior aspect of the membrane.

Wang et al (1998) found that the blood supply to the strap muscles particularly sternohyoid and superior belly of omohyoid consistently arose from a branch of the superior thyroid artery most commonly terminating in the cricothyroid membrane.

Sato et al (2002) investigated cricoid area using computer graphics and its histological structure and pathology were studied using whole organ serial sections. They found that the cricoid area was found to have adipose tissue, loose elastic and collagenous fibres. Many vessels were present in the cricoid area and a superficial branch of the cricothyroid artery ran through it. Vessels in the cricoid area penetrated the anteroinferior portion of the conus elasticus and extended into the prelaryngeal region.

Boon et al (2004) states "…the cricothyroid artery usually arises from the superior laryngeal artery, a branch of the superior thyroid artery. The right and left cricothyroid arteries trasverse the superior part of the cricothyroid membrane and have not been found to be clinically significant for the procedure. He says that in most specimens the artery crossed the upper half of the cricothyroid membrane. The artery gives off branches, which penetrate the membrane and then run superiorly toward the thyroid cartilage. Occasionally two cricothyroid arteries anastomosed in the midline to form the median descending artery supplying the pyramidal lobe of the thyroid gland. Boon et al also state that there are no major arteries, veins or nerves in the area of the cricothyroid membrane. Major anomalous vessels do not overlie the cricothyroid membrane. The common carotid artery and internal jugular vein lie posterolateral to the cricoid cartilage and staying in the midline will prevent injury to these structures.

David R. Gens (2004) states that the only vascular structure that may be injured during the course of a properly performed cricothyroidotomy is the thyroid ima artery, a branch of the aorta that runs up to the thyroid gland in the midline and infrequently reaches the level of the cricothyroid membrane. Arterial bleeding can be from the thyroid ima artery or from a small artery at the base of the cricothyroid membrane.

Ortug G et al., 2005, studied the clinical implication of the dimensions and vascular anatomy of the cricothyroid space in the Turkish population. The study was done on 5 women and 45 men autopsy materials in the criminal lab in the Ministry of Justice, Istanbul, to establish the topographic distribution and the number of perforating vessels in the Turkish population. Superficial vascular structures of the cricothyroid membrane at Cricothyroid space and their foramens into the intralaryngeal area were studied. In 50 cases, a total of 180 vessels were seen; 78 were situated in the mid-line, 53 vessels were at the right side, and 49 vessels were at the left side. They also found that in 20 of the specimens, the vessels were passing through foramens in the membrane into the intralaryngeal area. Since this area is important with regard to surgical procedures, spread of laryngeal cancer, and traumatic lesions of the larynx, it was stated that the clinical and surgical importance of the vascular anatomy and the dimensions of the cricothyroid space should be given importance.

2. VEINS

Krausen AS (1976) found in a cadaver based study on 10 embalmed head and neck specimens that 6 of the 10 cases showed large tributaries of the inferior thyroid vein overlying the cricothyroid membrane. He says, the inferior thyroid veins and their multiple tributaries are the ultimate guardians of the cervical trachea. This plexus of veins is consistently encountered during low tracheostomy. Even cricothyroidotomy is potentially complicated by hemorrhage subsequent to a tear in a tributary of the inferior thyroid venous system. He states that an awareness of such anatomical considerations should result in safer surgical procedures.

Dover et al (1996) in his landmark study of the dimensions and structures related to the membrane, found that in the subcutaneous tissue, paired anterior jugular veins crossed the membrane in a vertical direction in the majority of specimens. He also found numerous venous tributaries of the superior and inferior thyroid veins crossing the cricothyroid membrane in 80% of 15 dissections. Deep to the sternohyoid muscles, he found that small veins from the region of the thyroid isthmus traversed the cricothyroid membrane, followed the cricothyroid and superior thyroid arteries, and drained into the internal jugular vein. He also suggests that wound bleeding due to injury of the anterior jugular vein or anterior branch of the superior thyroid artery is possible following a horizontal skin incision.

Brofeldt et al (1996) reports on bleeding from the anterior jugular veins in one patient during a cricothyroidotomy which was controlled without any problem.

David M.Anderson (1998) says that superficial veins arising from the superior and inferior thyroid vein and the anterior jugular systems are encountered in the area of the cricothyroid membrane.

David R.Gens (2004) feels that venous bleeding after puncture of the cricothyroid membrane almost always occurs from small veins and usually stops spontaneously. Usage of a vertical neck skin incision decreases the chance of bleeding.

Boon et al (2004) states that the anterior jugular vein runs in a vertical fashion in the lateral aspect of the neck and should be uninvolved if one stays in the midline. Narrod et al (1985) and Walls (1988), recommend an initial vertical incision of the skin and cervical fascia to avoid these vascular structures laterally. Thereafter the cricothyroid membrane is incised horizontally.

3. SOFT TISSUE STRUCTURES

Pyramidal lobe of thyroid

Blumberg NA (1981) when studying thyroid glands during surgery in 17 patients and the records of a further 53 patients found that the pyramidal lobe was found in 65%. He therefore regarded the pyramidal lobe as a normal component of the thyroid gland and not a congenital abnormality.

Levy et al (1982), on studying the incidence of the pyramidal lobe on gamma camera pertechnetate and radioiodine thyroid scans found that 17% of normals had a pyramidal lobe on the scans.

Siraj et al (1989) studied thyroid scintigraphs in 207 Pakistani patients with a view to investigate the anatomical origin of the pyramidal lobe. The pyramidal lobe was visualized in 41% of the cases, with a greater incidence among females as compared to males.

Harjeet et al (2004) studied the shape of the thyroid gland and its extension as the pyramidal lobe in 410 male and 160 female adults from Chandigarh, India. The incidence of the pyramidal lobe was 28.9% in adults.

Boon et al (2004), states that the thyroid gland has a pyramidal lobe in 40% of people. This lobe may extend as high as the hyoid bone and therefore may be at risk of injury when performing a cricothyroidotomy. This lobe is usually situated to the left of the midline.

Levator Glandulae Thyroidae

Harjeet et al (2004) studied the attachments of levator glandulae thyroidae in 410 male and 160 female adults from Chandigarh, India. The incidence of the levator glandulae thyroidae was 19.5% in adults.

Posterior Laryngeal Wall

Carter DR, Meyers AD (1978), together with 50 head and neck surgeons defined the boundaries of the subglottic larynx. The larynx of 50 adult cadavers was removed and measured. The results revealed significantly smaller subglottic dimensions for women than for men.

The American Association of Clinical Anatomists (1999) on explaining the procedure cricothyroidotomy wrote that if the scalpel blade penetrates too deeply into the infraglottic cavity, it should be prevented from entering the laryngopharynx by the wide, posterior lamina of the cricoid cartilage.

Boon et al (2004), states that the airway is narrow in a child. This makes posterior penetration of the tracheal wall much more likely in the child and infant.

ANATOMICAL PITFALLS OF THE PROCEDURE

The anatomically relevant complications of a cricothyroidotomy are minor compared to the catastrophic morbidity associated with failure to secure an airway.

However the anatomically relevant complications are as follows:

Inability to palpate surface neck landmarks

David M.Anderson (1988) while describing the procedure states that the thyroid cartilage is prominent in men and in thin patients and thus easy to palpate, but in children, women and obese patients, and those with neck edema or hematoma, the structures can be difficult to identify. In children the landmarks are quite different because the thyroid cartilage does not completely fuse until adolescence. In them, the hyoid bone and cricoid cartilage are more prominent structures in the neck. This makes identification of the cricothyroid membrane more difficult but not impossible.

Stewart (1989), states that the anterior midline structures of the neck are not always easily palpable but the thyroid notch can be felt in most patients.

Leibovici et al (1996), from the Hadassah University Hospital, Jerusalem, assessed the efficacy of pre-hospital cricothyroidotomy performed by military physicians during a 3.5 year period. 26 were performed, of which 23 were successful (88.4%). Failures were due to poor anatomic identification of the cricothyroid membrane. He stated that since cricothyroidotomy is a life saving procedure, it should be a part of the armamentarium of any physician.

Boon et al (2004), in his clinical anatomy review states, "…in massive neck swelling caused by subcutaneous edema or hematoma, emergency cricothyroidotomy can be very difficult as normal anatomical landmarks get obliterated".

Henderson et al (2004), mentions that Cricothyroidotomy is sometimes particularly difficult in the obese patient, and can be facilitated by passage of an introducer or use of a tracheal retractor.

Relevance of dimensions of the Cricothyroid membrane in cricothyroidomy

Dover et al (1996), reported on the dimensions of the cricothyroid membrane in a study of 15 cadaver specimens. The average width of the cricothyroid membrane between the cricothyroid muscles was 8.2 mm and the average height 10.4 mm. Based on this study the American Association of Clinical Anatomists (1999) stated that the outer diameter of the endotracheal tube should therefore not exceed 8 mm, and recommended an inner diameter of at least 5mm to provide good airflow. Smaller cannulas are easier to insert, but the narrower the internal diameter, the more resistance to air flow. A larger cannula may fracture the thyroid or cricoid cartilage.

McGill et al (1982), reports a case where a longitudinal fracture occurred through the thyroid cartilage, causing severe dysphonia when an oversized tube was passed through the cricothyroid membrane. The tube had an outer diameter of 12 mm. This is 3mm larger than the average height of the cricothyroid membrane (9-10 mm studied by Kress and Balasubramaniam, 1982).

Intra and postoperative bleeding

As mentioned earlier, numerous arteries and veins are reported in front of the cricothyroid membrane that could bleed if punctured during a cricothyroidotomy.

Vocal cords

Walls (1988), states that the cords are situated superiorly about 1 cm above the site of incision. The tube should be aimed downward in order not to injure the vocal cords.

Suzanne and Brenda (1992) describe how once the cricothyroid membrane is identified a needle or any sharp instrument is inserted at a 10- to 20-degree caudal direction in the midline just above the upper part of the cricoid cartilage to avoid injury to the vocal cords above.

Bennett et al (1996) demonstrated in a cadaver study that the mean distance from the upper border of the cricothyroid membrane to the vocal cords was 9.78mm.

David M.Anderson (1998) on describing a cricothyroidotomy mentions that during a needle cricothyroidotomy, the membrane is punctured by approaching at a 30-45 degree angle in a caudal direction to avoid injury to the vocal cords above.

Anterior cervical fascia

Simon (1983), state that injury of this fascial layer may cause soft tissue edema to develop and make location of the cricothyroid membrane extremely difficult.

Injury to the pyramidal lobe of thyroid gland

Boon et al (2004), says that this lobe may extend as high as the hyoid bone and therefore may be at risk of injury when performing a cricothyroidotomy. He says that caution should be taken not to incise the thyroid isthmus or the pyramidal lobe of the thyroid gland as they are highly vascular structures.

Incision over the Thyrohyoid space

McGill et al (1982) studied the complications of 38 emergency cricothyrotomies done over a 3 year period. 14 immediate complications occurred (32%), of which the most frequent was incorrect placement of the tube through the thyrohyoid membrane.

Subglottic stenosis

Sise (1984), states that the risk of subglottic stenosis is reported to be higher in children and adolescents. The mucosa is more fragile, looser, and softer, making edema and laceration more likely and thus cause subglottic stenosis.

Boon et al (2004), states that subglottic stenosis following cricothyroidotomy is reported most frequently in long term cricothyroidotomy subjects. It is rare in tracheostomy. This condition is caused by mucosal damage due to a tube eroding the mucosal surface by excessive cuff pressures, frequent tube movement and rigid tubes. This is seen more frequently when large bore tubes are used. Subglottic stenosis was found to be more frequent if cricothyroidotomy was done in those with pre-existing laryngeal diseases such as diptheria, tuberculosis and ludwigs angina.

Dysphonia and Hoarseness

Dysphonia and hoarseness due to damage of the vocal cords following a cricothyroidotomy has been reported by several people.

Boyd et al (1979), reports that hoarseness is due to a small amount of granulation tissue formed below the vocal cords after cricothyroidotomy.

John V. and Charles E. (1989) state that damage to the cricothyroid membrane can cause changes in the vocal ligaments resulting in changes of the vocal quality of voice.

Bennett et al (1996) reports that dysphonia can occur secondary to a tracheal fracture, usually due to an insertion of an oversized tube. It may also be the result of cutting the vocal cords, especially if the incision is made close to the thyroid cartilage. The incision should be made along the superior border of the cricoid cartilage.

Posterior Laryngeal perforation

Jorden(1988) and Miklus et al (1989) suggest that perforation of the esophagus and formation of a tracheo-esophageal fistula is a theoretical complication of cricothyroidotomy. David M Anderson (1998), states that overzealous insertion of a tracheostomy tube into the cricothyroid space may lead to creating a false passage, posterior tracheal perforation or esophageal perforation.

David R Gens (2004), reports that inadvertent perforation of the esophagus or back wall of the trachea or larynx is infrequent.

Boon et al (2004), suggests that care should be taken not to incise or push the needle too deeply after entering the infraglottic cavity. He also stated that the airway is narrow in a child. This makes posterior penetration of the tracheal wall much more likely in the child and infant.

Recurrent laryngeal nerve palsy

Boon et al (2004) in his clinical anatomy review comments that the nerve lies between the trachea and the esophagus at the level of the cricoid cartilage. Therefore staying in the midline and taking care not to injure the posterior wall of the subglottic airway will ensure avoidance of these nerves.

David R. Gens (2004), reports that laceration of the trachea, esophagus or recurrent laryngeal nerves is extremely rare and is due to inadequate knowledge of the anatomy of the neck.

Thyroid cartilage fracture

McGill et al (1982), reports a case where a longitudinal fracture occurred through the thyroid cartilage, causing severe dysphonia when an oversized tube was passed through the cricothyroid membrane. The tube had an outer diameter of 12 mm. This is 3mm larger than the average height of the cricothyroid membrane (9-10 mm studied by Kress and Balasubramaniam, 1982). Various authors (McGill et al., 1982; American association of Clinical Anatomists, 1999), advice that the outer diameter of the tube should not be more than 8 mm.

Boon et al (2004), state that laryngeal damage may occur due to an oversized tube being forced through the relatively small cricothyroid space.

Children

Dover et al (2004), in his landmark study reports that the height of the cricothyroid membrane is not as high as in the adult (3mm in infants as compared to 9-10 mm in adults). Only a needle cricothyroidotomy is indicated for children less than 10 years. The airway is narrow in a child. This makes posterior penetration of the tracheal wall much more likely in the child and infant.

PROCEDURES REQUIRING PUNCTURE OF THE CRICOTHYROID MEMBRANE

1) **For Emergent Airway Access** - Cricothyroidotomy is done in certain emergency situations in which endotracheal intubation and tracheostomy are either not possible or contraindicated.

2) **Botox Injections For Patients With Adductor Spasmodic Dysphonia** – Rubin et al (2004), injected Botulinum toxin type A (Botox) injections into both thyroarytenoid

muscles via the cricothyroid membrane to treat patients with adductor spasmodic dysphonia to improve the voice related quality of life (V-RQOL).

3) **Transcricothyroid Injection Of Local Anesthetic –** Wong and McGuire (2000), did a study of transcricothyroid injection of a local anesthetic (lidocaine), into the larynx as airway topical anesthesia to perform awake intubation of patients.

4) Yamaguchi et al (1996), inserted a catheter through the cricothyroid membrane in two patients with a pulmonary fungus ball of aspergillosis to administer an anti-mycotic into the fungus ball.

5) **Injection Of Collagen And Teflon Into Vocal Fold** - Patients having malignant chest diseases sometimes suffer from vocal fold paralysis. Sagawa et al (1999), describes how using a long needle, collagen is injected through the cricothyroid membrane into the vocal fold to improve function. It has been estimated that more than 70% of patients with Parkinson disease experience voice and speech disorders. Berke et al (1999) showed how collagen augmentation demonstrated satisfactory improvement in 75% of patients. Ward et al (1985),McCaffrey T.B and Lipton R (1989), describe a transcricothyroid teflon augmentation of the vocal cord in patients with paralytic dysphonia.

6) **Intra Operative Neuro Monitering Of The Recurrent Laryngeal And Vagus Nerves** during surgery– This system consists of a stimulation circuit in which bipolar hook wire electrodes are inserted percutaneously through the cricothyroid membrane and placed on the thyroarytenoid or vocalis muscle. It is found to be safe and is advocated by various authors like Severtson et al (1997), Kienast et al (1998) and Kunath et al (1999) and is reliable.

7)**Minitracheotomy**- Wain et al (1990), Balkan et al (1996) and Hess D.R (2005) describe it as a simple percutaneous technique in which a small bore tube of 4.0mm internal diameter is inserted via the cricothyroid membrane to remove excess secretion or aspirated material from the tracheobronchial tree in patients with sputum retention and atelectasis . It can also be used for adminstration of oxygen. It avoids the disadvantages of conventional tracheostomy and endotracheal intubation.

8) **Tracheal Ph Monitoring In Acid Reflux Associated Asthma** –Donnely et al (1993) from the Cardiothoracic Centre, Liverpool, UK, reports a new technique for simultaneous tracheal and esophageal pH monitoring in patients with acid reflux associated asthma.

Tracheal pH is measured using a pH electrode introduced through the cricothyroid membrane. A standard esophageal pH electrode is placed in the usual position. Patients with acid aspiration show a tracheal pH less than 5.5.

9)**Electromyography Of Posterior Cricoarytenoid (PCA) Muscle** - Mu LC and Yang SL (1990), developed a method of needle electrode placement in the posterior cricoarytenoid (PCA) muscle by inserting a needle electrode through the cricothyroid membrane and penetrating the lamina of the cricoid cartilage to reach the PCA muscle. This has been used to diagnose more than 1200 cases of laryngeal motor disorders.

HISTOLOGY OF THE CRICOTHYROID MEMBRANE

Lanz and Wachsmuth (1955), describe the Conus Elasticus as a submucous elastic membrane.

G.M.Wyburn (1964), describes the conus elasticus as a fibro-elastic membrane containing a thick band of elastic tissue connecting the thyroid, cricoid and arytenoid cartilages.

Hollinshead (1968), describes the conus elasticus or cricothyroid membrane as a strongly developed layer of elastic tissue.

Reidenbach (1996), on studying the histology of plastinated sections of the larynx says that the cricothyroid membrane is composed of densely arranged collagen fibres. She also says that it may be pierced by small blood vessels, near its attachment zones to the thyroid and cricoid cartilage.

According to Dover et al (1996), the cricothyroid membrane is a dense fibro elastic trapezoidal membrane with ventral densely arranged fibres bordered laterally by the cricothyroid muscles. Sato et al (2002), investigated the three- dimensional distribution of the cricoid area using computer graphics and also studied the histological structure and pathology using whole organ serial sections. The cricoid area was found to have adipose tissue, loose elastic and collagenous fibres.

CHAPTER FOUR - MATERIALS AND METHODS

MATERIALS

The study was performed in the Institute of Forensic Medicine, Government Madras Medical College and Research Institute, Chennai, India on 50 fresh adult non-formalin-fixed human postmortem cadavers (37 males, 13 females), who had died within 24 hours before the examination. Cadavers of four children and ten neonates were also studied. The subjects were all South Indians. The anterior neck was normal and had no injury or disfigurement. Cadavers of children were collected from the Institute of Forensic Medicine, Madras Medical College and Research Institute, Chennai. The neonatal specimens were obtained from the Institute of Obstetrics and Gynaecology, Egmore, Chennai and the Christian Medical College and Hospital, Vellore.

METHODS

Identification of anatomical landmarks

Midline of the neck extends from the chin to sternum. The anterior midline structures of the neck (in order from superior to inferior) are: Mandible, floor of the mouth, body of the hyoid bone, thyrohyoid membrane, thyroid notch, laryngeal prominence, cricothyroid membrane, rounded arch of the cricoid cartilage, crico-tracheal ligament and the upper rings of the trachea which are partly masked by the isthmus of the thyroid gland. They are not always easily palpable but the thyroid notch is palpable in most subjects. Once the thyroid notch is identified, the finger is allowed to run down the midline to a depression between the lower border of the thyroid cartilage and the upper border of the cricoid cartilage. This depression represents the cricothyroid membrane. This region between the inferior border of the thyroid cartilage and the superior rim of the cricoid arch connected by the cricothyroid membrane and partly covered by the cricothyroid muscles ventrolaterally has been termed the cricothyroid space (CS) by Reidenbach MM,(1996) and is important with regard to surgical procedures, spread of laryngeal cancer and traumatic lesions of the larynx. The cricoid cartilage is located approximately 2 to 3 centimeters inferior to the thyroid cartilage, and is the only prominent circumferential ring in the upper airway. The hyoid bone is palpable in the midline superior to the thyroid cartilage.

Dissection

Anatomical dissection was done in the infrahyoid region of the anterior neck. An I-shaped incision was made on the skin of the front of neck between the hyoid bone and sternum and the skin carefully reflected on either side. The superficial fascia was inspected. Vascular structures if any and platysma if found within the fascia was identified and noted. The investing layer of the deep cervical fascia was identified and opened carefully with a scalpel and fine scissors. Infra hyoid group of strap muscles was identified. Vascular and soft-tissue structures found between the investing layer and pretracheal layer of the deep cervical fascia was identified and noted. The pretracheal fascia was then opened. The Vascular and other soft-tissue structures in the cricothyroid space (closely related in front of the cricothyroid membrane) were identified, noted and then gently removed. The cricothyroid membrane was then identified in the interval between the cricoid and thyroid cartilages. The membrane was cleaned between the two cricothyroid muscles. The working dimensions of the cricothyroid membrane were then measured i.e. the area between the cricothyroid muscles laterally, the inferior border of thyroid cartilage superiorly and the superior rim of cricoid cartilage inferiorly. Because the exposed portion of the membrane is actually trapezoidal in shape, wider above than below, measurements included the width at three levels. The cricothyroid membrane was then cut along its inferior and superior attachments, removed from the body and its thickness measured using a vernier caliper. The depth of the larynx at the level of the upper border of the cricoid cartilage was measured using a vernier caliper. The cut cricothyroid membrane was then stored in 5% formalin solution and used for histological study.

Measurement

The age in years and gender of the individual was noted from official forensic records.

The stature height of the individual was measured in centimeters using a measuring tape.

The circumference of the neck was measured at the level of the thyroid notch using a measuring tape.

The positions of the following palpable landmarks of neck – cricoid cartilage, thyroid notch, and mandible were noted, and their distance from the sternum was measured as follows.

1. A1- Length of the neck in the anterior midline between the suprasternal notch and mandible in extended position of the neck (A1) in cm.
2. A2- Length of the neck between the suprasternal notch and thyroid notch in extended position of the neck (A2) in cm.
3. A3- Length of the neck between the suprasternal notch and upper border of the cricoid cartilage in extended position of the neck (A3) in cm.
4. A4- Length of the neck between the suprasternal notch and upper border of the cricoid cartilage in neutral position of the neck (A4) in cm.
5. P1- Length of the posterior neck from the external occipital protuberance to the seventh cervical spine in neutral position of the neck (P1) in cm.
6. W1- Upper transverse width of the cricothyroid membrane between the cricothyroid muscles along the lower border of thyroid cartilage (in mm). Because the exposed portion of the membrane is actually trapezoidal in shape, wider above than below, measurements included the width at three levels.
7. W2- Middle transverse width of the cricothyroid membrane between the cricothyroid muscles (in mm)
8. W3- lower transverse width of the cricothyroid membrane between the cricothyroid muscles along the superior border of the cricoid cartilage (in mm).
9. H1- Height of the cricothyroid membrane in extended position of neck (in mm).
10. H2- Height of the cricothyroid membrane in neutral position of neck (in mm).

11. TM- Anteroposterior thickness of the cricothyroid membrane (in mm).

12. DL- Anteroposterior depth of the subglottic larynx at the level of the upper border of cricoid cartilage, between the outer rim of the upper border of cricoid cartilage and posterior wall of the larynx (in mm).

Measurements W1, W2, W3, H1 and H2 were done using a divider and vernier caliper, whereas TM and DL was measured using the vernier caliper alone.

Vascular and soft-tissue structures at risk of injury present in the cricothyroid space were noted and percentage of incidence was calculated.

Analysis

In the adults, the measured parameters were statistically analyzed. The range, mean and standard deviation was calculated for each parameter. Male and female values were compared by Student's t-test to see if there was any significant difference between the sexes, for example: if the height or width of the cricothyroid membrane, or the depth of larynx, was significantly different between the male and female subjects. The sex, age, height and neck parameters were statistically correlated with the dimensions of the cricothyroid membrane to see if there was significant association between them. For example, if stature height, length of anterior neck, or circumference of the neck of the individual correlates with the height or width of the cricothyroid membrane. Simple regression analysis was made for dimensions of the cricothyroid membrane against height and neck parameters. A regression co-efficient was then derived and regression equations were made.

In children and neonates, the dimensions of the membrane, depth of larynx and location of cricothyroid space were statistically analyzed. The range, mean and standard deviation were calculated. Vascular and soft-tissue structures at risk of injury were noted.

Histology and Photomicrography

Histological studies were done at the Dr.A.L.Mudaliar PostGraduate Institute of Basic Medical Sciences, Taramani, Chennai. The cricothyroid membrane was cut and removed from the cadaver, transferred in 5% formalin solution and later fixed in 5%formalin saline. Fixed tissues were impregnated and embedded in paraffin wax. Ribbon sections were done using a rotatory microtome at 6-10 Armstrong thickness. Staining was done by 3 methods:

- Routine Haematoxylin and Eosin stain
- Mallory's Trichrome stain specific for connective tissue.
- Special stain – by Verhoeff's method specific for elastic and collagen fibres.

Verhoeff's method is as follows:

Staining solution- this is prepared from

Stock 5% alcoholic hematoxylin …… 20 ml

10% ferric chloride …………………..8 ml

Verhoeffs iodine (Iodine 2g, potassium iodide 4g, water 100ml)… 8 ml

This should be freshly prepared, and the solutions added to a flask in the order given.

Method:

1. Stain for 15 – 30 minutes until sections are jet black.
2. Differentiate in 2% ferric chloride solution until elastic fibres are clearly seen; rinse in water and examine under the low power of a microscope. If overdifferentiated, sections maybe restained.
3. Wash in water, then in 95% alcohol to remove iodine staining.
4. Wash in water for 5 minutes.
5. Counterstain with Van Gieson's stain for 3 minutes.
6. Dehydrate, clear and mount.

<u>Results expected</u>:

Elastic fibres and nuclei ……… Black to blue black

Cytoplasm and muscle ………. Yellow

Collagen ……………………… Red

Photomicrography was done at 2X, 4X, 10X and 40 X magnifications.

CHAPTER FIVE – OBSERVATION OF THE STUDY

Results of the study are divided into 4 sections:

SECTION 1 – ANALYSIS IN ADULTS

SECTION 2 – ANALYSIS IN CHILDREN

SECTION 3 – ANALYSIS IN NEONATES

SECTION 4 – HISTOLOGY OF THE CRICOTHYROID MEMBRANE

SECTION 1 – ANALYSIS IN ADULTS

37 male and 13 female fresh cadavers were examined. The age group ranged from 17 to 83 years with a mean age of 38.97 years in males and 48.46 years in females. The height of the subjects ranged from 135 to 179 centimeters with a mean height of Male 158.60 cm in males and 138.50 cm in females.

The study showed the following results:

Table 1 shows the descriptive statistics in the total adult group. 'N' refers to the total number of adult subjects = 50; the minimum and maximum range, range statistic, the mean statistic, standard error of mean and standard statistic for each parameter is given.

Table 2 shows the group statistic for adults, gender wise for N = 37 male and 13 female subjects. The mean, standard deviation and standard error of mean were also calculated. Results show that observed values are different in male and female subjects in most parameters. These differences in values are later compared by student t-test to check for significance in differences.

Table 3 gives a simplified version of the measured parameters sexwise in adults (37 male and 13 female). It shows the range, mean, standard deviation and 'p' value. **Student t-test** was done to verify if there is any significant difference between observed values between male and female subjects. Student t-test is a statistical test of significance to prove if there is any significant difference between two groups of observed values or people groups. 'P' values greater than 0.05 show that there is no significant difference in the observed values between males and female subjects, whereas a 'p' value less than 0.05 shows that a significant difference exists in the observed values between male and female subjects.

A) DIMENSIONS OF CRICOTHYROID MEMBRANE IN ADULTS

Width and height of the working dimensions of cricothyroid membrane were measured using a divider and vernier caliper.

Since the exposed portion of the membrane is actually trapezoidal in shape, wider above than below, measurements included the width at three levels.

Height of the cricothyroid membrane was measured in both neutral position and extended position of neck. Tables 4a and 4b show the working dimensions of the cricothyroid membrane in adults.

TRANSVERSE WIDTHS OF THE CRICOTHYROID MEMBRANE

Table 4a shows the dimensional width of the membrane at three levels gender wise in the adult group. 'W1' is the upper transverse width of the cricothyroid membrane between the cricothyroid muscles along the lower border of thyroid cartilage (in mm). 'W2' is the Middle transverse width of the cricothyroid membrane between the cricothyroid muscles (in mm). 'W3' is the lower transverse width of the cricothyroid membrane between the cricothyroid muscles along the superior border of the cricoid cartilage (in mm).

As per table 4a, the upper transverse width of cricothyroid membrane (W1) ranged from 5.10 to 17.0 mm. The mean was 11.38 ± 2.64 mm in the male and 8.66 ± 1.50 mm in the female. **Student t- test showed that W1 is significantly more in the male than in the female.**

Middle transverse width of cricothyroid membrane (W2) ranged from 3.0 to 12.2 mm. The mean was 8.36 ± 2.06 mm in the male and 6.11 ± 1.28 mm in the female. There was a significant gender difference. **Student t- test showed that W2 is significantly more in the male than in the female.**

Lower transverse width of cricothyroid membrane (W3) ranged from 0.0 to 8.0 mm. The mean was 3.69 ± 1.81 mm in the male and 2.83 ± 1.82 mm in the female. **There was no significant gender difference in W3.**

The width of the cricothyroid membrane is found to be more in males as compared to females**. Student t-test (**Statistical test for significance**) showed that this difference is statistically significant.** This will have clinical implications on the size of the endotracheal tube inserted in males and females. Diameters of tubes will have to be less in females.

VERTICAL HEIGHT OF THE CRICOTHYROID MEMBRANE

Table 4b shows the dimensional height of the cricothyroid membrane in adult male and female subjects. The cricothyroid membrane is known to be an elastic membrane. As such, height was measured in both extended and neutral position of neck to see if any significant differences in values exist. This would have implications on the size of the tube inserted.

'H1' refers to the height of the cricothyroid membrane in extended position of neck (in mm) and **'H2'** is the height of the cricothyroid membrane in neutral position of neck (in mm).

As per table 4b, the vertical height of cricothyroid membrane in extended position of neck **(H1)** ranged from 4.0 to 13.0 mm. The mean was 8.72 ± 1.93 mm in the male and 7.51 ± 1.77 mm in the female. Though the values of H1 are comparatively more in males, Student t- test (test for significance) showed that there was **no statistically** significant gender difference in H1 between male and female subjects with a 'p' value of 0.053.

Vertical height of cricothyroid membrane in neutral position of neck **(H2)** ranged from 3.0 to 10.0 mm. The mean was 6.54 ± 1.83 mm in the male and 5.75 ± 1.68 mm in the female. Though the values of H2 are comparatively more in males, Student t- test showed that there was **no statistically** significant gender difference in H2 between male and female.

There is a significant difference in the height of the membrane in neutral and extended position of the neck (6.3 mm in neutral position and 8.4 mm in extended neck). The cricothyroid membrane is known to be an elastic membrane. **The changes in the height of the membrane could be attributed to the elasticity of the membrane as well as to the mobility of the synovial cricothyroid joint. These values will have clinical implications on the size and diameters of the tube chosen for insertion into the cricothyroid space.**

B) <u>DEPTH OF LARYNX AT THE LEVEL OF THE UPPER BORDER OF CRICOID CARTILAGE</u>

Anteroposterior depth of the subglottic larynx (DL) was measured at the level of the upper border of the cricoid cartilage from the outer rim of the cricoid cartilage to the posterior laryngeal wall.

Table 5 shows the observed values of depth of larynx in adult male and female subjects. Anteroposterior depth of larynx (DL) at the level of the cricoid cartilage ranged from 13.0 to 25.25 mm. **The mean was 20.48 ± 2.31 mm in the male and 15.52 ± 1.33 mm in the female.**

Student t- test (Test for statistical significance) showed that the depth of the larynx was **significantly more in the male as compared to the female subjects** with a p- value less than 0.05.

C) <u>AVERAGE LOCATION OF THE CRICOTHYROID MEMBRANE FROM SUPRASTERNAL NOTCH</u>

The average location of the lower border cricothyroid membrane from the suprasternal notch (measured as the distance between the upper border of the manubrium sternum to the upper border of the cricoid cartilage) is represented by A3 in the extended position and A4 in the neutral position of neck.

It represents the average location of the lower border of the cricothyroid membrane where a transverse stab incision is usually made during a surgical and needle cricothyroidotomy. Incision is **not** made along the upper part of the cricothyroid membrane due to the presence of the transverse cricothyroid artery which usually runs along the lower border of the thyroid cartilage. Instead the incision or puncture of the membrane is **usually made** at the lower margin of the cricothyroid membrane along the upper border of the cricoid cartilage represented by A3 in the extended position and A4 in the neutral position of neck.

Table 6 shows the observed values for average location of the cricothyroid membrane in male and female subjects.

As per table 6, average location of the lower margin of the cricothyroid membrane from the upper border of the suprasternal notch **in extended position of neck** ranges from 4.5 to 11.0 cm. The mean is 7.86 ± 1.36 cm in the male and 8.13 ± 1.35 cm in the female. Student t-test showed that there was no significant gender difference.

As per table 6, average location of the lower margin of the cricothyroid membrane from the upper border of the suprasternal notch **in neutral position of neck** ranged from 2.0 to 8.0 cm. The mean was 5.27 ± 1.76 cm in the male and 4.52 ± 1.45 cm in the female. Student t-test showed that there was no significant gender difference.

In the total group however, the average distance of the cricothyroid membrane from the sternum is about 7.9 or 8 cm in extended neck and 5.0 centimeters in neutral position of neck. These values will have clinical significance in localizing the position of the cricothyroid membrane. This becomes especially useful when normally palpable landmarks of neck are impalpable due to a large subcutaneous hematoma or edema.

D) <u>REGRESSION EQUATION FOR LOCATION OF CRICOTHYROID MEMBRANE</u>

Regression analysis was done and equations derived to locate the lower border of cricothyroid membrane by regressing stature height of the individual with anterior neck parameters A3 and A4. Incision or puncture of the cricothyroid membrane is **usually done at the lower border of the cricothyroid membrane** (along the upper margin border of the cricoid cartilage). This is represented by A3 in the extended position and A4 in the neutral position of neck. The regression analysis is shown in the figure.

The results are:

Regression equation for locating position of lower border of cricothyroid membrane in extended position of neck is:

A3 (in cm) = - 1.91E-02 (stature height in cm) + 10.868

Regression equation for locating position of lower border of cricothyroid membrane in neutral position of neck is:

A4 (in cm) = - 6.71E-03 (stature height in cm) + 6.021

Example - Considering formula 2, if the stature height of the individual is 160 cm, then average location of the lower border of cricothyroid membrane is derived using the formula A4 (in cm) = - 6.71E-03 (160) + 6.021

= - 0.00671 (160) + 6.021

= - 1.0736 + 6.021

= 4.94 cm

E) STRUCTURES AT RISK DURING PUNCTURE OF CRICOTHYROID MEMBRANE

The cricothyroid space was carefully dissected in all fifty adult cadavers and the results carefully analyzed and tabulated. Various soft tissue structures as well as arteries and veins were encountered during dissection of the cricothyroid space. These would possibly be at risk of injury and hemorrhage if punctured during a cricothyroidotomy. There frequency and percentage of occurrence is shown in the **Table 7**.

As per table 7, the structures seen during dissection of the cricothyroid space and which are possibly at risk of injury are: Anterior jugular vein in 34% of cases, sternohyoid muscle in 82%, platysma in 10%, transverse cricothyroid artery in 100% of cases, thyroidea ima artery in 2%, levator glandulae thyroidea in 16%, pyramidal lobe of thyroid in 16%, venous tributaries in 4%, pad of fat in 22%, and jugular venous arch in 2% of cases.

Anterior jugular vein

The anterior jugular vein was seen coursing vertically opposite the cricothyroid membrane in 34% (17 out of 50cases studied).

The anterior jugular venous pattern was seen to present as one of the following three types.

Type 1- as only a single anterior median jugular vein; seen in 4 cases (8%)

Type 2 –as paired anterior jugular veins; seen in 11 cases (22 %)

Type 3 – Triple jugular veins (a median anterior jugular vein in addition to paired lateral jugular veins seen in 12 cases (24%).

In total, a midline (median) jugular venous vessel lying in the cricothyroid space opposite the membrane, capable of bleeding if punctured was present in 17 out of 50 specimens (34%).

Surprisingly the anterior jugular vein was completely absent in 23 of 50 dissected cases (46%), which is a significant proportion.

Sternohyoid muscle

The sternohyoid is a muscle belonging to the infrahyoid group of strap muscles. It is paired and lies close to each other in the midline. In my study the medial border of the muscles was seen to touch each other in the midline in 27 out of 50 cases (54%). It is therefore at risk of injury while performing a stab cricothyroidotomy and being a vascular structure it is capable of bleeding and producing an alarming hemorrhage if injured. In 7 of 50 cases it was far lateral to the working width of the cricothyroid space and hence safe from injury. In the rest 16 cases they were at variable distances from each other. Incising the skin vertically in the midline could avoid damage to the muscle.

Platysma

Fibres of the platysma muscle were seen to cross the midline of neck lying in the subcutaneous tissue opposite the cricothyroid space in 5 cases (10%). In the rest of the cases, the muscle fibres were further away from the membrane. Again, muscle fibres being vascular could be at risk of bleed if injured during a cricothyroidotomy.

Transverse Cricothyroid Artery

The transverse cricothyroid artery was seen in all 50 cases (100%). In 47 cases (94%), it arose as a branch from the main pedicle of the superior thyroid artery. In 3 cases (6%), it arose as a branch from the superior laryngeal branch of superior thyroid artery. In all dissected specimens (100%) it was seen crossing the membrane close to the lower border of the thyroid cartilage. In 46 of the dissected specimens (92%), the right and the left transverse cricothyroid arteries joined together in the midline to form a single median descending artery. This median descending artery most often runs downwards on the surface of the membrane to a variable extent to supply the isthmus of the thyroid gland, strap muscles, pyramidal lobe of thyroid and levator glandular thyroidae if present. The median descending cricothyroid artery also anastomosed with the anterior branches of the superior thyroid artery over the superior border of the isthmus in 11/50 cases (22%). Only in one case the median cricothyroid artery was seen running upwards beneath the lower border of the thyroid cartilage. The transverse cricothyroid artery as well as the median descending artery gave smaller branches that pierced the upper part of cricothyroid membrane in 39 out of 50 cases (78%). Multiple perforations were seen in some whereas single large perforations were seen in most. These perforating vessels are known to anastomose with endolaryngeal arteries.

The thyroidae ima artery

The thyroidae ima artery was seen in one specimen (2%) arising from the arch of aorta, running upwards, crossing the cricothyroid space to reach up to the level of the hyoid bone.

Levator glandulae thyroidea

The Levator glandulae thyroidea (LGT) was seen in 8 cases (16%) lying opposite the membrane. In the remaining 42 cases (84%) it was absent.

Pyramidal lobe of thyroid

The Pyramidal lobe of thyroid (PT) was seen in 8 cases (16%) lying in front of the cricothyroid membrane. It was absent in the remaining 42 cases (84%).

Jugular venous arch

The jugular venous arch is a venous arch connecting the two anterior jugular veins, normally situated in the suprasternal space of Burns. Rarely, it can be situated high up in the neck opposite the cricothyroid membrane. In my study, the jugular venous arch was seen in opposite the cricothyroid space in 1 specimen (2%).

F) THICKNESS OF THE CRICOTHYROID MEMBRANE

Thickness of cricothyroid membrane was measured after removal using vernier caliper. The observed values are shown in **Table 8**.

Thickness of cricothyroid membrane (TM) ranged from 1.35 to 9.0 mm. The mean was 3.50 ± 1.29 mm in the male and 2.78 ± 0.67 mm in the female.
Though mean values are more in male subjects, student t-test showed that there was no statistically significant gender difference.

G) CORRELATION ANALYSIS

Correlation analysis was done to see if age of the individual, stature height and neck parameters correlates positively with the dimensions (width and height) of the cricothyroid membrane.
Table 9 lists the correlation table of the measured parameters against the width and height of the cricothyroid membrane. The values given are the Correlation coefficients.
The symbol '*' shows that correlation is 'significant' at the 0.05 level and double asterisk '**' shows that correlation is 'highly significant' at the 0.01 level (2-tailed). This study shows whether the dimensions of the membrane correlate and is proportionate to other measured parameters.

H1 - The study shows that height of the membrane in extended position of neck H1, correlates highly significantly and positively with the transverse widths of the membrane W1, W2, W3 at the 0.01 level. H1 also correlates highly significantly and positively with the height of the neck A1 at the 0.01 level and with A2, A4 and H2 at the 0.05 level.

H2 - The study shows that height of the membrane in neutral position of neck, H2 correlates highly significantly with W1 and W2 at the 0.01 level. It also correlates significantly and positively with the A1, H2 and W3 at the 0.05 level.

W1 – the study shows that the width of the membrane along the lower border of the thyroid cartilage correlates highly significantly with the widths of the membrane anywhere at other places.

Width of the membrane, W1 is highly proportional to the height of the membrane H1 at the 0.01 level. W1 correlates significantly with the depth of the larynx and H2 at the 0.05 level. Stature height of the individual correlates significantly with the width W1 of the membrane at the 0.05 level.

W2 - the study shows that the middle transverse width of the membrane correlates significantly with the widths of the membrane at other levels.

Width of the membrane W2 also correlates highly significantly with the heights of the membrane H1 and H2 at the 0.01 level. W2 correlates significantly with the depth of the larynx. W2 correlates significantly with the length of the neck, A1.

W3 – the study shows that the width of the membrane along the upper border of the cricoid cartilage correlates highly significantly with the widths of the membrane at other places.

W3 correlates with the heights of the membrane H1 and H2 at the 0.05 level. W3 also correlates significantly with the length of the posterior region of neck, P1 at the 0.05 level.

Stature Height correlates significantly and positively with upper transverse width of cricothyroid membrane (W1);

Anterior length of the neck in extended position (A1) correlates positively with the height of the cricothyroid membrane H1 and H2, and the middle transverse width of cricothyroid membrane (W2);

Distance between the suprasternal notch and thyroid notch in extended position of neck (A2) is directly proportional to the vertical height of cricothyroid membrane in extended position of neck (H1);
Distance between the suprasternal notch and upper border of cricoid cartilage in neutral position of neck (A4) correlates significantly with the vertical height of cricothyroid membrane in extended position of neck (H1);

Posterior height of the neck (P1) is proportional to the width W3 of the membrane.
Widths of the neck W1, W2, and W3 are proportionate to each other.
H2 correlates positively and significantly with H1;
The heights of the membrane H1and H2 correlates independently, positively and significantly with the widths of the membrane W1, W2 and W3;

Depth of the larynx also correlates positively with the circumference of the neck;
W1 and W2 are proportional to the depth of the larynx (DL);
Height of the cricothyroid membrane does not correspond to the stature height of the individual;
Width of the cricothyroid membrane does not correspond to the circumference of the neck.

H) <u>REGRESSION ANALYSIS OF THE OBSERVED VALUES</u>

Regression analysis and regression equations were done to determine the dimensions (width and height) of the cricothyroid membrane from available parameters such as stature height and neck parameters.

Table 10 shows - Widths and heights of the cricothyroid membrane (Dependent variables, Y) are regressed against measured parameters (independent variables, X), using simple regression equation at Y = bX + a in 50 adult subjects; where b= coefficient of regression; a = intercept (constant); r^2 = square of coefficient of correlation known as coefficient of determination; S.E.E= standard error of estimate; p= level of significance.

W1, W2, H1, and H2, are regressed against stature height, A1, A2, A3, A4, Neck circumference, and P1.

Measured parameters A1, A2, A3, and A4 are also regressed against the height of the subjects.

Regression equations derived from regression analysis

As per the regression equation Y= bX + a, where ‘Y’ is a dependant variable such as the height and width of the cricothyroid membrane, ‘b’ is the coefficient of regression, ‘a’ is a constant and ‘X’ is an independent variable (or known variable) such as stature height, A1, A2, neck circumference or P1, the following equations were derived.

Regression equations for upper transverse width of cricothyroid membrane, W1(in mm) =

= 3.665E-02 (Stature height in cm) + 5.052 mm

= 0.359 (A1 in cm) + 4.820 mm

= 0.350 (A2 in cm) + 6.970 mm

= - 0.255 (A3 in cm) + 12.699 mm

= - 0.102 (A4 in cm) + 10.667 mm

= 8.788E-02 (neck circumference in cm) + 7.235 mm

= 0.303 (P1 in cm) + 6.626 mm

Regression equations for middle transverse width of cricothyroid membrane at W2(in mm)=

= 2.210E-02 (stature height in cm) + 4.386 mm

= 0.350 (A1 in cm) + 2.060 mm

= 0.320 (A2 in cm) + 4.392 mm

= - 9.39E-02 (A3 in cm) + 12.699 mm

= 0.115 (A4 in cm) + 6.908 mm

= 2.934E-02 (neck circumference in cm) + 6.798 mm

= 0.223 (P1 in cm) + 4.799 mm

Regression equations for lower transverse width of cricothyroid membrane at W3 were not calculated as they are not clinically significant.

Regression equations for vertical height of cricothyroid membrane in extended position of neck are H1 (in mm) =

= 1.926E-02 (stature height in cm) + 5.449 mm

= 0.385 (A1 in cm) + 2.119 mm

= 0.397 (A2 in cm) + 4.201 mm

= 0.234 (A3 in cm) + 6.552 mm

= 0.428 (A4 in cm) + 6.289 mm

= - 8.04E-02 (neck circumference in cm) + 11.096 mm

= 0.248 (P1 in cm) + 5.091 mm

Regression equations for vertical height of cricothyroid membrane in neutral position of neck are H2 (in mm) =

= 1.786E-02 (stature height in cm) + 3.591 mm

= 0.308 (A1 in cm) + 1.309 mm

= 0.244 (A2 in cm) + 3.745 mm

= 3.610E-02 (A3 in cm) + 6.047 mm

= 0.343 (A4 in cm) + 4.520 mm

= - 8.01E-02 (neck circumference in cm) + 9.014 mm

= 0.228 (P1 in cm) + 3.280 mm

Example- if the A4 measurement of an individual from the suprasternal notch to the cricoid cartilage **is known** to be 3.5 cm, then using the above formula Y = bX+a, vertical height of the cricothyroid membrane would be:

H2 = 0.343 (A4) + 4.520 (mm)

= 0.343 (3.5) + 4.520 (mm)

= 1.200 + 4.520 (mm)

= 5.720 mm

W2 = 0.115 (A4 in cm) + 6.908 mm

= 0.115 (3.5) + 6.908 mm

= 0.4025 + 6.908 mm

= 7.3105 mm

Using these values a cricothyroidotomy tube of outer diameter size 5.5 mm can be introduced safely into the cricothyroid space to aid in ventilation.

Race, heredity, climate, and nutritional status of a population are known to affect the body size and dimensions. Though the validity of the regression models (equations) derived was not tried on other populations, the coefficients of determination are over a reasonable percentage, the standard errors of the regression coefficient are small, and the standard errors of estimate are low. Therefore, our regression models should be applicable to different populations.

SECTION 2 – ANALYSIS IN CHILDREN

The study was done on 4 children ages ranging from 4 to 9 years with a mean age of 6.75 years. Their stature height ranged from 93.0 - 124.0 cm with a mean height of 107.75 +/- 12.92 cm. The results are tabulated in Tables 11 and 12.

A) DIMENSIONS OF THE CRICOTHYROID MEMBRANE IN CHILDREN

Dimensional measurement of the pediatric cricothyroid membrane included width at three levels and height H1 and H2 in extended and neutral position of the neck. The observed values are shown in table 11a and 11b.

Transverse width of cricothyroid membrane in children

As per table 11a, upper transverse width of cricothyroid membrane (W1) ranged from 6.0 to 8.2 mm. The mean was 7.225 ± 0.9133 mm.

Middle transverse width of cricothyroid membrane (W2) ranged from 4.3 to 7.2 mm. The mean was 5.7625 ± 1.3060 mm.

Lower transverse width of cricothyroid membrane (W3) ranged from 1.0 to 3.35 mm. The mean was 2.3375 ± 1.0594 mm

Vertical height of cricothyroid membrane in children

As per table 11b, vertical height of cricothyroid membrane in extended position of neck (H1) ranged from 4.3 to 6 mm. The mean was 5.1625 ± 0.7087 mm.

Vertical height of cricothyroid membrane in neutral position of neck (H2) ranged from 4.0 to 4.2 mm. The mean was 4.0750 ± 0.0957 mm.

B) DEPTH OF LARYNX AT THE LEVEL OF UPPER BORDER OF CRICOID CARTILAGE IN CHILDREN

Depth of larynx in children was measured at the level of the upper border of cricoid cartilage from the outer rim of the cricoid to the posterior laryngeal wall. These values would help the physician to avoid penetration of posterior laryngeal wall during a surgical or needle cricothyroidotomy.

Observed values are shown in **Table 12**. Anteroposterior depth of larynx (**DL**), ranged from 8.0 to 13.35 mm. The mean was 10.4 ± 2.3906 mm.

C) POSITION OF CRICOTHYROID MEMBRANE FROM SUPRASTERNAL NOTCH IN CHILDREN

The average location of the **lower border of the cricothyroid membrane** from the suprasternal notch (measured as the distance between the upper border of the manubrium of sternum to the upper border of the cricoid cartilage) is represented by A3 in the extended position and A4 in the neutral position of neck. It represents the average location of the lower border of the cricothyroid membrane **where a transverse stab incision is usually made** during a surgical and needle cricothyroidotomy.

Observed values are shown in **Table 13.**

As per table 13, average location of the lower margin of cricothyroid membrane from the upper border of the suprasternal notch in extended position of neck (A3), ranged from 5.5 to 9 mm. The mean was 6.75 ± 1.5545 mm.

As per table 13, average location of the lower margin of the cricothyroid membrane from the upper border of the suprasternal notch in neutral position of neck (A4), ranged from 3.0 to 7.0 mm. The mean was 4.625 ± 1.7017 mm.

These values will have clinical significance in localizing the position of the cricothyroid membrane especially when normally palpable landmarks of neck are impalpable due to a large subcutaneous hematoma or edema.

D) <u>THICKNESS OF THE CRICOTHYROID MEMBRANE IN CHILDREN</u>

Thickness of the cricothyroid membrane was measured using a vernier caliper.

Thickness of the cricothyroid membrane (TM), ranged from 2.0 to 6.0 mm. The mean was 3.52 ± 1.88 mm. The observed values are given in **Table 14**.

E) <u>STRUCTURES FOUND IN FRONT OF THE MEMBRANE IN CHILDREN</u>

Dissection of the cricothyroid space in children revealed vascular and soft tissue structures in the area. The frequency and percentage of occurrence of these structures are given in **Table 15**. These structures may be involved during the performance of a cricothyroidotomy.

As per table 15 :

A midline Anterior jugular vein was found in one case (25%);

the sternohyoid muscle was seen touching each other in the midline in all the children studied (100%);

fibres of platysma crossed the midline opposite the cricothyroid membrane in 25% of children;

the transverse cricothyroid artery was seen crossing the upper part of the membrane in all the children (100%);

levator glandulae thyroidea was seen in 25% crossing anterior to the membrane;

and the pyramidal lobe of thyroid was seen opposite the membrane in 25% of cases.

SECTION 3 – ANALYSIS IN NEONATES

The study was done on 10 full term neonatal specimens. Measurements observed include working dimensions of the cricothyroid membrane, location of the cricothyroid space and depth of the subglottic larynx at the level of the cricothyroid membrane.

The study in neonates revealed the following.

A) <u>DIMENSIONS OF THE CRICOTHYROID MEMBRANE IN THE NEONATE</u>

Dimensions of the cricothyroid membrane included widths at three levels and height of the membrane.

Results are tabulated **in table 16A and 16B**.

Width of the cricothyroid membrane at W1 ranged from 2.1 - 4.4 mm with a mean of 3.23 +/- 0.89 mm.

W2 ranged from 1.0-3.1 mm with a mean of 2.16 +/-0.57 mm

W3 ranged from 0.0-1.4 mm with a mean of 0.54 +/- 0.57 mm.

Height of the cricothyroid membrane in neonates ranged from 1.0- 3.25 mm with a mean height of 2.40 +/- 0.67 mm.

Working dimensions of the cricothyroid membrane are very small in neonates and will have clinical implications on the procedure itself.

B) DEPTH OF THE LARYNX AT THE LEVEL OF THE UPPER BORDER OF THE CRICOID CARTILAGE IN NEONATES

Depth of larynx in neonates was measured at the level of the upper border of cricoid cartilage from the outer rim of the cricoid to the posterior laryngeal wall.

These values would help the physician to avoid penetration of posterior laryngeal wall during a surgical or needle cricothyroidotomy.

Observed values are shown in **Table 17**.

Anteroposterior depth of larynx (DL), ranged from 3.0 to 11.25 mm. The mean was 5.76 +/- 2.6 mm.

C) LOCATION OF THE CRICOTHYROID SPACE FROM THE UPPER BORDER OF STERNUM IN NEONATES

The average distance of the cricothyroid space from the suprasternal notch (measured as the distance between the manubrium sternum to the upper border of the cricoid cartilage) is represented by 'A' in millimeters.

This is illustrated in **table 18.**

These values would be useful to locate the membrane and resuscitate the baby if necessary.

SECTION 4 – HISTOLOGY OF THE CRICOTHYROID MEMBRANE

The cricothyroid membrane was found to be continuous on its deeper aspect with the mucosa of the subglottic larynx (which together forms the vocal cord). Hence the lining epithelium of the subglottic larynx is observed in the photographs.

The cricothyroid membrane is observed to be a fibroelastic membrane consisting of both collagen and elastic fibres. This is observed both with Hematoxylin & Eosin stain as well as with Verhoeffs' special stain for elastic and collagen fibres.

In the Hematoxylin & Eosin staining technique, bundles of parallel elastic fibres are seen interspersed with the collagen fibres.

In Verhoeffs'staining method, elastic fibres take up a black to blue-black stain and collagen fibres take up a red appearance. These are seen very clearly in the slides.
The collagen and elastic fibres are seen to be interspersed having almost an equal proportion.

CHAPTER SIX - DISCUSSION

The cricothyroid membrane is important for several subglottic procedures.

Cricothyroidotomy done to establish an airway is a life saving procedure and a clinical skill that needs to be developed in all hospitals and health care teams. This is often done by anesthetists and emergency care physicians. It is also done by paramedical staff and ICU and flight nurses.

Though several authors and textbooks have mentioned the cricothyroid membrane, few have described its attachments and very few have studied its dimensions. Only two studies have been done so far regarding the dimensions of the membrane; both of which are western studies done in the United States of America.

Race, heredity, climate, and nutritional status of a population are known to affect the body size and dimensions.

One of the main reasons for this study is to give values for our south Indian population and racial group. I also studied in detail the possible soft tissue structures and vessels found opposite the cricothyroid membrane that could be at risk of injury during the procedure.

Tube sizes for emergent subglottic intubation have been reconsidered and new tube sizes suggested based on my study to suit our south Indian population.

PREVIOUS STUDIES DONE

Dimensions of the cricothyroid membrane are reported only by 3 study groups, of which only 2 have studied the ‘working dimensions’ of the membrane relevant for any subglottic procedure. They are Dover K, Howdieshell TR and Colbora GL (1996), who studied the dimensions and vascular anatomy of the cricothyroid membrane; and Bennett JD, Guha SC, and Sankar (1996) who studied the dimensions of the cricothyroid membrane. Kress and Balasubramaniam (1982) also studied the membrane in adult subjects but measurements include the width of the membrane beyond the cricothyroid muscles and its total height up to the vocal cord, which is not very relevant clinically for a subglottic procedure.

Most internationally reputed clinical textbooks and journals of anesthesia, emergency medicine and critical care quote the 'landmark' article by Dover et al.

RACIAL GROUP OF STUDY

Dover et al (1996) did his study on cadavers in the Medical college of Georgia, Augusta, USA.

Bennett et al (1996) did their study on fresh cadavers in the University of Texas Medical Branch in Galveston, USA.
Both of the studies (which are also the most quoted), have been done on Western subjects.

No studies have been done anywhere else or on any other racial group.

My study has been done on adult South Indian subjects. It is also the third documented study in the world regarding working dimensions of the human cricothyroid membrane.

SAMPLE SIZE OF STUDY

Kevin Dover (1996), in his landmark article studied only 15 adult cadavers (9 male and 6 female).

Bennett et al (1996) studied only 13 adult cadavers. Sex of the cadavers was not mentioned in the results of his study.

The present study (2006) includes a sample size of 50 adult cadavers (37 male and 13 female), which is the largest sample size so far. My study also includes children and neonates.

AGE GROUP OF STUDY

Kevin Dover (1996), in his landmark article studied adult subjects in the age group ranging from 70 – 92 years (which is an elderly age group).

Bennett et al (1996), does not mention the age range of his adult subjects.

My present study includes a much wider age group ranging from 17 to 83 years with a mean age of 39 years in males and 48 years in females.

I have also studied the dimensions of the cricothyroid membrane in children and neonates.
No previous studies have been reported on the dimensions of the membrane in children. Only one previous study has been reported on dimensions of the cricothyroid membrane in neonates done by Navsa N, Tossel G and Boon JM (2005), in the department of Anatomy, University of Pretoria, South Africa.

My study will be the second reported study done on neonates; and also the first done on a non-African racial group.

COMPARISON OF THE DIMENSIONS OF THE CRICOTHYROID MEMBRANE IN ADULTS

Dover et al (1996), in his study on the dimensions of the cricothyroid membrane, reports the average '**working dimensions**' of the membrane, '**between the two cricothyroid muscles**' in the total group (male and female included) to be :

Maximal average width (at W1) - 10.9mm (range = 8.0 – 14.0)

Average height - 10.4 mm (range = 7.5 – 13.0)

The position of the neck is not mentioned.

Bennett et al (1996) studied the 'working dimensions' of the cricothyroid membrane in 13 adult fresh cadavers and reports as follows:

Maximal average width (at W1) - 12.38 mm (range = 9 – 19)
Average height - 13.69 mm (range = 8 – 19)

The results of the present study (2006) are**:**

Maximal average width (at W1) - 10.7 mm
Average height - 8.4 mm in the extended position of neck, and 6.3 mm in the neutral position of neck.

A comparison of the dimensions of the cricothyroid membrane in the total adult group of previous studies with present study is shown in **Table 20**.

As per Table 20, the results of the studies show that the dimensions are consistently smaller in the South Indian racial group.

Dimensions are largest in the study done by Bennett et al. The height of the membrane studied by him averages 13.7 mm whereas it is only 8.4 mm in my study. The width of the membrane studied by him averages 12.38 mm whereas it is only 10.7 mm in my study.

This shows very clearly that tube sizes recommended for western subjects cannot be used in other racial groups such as ours. This would fracture the laryngeal cartilages and cause injury to the vocal cords.

Though the width of the membrane is almost similar in Dover's landmark study and mine, the height is significantly different (10.4 mm in Dover's study; and only 8.4 and 6.3 mm in my study in extended and neutral position of neck respectively).

Previous studies have not compared differences in height in extended and neutral position of neck. The cricothyroid membrane being an elastic membrane is capable of stretching. Results of my study show that the height of the membrane in extended position of neck (H1) is 8.4 mm, and in neutral position of neck (H2) is 6.3 mm. These values become useful in clinical conditions, such as when patients with high cervical spinal cord injury (in whom neck extension is contraindicated) require a cricothyroidotomy.

ADULT MALE/ FEMALE DIMENSIONAL COMPARISON

Dover et al (1996) did his study on 9 male and 6 female cadavers. He reports that the average width and height were consistently smaller in females.

Bennett et al (1996), does not give a gender statistic in his study.

In the present study (2006), I have studied the male and female differences in 37 male and 13 female cricothyroid membranes.

A comparison of observed values is shown in the **Table 21.**

As per Table 21, it is observed that both male and female values are comparatively smaller in the present study compared to Dover et al. This obviously concludes two important things. One, dimensions are smaller in females; second, present values are smaller than western values.

DIMENSIONS OF CRICOTHYROID MEMBRANE IN NEONATES

Table 22 shows a comparison of dimensions of the cricothyroid membrane of previous studies with present study.

Only one previous study has been done to determine the dimensions of the cricothyroid membrane in neonates.

Navsa N, Tossel G and Boon JM (2005) studied the dimensions of the neonatal cricothyroid membrane in 27 neonatal cadavers. They found the mean height of the membrane to be 2.61 mm (standard deviation: 0.71) and width of 3.03 mm (standard deviation: 0.63).

The results of my present study (2006) showed the mean height of the membrane to be 2.40 mm (standard deviation: 0.67) and mean width to be 2.16 mm (standard deviation:0.57).

The results of my study agree strongly with the previous one study done by Navsa et al (2005). Both studies show similar values.

These findings indicate that the dimensions of the cricothyroid membrane is too small for passing an endotracheal tube, as dimensions of the tube would exceed the dimensions of the membrane. This could fracture the cartilages of the neonatal larynx. Instead passage of a needle cricothyroidotomy should be preferred in neonates.

DIMENSIONS OF THE MEMBRANE IN CHILDREN

No previous studies have been documented on children till date.

Results of my present study show that,

Average width (W2): 5.8 mm (4.3 – 7.2)

Height (H1) in extended neck: 5.2 mm (4.3 – 6.0)

Height (H2) in neutral neck: 4.1 mm (4.0 – 4.2)

Present study shows that observed values in children are smaller when compared with observed values in adults. However, observed values in children are much larger when compared to neonatal values.

On a practical level, endotracheal tubes with an outer diameter of up to 4.0 mm could be used in children during a cricothyroidotomy. Intravenous cannula and large bore needles can also be used.

DEPTH OF LARYNX AT LEVEL OF UPPER BORDER OF CRICOID CARTILAGE

No previous studies have measured depth of larynx at the level of cricoid cartilage with reference to a cricothyroidotomy.

However penetration and perforation of the posterior wall of larynx and esophagus with injury to the recurrent laryngeal nerve and large blood vessels have been documented.

Carter DR, Meyers AD (1978) on dissecting the larynx of 50 adult cadavers found that subglottic dimensions were significantly smaller in women than in men.

Miklus et al (1989) states that care should be taken not to incise or push the needle too deeply after entering the infraglottic cavity resulting in perforation of the esophagus and formation of a tracheo-esophageal fistula.

Boon et al (2004), states that the airway is narrow in a child. This makes posterior penetration of the tracheal wall much more likely in the child and infant.

Boon et al (2004) also states that the recurrent laryngeal nerve lies between the trachea and esophagus at the level of the cricoid cartilage and enters the larynx posteriorly. Injury to the recurrent laryngeal nerve may lead to vocal cord paralysis. Therefore, staying in the midline and taking care not to injure the posterior wall of the subglottic airway will ensure avoidance of these nerves.

This part of the present study was included to let the physician performing a cricothyroidotomy know how deep the posterior wall of the larynx is from the surface. This would enable him to avoid penetration of the posterior laryngeal wall with the scalpel or needle during the procedure. Results showed that average depth of larynx is:

Adult males: 20.5 mm
Adult females: 15.5 mm
Children: 10.40 mm
Neonates: 5.76 mm

The depth of the subglottic larynx increases with advancing age.

My study agrees with Carter and Meyers (1978) that subglottic dimensions are smaller in female subjects compared to males.

My study agrees with Boon et al (2004) that the airway gets narrower in children and neonates. This makes posterior penetration of the tracheal wall much more likely in the child and infant.

AVERAGE LOCATION OF CRICOTHYROID MEMBRANE FROM SUPRASTERNAL NOTCH

Mc Gill et al (1982) and Walls RM (1988) stress that identification of anatomical landmarks and knowledge of the anatomy of anterior neck is essential for successful placement of the tube.

McGill et al (1982) studied the complications of 38 emergency cricothyroidotomies. 14 immediate complications occurred of which the most frequent was incorrect placement of the tube through the thyrohyoid membrane.

David M.Anderson (1988) while describing the procedure states that the thyroid cartilage is easy to palpate in men and in thin patients, but in children, women and obese patients, and those with neck edema or hematoma, the structures can be difficult to identify. This makes identification of the cricothyroid membrane more difficult but not impossible.

Dover et al (1996) on presenting his landmark article on the dimensions of the membrane says that "…the placement of a horizontal skin incision too cephalad or caudad may lead to inadvertent thyrohyoid membrane or tracheal insertion of the airway.

Leibovici et al (1996) from the Hadassah University Hospital, Jerusalem, assessed the efficacy of pre-hospital cricothyroidotomy performed by military physicians during a 3.5 year period. 26 were performed out of which 23 were successful (88.4%). Failures were due to poor anatomic identification of the cricothyroid membrane.

The aim of the present part of the study is to give the physician a rough idea of the position of the cricothyroid space (lower limit of the cricothyroid membrane) form the suprasternal notch.

This will be useful if palpation of surface landmarks is difficult and a blind attempt is warranted to save life.

Average distance of lower border of cricothyroid space from suprasternal notch in extended position of neck (A3) is:

In Adult Males - 7.9 +/- 1.4 cm

In Adult Females – 8.1 +/- 1.3 cm

In Total Adult group – 7.9 +/- 1.3cm

In Children – 6.8 +/- 1.55 cm

In Neonates – 2.05 +/- 0.63 cm

Average distance of cricothyroid space from suprasternal notch in the neutral position of neck (A4):

In Adult Males - 5.3 +/- 1.8 cm

In Adult Females – 4.5 +/- 1.4 cm

In Total Adult group – 5.0 +/- 1.7 cm

In Children – 4.6 +/- 1.7 cm

In Neonates – 2.05 +/- 0.63 cm

In the total adult group combined, the average distance of the cricothyroid membrane from the sternum is about 8 cm in extended neck and 5.0 centimeters in neutral position of neck. This means that in the adult in whom neck landmarks are not palpable, a blind puncture can be attempted about 8.0 cm from the suprasternal notch in male patients and 5.0 cm from the suprasternal notch in female patients.

David R.Gens (2004) states that the cricothyroid membrane is located approximately 1/3rd of the distance from the manubrium to the chin in the midline in a patient with a normal habitus. In a patient with a short, obese neck, the membrane may be hidden at the level of the manubrium. In a patient with a thin, long neck, it may be midway between the chin and the manubrium.

In my present study, I found that the lower border of the cricothyroid membrane (where the incision is usually carried out) is located about:

1/2 (49%) the distance between the chin and sternum **in extended position of neck** in male and female subjects (A3/A1);

1/3 (31%) of the distance between the chin and sternum **in neutral position** of neck **in males** (A4/A1) and about 1/4 of the distance (28%) between the chin and sternum in neutral position of neck **in females** (A4/A1);

Little more than 1/2 the distance (57%) between the chin and sternum in extended neck **in children** (A3/A1);

Little less than 1/2 the distance (39%) between the chin and sternum in neutral position of neck in children (A4/A1)

These values again will be useful if palpation of surface landmarks is difficult and a blind attempt is required to establish an airway.

STRUCTURES AT RISK IN THE CRICOTHYROID SPACE DURING PERFORMANCE OF A CRICOTHYROIDOTMY

Several structures are believed to be at risk opposite the cricothyroid membrane during performance of a cricothyroidotomy. A few authors have mentioned a few structures separately. In fact Dover et al (1996) in his landmark article only studied the vascular structures at risk.

Transverse cricothyroid artery

E.W.Walls (1964) in the Cunningham textbook of anatomy describes the cricothyroid artery passing forwards across the cricothyroid muscle to anastomose in front of the cricothyroid ligament with its fellow of the opposite side. Fatal airway hemorrhage after cricothyroidotomy has been reported by Safer and Penninckx (1967), Unger and Moser (1973), Schillaci et al (1976), with laceration of the cricothyroid artery and resultant endobronchial bleeding and asphyxia. Williams et al (1989) in the British edition of Gray's Anatomy describe the artery crossing the superior portion of the median cricothyroid ligament. Dover et al (1996) in his landmark study identified a transverse cricothyroid artery in 14 cadavers (93%). He saw them coursing across the upper one-third of the cricothyroid membrane in 13 specimens (93%) and across the lower portion in one cadaver. Bennett et al (1996), in his study reported eight subjects (62%) who had an artery running transversely across the cricothyroid membrane.

In my present study (2006), I found the transverse cricothyroid artery to be present in all 50 cases of the adult cadavers dissected (100%). In all 50 cases the artery coursed through the upper part of the membrane close to or along the lower border of the thyroid cartilage. The transverse cricothyroid artery was also seen crossing the upper part of the cricothyroid membrane in all the children cadavers in my study (100%).

E.W.Walls (1964) in the Cunningham textbook of anatomy describes the cricothyroid artery as a branch of the thyroid artery given in the muscular triangle. Lippert et al (1985) and Bergmann et al (1988) say that the cricothyroid artery usually arises from the superior laryngeal branch of the superior thyroid artery and commonly has rich anastomoses with the superior laryngeal artery deep to the thyroid lamina. In 5% of cases, the cricothyroid artery may totally replace the superior laryngeal artery. Dover et al (1996) in his landmark study of the membrane reports on the cricothyroid artery arising from the superior thyroid artery in 93% of 15 cases studied. Boon et al (2004) states "…the cricothyroid artery usually arises from the superior laryngeal artery, a branch of the superior thyroid artery.

In my present study (2006), in 47 cases (94%), the transverse cricothyroid artery arose as a branch from the main pedicle of the superior thyroid artery. In 3 cases (6%), it arose as a branch from the superior laryngeal branch of Superior thyroid artery.

E.W.Walls (1964) in the Cunningham textbook of anatomy describes the cricothyroid artery as anastomosing in front of the cricothyroid ligament with its fellow of the opposite side. Dover et al (1996) in his landmark study found that occasionally, two enlarged cricothyroid arteries anastomosed in the midline giving origin to a median descending artery supplying a pyramidal thyroid lobe.

In my present study (2006), in 46 of the dissected specimens (92%), the right and the left transverse cricothyroid arteries joined together in the midline to form a single median descending artery. This median descending artery most often runs downwards on the surface of the membrane to a variable extent to supply the isthmus of the thyroid gland, strap muscles, pyramidal lobe of thyroid and levator glandular thyroidae if present.

Donald and Bernstein (1975) found that endolaryngeal arteries in the submucosa of the larynx anastomose with the cricothyroid arteries via a perforating branch. Dover et al (1996), in his study of the membrane reports that branches of the cricothyroid artery penetrated the cricothyroid membrane and ascended along the undersurface of the thyroid cartilage to supply the laryngeal mucosa. Reidenbach (1998) studied the histology of the cricothyroid membrane and found that the membrane is pierced by small blood vessels near its attachments to the thyroid and cricoid cartilages. Sato et al (2002), investigated the three dimensional distribution of the cricoid area using computer graphics and found that vessels in the cricoid area penetrated the anteroinferior portion of the conus elasticus and extended into the prelaryngeal region.

In my present study (2006), the transverse cricothyroid artery as well as the median descending artery gave smaller branches that pierced the upper part of cricothyroid membrane in 39 out of 50 cases (78%). Multiple perforations were seen in some whereas single large perforations were seen in most.

Walls (1988) states that since the cricothyroid artery courses through the upper part of the membrane (closer to the thyroid cartilage) it is recommended to make the incision in the lower half of the cricothyroid membrane along the superior border of the cricoid cartilage.

I certainly agree with this statement since I found the cricothyroid artery to course through the upper part of the membrane in all of the 50 cases. The incision should not be made alongside the inferior border of the thyroid cartilage.

<u>Sternohyoid muscle</u>

The sternohyoid is a paired strap muscle lying close to the midline. It can be at risk of injury when a transverse stab incision is made using a scalpel in surgical cricothyroidotomy. In my study the muscle was found closely related to the anterior surface of cricothyroid membrane in 82% of cases. In 54% (27 cases) the medial border of the muscle was seen to touch each other in the midline. The sternohyoid muscle was also seen touching each other in the midline in all the children studied (100%). Being a vascular structure it is capable of bleeding and producing hemorrhage if injured. In 7 of 50 cases in the present study it was far lateral to the working width of the cricothyroid space and hence safe from injury.

Incising the skin vertically in the midline could avoid damage to the muscle.

No other study has documented the sternohyoid muscle as being at risk of injury.

<u>Platysma</u>

Fibres of the platysma muscle were seen to cross the midline of neck opposite the cricothyroid space in 5 adult cases (10%). Fibres of platysma crossed the midline opposite the cricothyroid membrane in 25% of children. Again, muscle fibres being vascular could be at risk of bleed if injured during a cricothyroidotomy.

Again no other study has documented this finding.

<u>Anterior jugular vein</u>

Dover et al (1996) in his landmark study found that paired anterior jugular veins in the subcutaneous tissue crossed the membrane in a vertical direction in the majority of specimens. Brofeldt et al (1996) reports on bleeding from the anterior jugular veins in one patient, which was controlled without any problem. Boon et al (2004) states that the anterior jugular vein runs in a vertical fashion in the lateral aspect of the neck and should be uninvolved if one stays in the midline.

In my present study (2006), the anterior jugular vein was seen in the subcutaneous tissue opposite the cricothyroid membrane in 34% of adult cases. It was found in 25% of children studied. The various patterns of the anterior jugular vein are given in chapter 4.

Various authors like Narrod et al (1985), Walls (1988) and David R.Gens (2004) recommend an initial vertical incision of the skin and cervical fascia to avoid these vascular structures laterally. Thereafter the cricothyroid membrane is incised horizontally.

I agree with the reasoning since the anterior jugular veins are usually paired structures found close to the midline in the subcutaneous tissue and making a vertical skin incision and staying close to the midline would avoid injury to the vein.

The thyroidae ima artery

David R. Gens (2004) states that the only vascular structure that may be injured during the course of a properly performed cricothyroidotomy is the thyroid ima artery, a branch of the aorta that runs up to the thyroid gland in the midline and infrequently reaches the level of the cricothyroid membrane.

In my present study, the thyroidae ima artery was seen in one adult specimen arising from the arch of aorta, running upwards, crossing the cricothyroid space to reach up to the level of the hyoid bone.

Pyramidal lobe of thyroid (PT)

Blumberg (1981) reports a 60-65% incidence of the pyramidal lobe. He found such a high incidence that he regarded the Pyramidal lobe as a normal component of the thyroid gland and not a congenital abnormality.

Levy et al (1982) quotes an incidence of 17% in normals.

Siraj et al (1989) reports an incidence of 41%.

Harjeet et al (2004), after studying 410 male and 160 female adults from Chandigarh, India reports an incidence of 28.9%.

Boon et al (2004), states that the thyroid gland has a pyramidal lobe in 40% of people. He says that the lobe may extend as high as the hyoid bone and therefore may be at risk of injury when performing a cricothyroidotomy.

In my present study (2006), the Pyramidal lobe of thyroid (PT) was seen in 16% of adult cadavers. It was also seen in 25% of children in my study. My values are similar to the study done by Levy et al. Levy et al also found that there was a correlation between elevated thyroid function in individuals and the incidence of a pyramidal lobe on thyroid scans.

<u>Levator glandular thyroidea</u>

The Levator glandular thyroidea (LGT) is a fibroglandular tissue seen most often attached to the isthmus of the thyroid gland.

Harjeet et al (2004) reports an incidence of the levator glandulae thyroidae in 19.5% of adults in Chandigarh.

In my present study, it was seen in 16% of the adult cases lying opposite the cricothyroid membrane. Levator glandular thyroidea was also seen in 25% of the child cadavers in my study.

<u>Jugular venous arch</u>

The jugular venous arch is a venous arch connecting the two anterior jugular veins in the suprasternal space of Burns. Rarely, it can be situated high up in the neck opposite the cricothyroid membrane.

In my present study (2006), the jugular venous arch was seen opposite the cricothyroid space in 1 adult specimen (2%).

SUGGESTED TUBE SIZE FOR EMERGENT SUBGLOTTIC INTUBATION

Dover et al (1996) reported the average width (W2) of the cricothyroid membrane between the cricothyroid muscles to be 8.2 mm and the average height 10.4 mm. Based on his study the American Association of Clinical Anatomists (1999) stated that the outer diameter of the endotracheal tube should therefore not exceed 8 mm. An inner diameter of at least 5mm is recommended to provide good airflow.

It has been shown that it is impossible to have a guaranteed successful exchange of gases through cannula that have an internal diameter less than 3mm. Vadodaria et al (2004), explained this on the basis of Poiseuille's law, which states that flow is proportional to the fourth power of the internal radius. Although it is quicker to insert a small diameter cannula, earlier and more reliable increases in PaO2 were achieved only with larger cannula.

McGill et al (1982), state that smaller cannulas are easier to insert, but the narrower the internal diameter, the more resistance to air flow. A larger cannula may fracture the thyroid or cricoid cartilage. McGill et al (1982) report a case where a longitudinal fracture occurred through the thyroid cartilage causing vocal dysphonia when an oversized tube with an outer diameter of 12 mm was inserted through the cricothyroid membrane. This is 3mm larger than the average height of the cricothyroid membrane of 9-10 mm reported by Kress and Balasubramaniam (1982). He also reports subglottic stenosis associated with forceful placement of oversized tracheostomy tubes.

Brofeldt et al (1996), report laryngeal damage due to an oversized tube being forced through the relatively small cricothyroid space.

Narrod JA, Moore EE, and Rosen P (1985) suggested that a number 6 tracheostomy tube be used for cricothyroidotomy. Using this technique, complications are rare.

David R.Gens (2004) while writing his ‘surgical airway management in emergency care’ says “…the diameter of the tube inserted is crucial. A 6-mm tracheostomy or 6-mm endotracheal tube is preferred (never larger than 7mm in either case). Tubes with internal diameters larger than 7 -mm are difficult to insert in the narrow space between the cricoid and thyroid cartilages”.

I discussed my observed dimensions of the cricothyroid membrane with a senior Professor of Anesthesia who commonly does a cricothyroidotomy in Christian Medical College, Vellore (a tertiary care hospital ranked as the countries best hospital a few years ago). He considered H2 and W2 values as the best indicators for a recommended tube size.

Considering this, it is recommended to use a cricothyroidotomy tube of outer diameter 6.0 mm in adult male, 5.5 mm in adult female and 4.0 mm in children.

The dimension of the cricothyroid membrane is too small in neonates for insertion of a tube through the narrow cricothyroid space. Since the dimensions are very small, only a needle cricothyroidotomy is advised and stab cricothyroidotomy discouraged in neonates. Introduction of endotracheal tubes can damage the feeble laryngeal cartilages.

These values are certainly different from western values suggested earlier by the American Association of Clinical Anatomists. Women certainly require tubes with smaller outer diameter than men.

Children require further smaller diameter tubes.

Since neonates have much smaller membrane dimensions, only needle cricothyroidotomy is advised and stab cricothyroidotomy strongly discouraged in neonates.

HISTOLOGY OF THE CRICOTHYROID MEMBRANE

Lanz and Wachsmuth (1955), describe the Conus Elasticus as a submucous elastic membrane.

G.M.Wyburn (1964), describes the conus elasticus as a fibro-elastic membrane containing a thick band of elastic tissue connecting the thyroid, cricoid and arytenoid cartilages.

Hollinshead (1968) describes the cricothyroid membrane as a strongly developed layer of elastic tissue.

Reidenbach (1996) says that the cricothyroid membrane is composed of densely arranged collagen fibres. She also says that it is pierced by small blood vessels, near its attachment zones to the thyroid and cricoid cartilage.

According to Dover et al (1996), the cricothyroid membrane is a dense fibro elastic trapezoidal membrane with ventral densely arranged fibres.

Sato et al (2002) describes the cricoid area as having adipose tissue, loose elastic and collagenous fibres.

According to my present study, the cricothyroid membrane is observed to be a fibroelastic membrane consisting of both collagen and elastic fibres as suggested earlier by Wyburn and Dover. This is observed both with Hematoxylin & Eosin stain as well as with Verhoeffs' special stain for elastic and collagen fibres. In the Hematoxylin & Eosin staining technique, bundles of parallel elastic fibres are seen interspersed with the collagen fibres.

In Verhoeffs'staining method, elastic fibres take up a black to blue-black stain and collagen fibres take up a red appearance. These are seen very clearly in the slides. The collagen and elastic fibres are seen to be interspersed having almost an equal proportion.

Collagen fibres may be present to give strength to the vocal cord and elastic fibres to give it mobility and elasticity for vibration during speech.

CHAPTER SEVEN - CONCLUSION

During their clinical training, medical students and residents perform a variety of invasive procedures. One such life saving procedure is cricothyroidotomy, done to establish an airway in the emergency setting.

The cricothyroid membrane is an important route for several other subglottic procedures as well. Though several authors and textbooks have mentioned the cricothyroid membrane, few have described its attachments and very few have studied its dimensions.

Only two adult studies have been documented till date; both of which are western studies done in the United States of America. No studies have documented the dimensions of the cricothyroid membrane in children. Only one African study has documented dimensions of neonatal cricothyroid membranes.

Race, heredity, climate and nutritional status are known to affect the body size of a population. It was my desire to study the dimensions of the cricothyroid membrane in our own South Indian population and also the structures at risk while puncturing the cricothyroid membrane.

Based on my results, I suggest a vertical skin incision as it minimizes the chance of soft-tissue hemorrhage from vertically oriented anterior jugular veins. Palpation of the cricothyroid membrane should be repeated after the skin incision is made to confirm the correct position of the membrane. A transverse stab incision of the membrane near its lower border adjacent to the cricoid cartilage is recommended to avoid injury to the transverse cricothyroid artery.

Tube sizes for emergent subglottic intubation have been reconsidered and new tube sizes suggested based on the present study to suit our south Indian population.

To avoid or manage complications of surgical cricothyroidotomy, knowledge of the dimensions, relations, and vasculature of the cricothyroid membrane is imperative. A solid knowledge of the anatomy behind a cricothyroidotomy may reduce the anxiety of the physicians and paramedics performing the procedure.

Cricothyroidotomy remains to be a safe and rapid means of securing emergency airway access in the absence of contraindications.

This is the largest study done so far and the first study done on a non-American adult group and the first done on a non-African neonatal racial group. It is also the first study done to report cricothyroid membrane dimensions in children.

It is my sincere hope that these values would be of immense help in the field of emergency medicine, anesthesia, intensive care management and neonatal care of the newborn.

My sincere appreciation to all in the field of emergency and critical care who strive to find means of resuscitating and saving precious lives.

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Modified Proforma For Working Dimensions Of Cricothyroid Membrane And Structures At Risk During Emergent Subglottic Intubation

General parameters

Case no:

Sex: Male/ female Age: Height:

Neck parameters:

A 1 =
A 2 =
A 3 =
A 4 =

Neck circumference =

CRICOTHYROID MEMBRANE

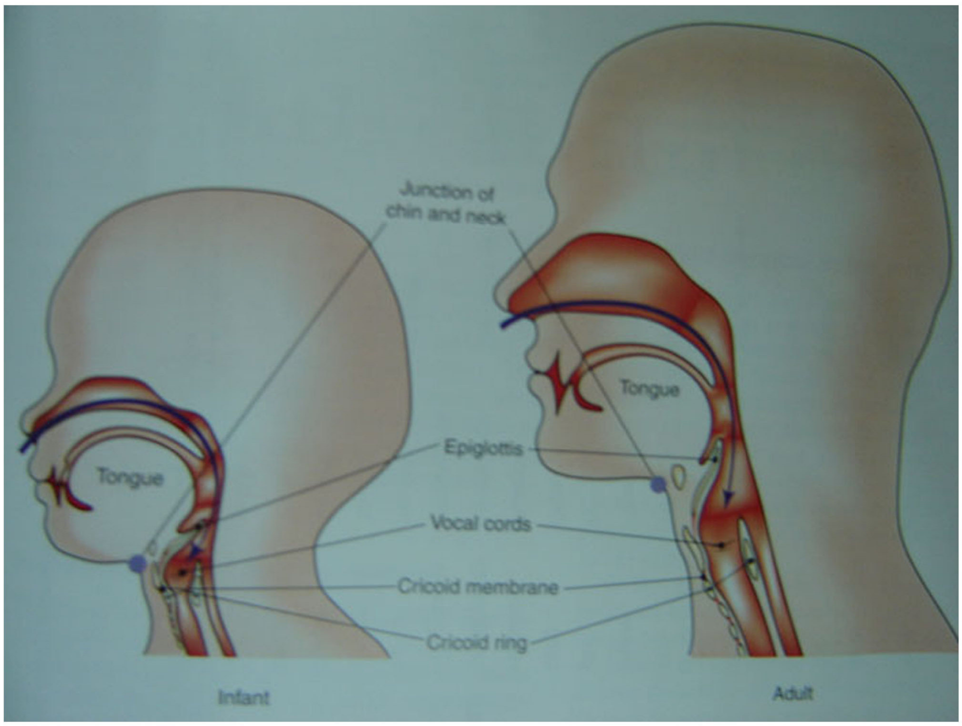
Dimensions

W1 =
W2 =
W3 =
H1 =
H2 =

Thickness of membrane =

Depth of larynx at the level of cricothyroid space =

Note the structures at risk in cricothyroid space =

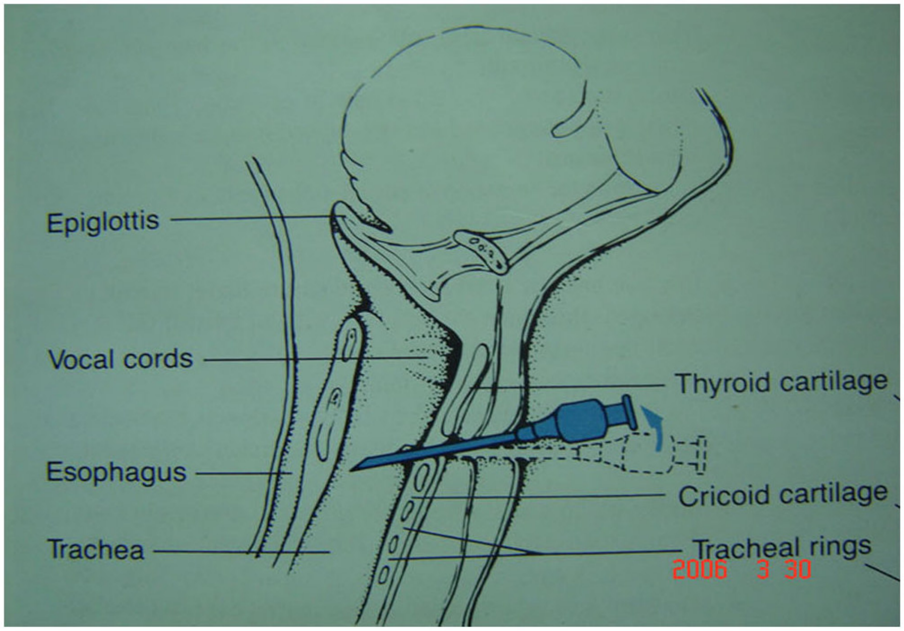


Pic 1 : Shows the Airway of Children & Adults

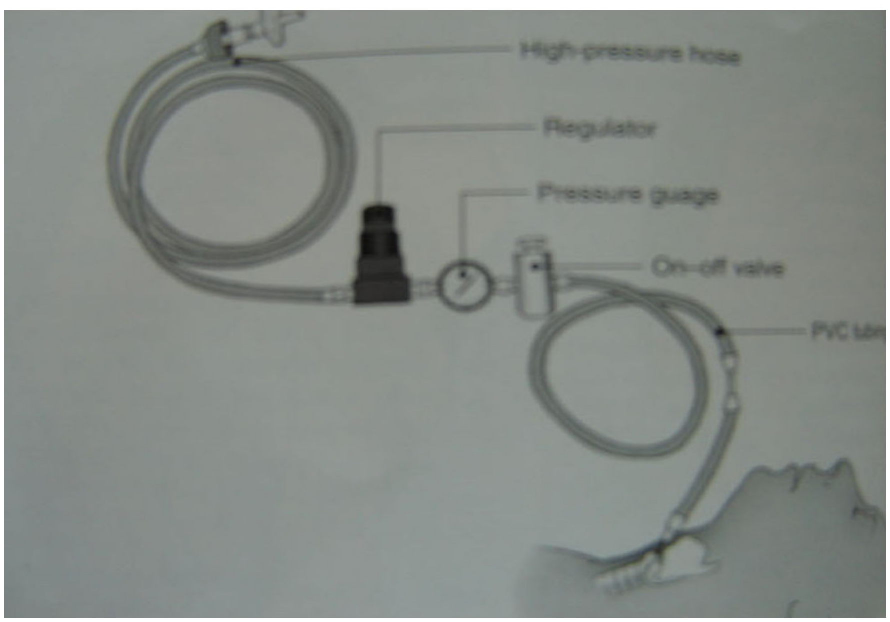
(Entry into the Airway can be made through the nasal apeture , mouth , crico thyroid membrane or trachea)

Pic.2A - Localizing the Cricothyroid Membrane

Pic.2B - Needle Cricothyroidotomy



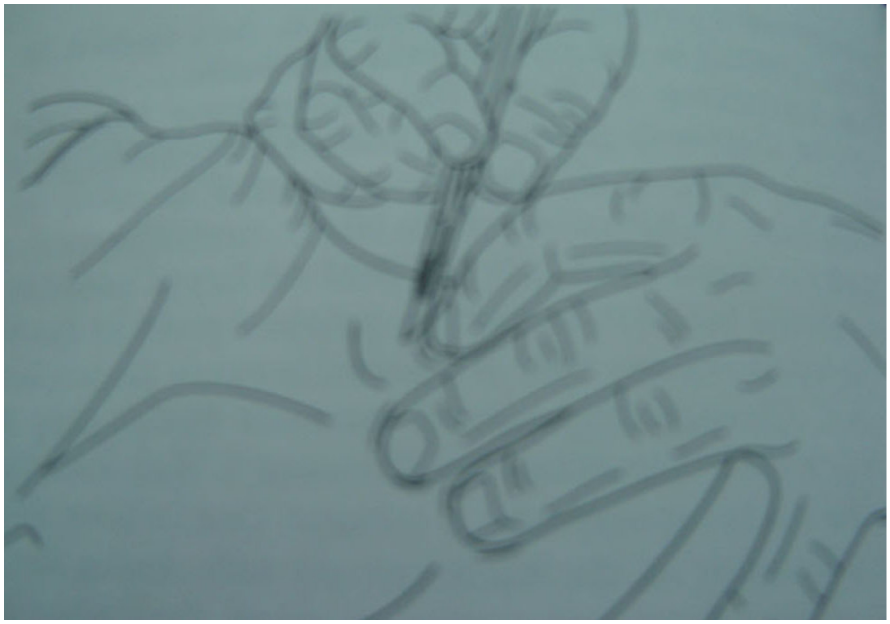
Pic. 2C - Needle in Cricothyroid Space



Pic. 2D - Needle Cricothyroidotomy connected to Ventilator Device

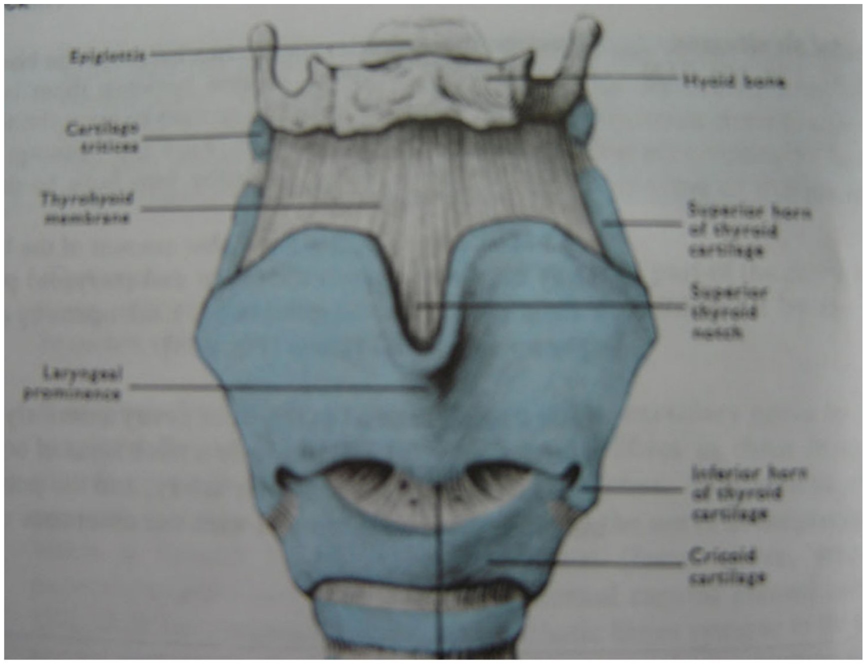
Pic.3A - Localizing the Cricothyroid membrane in neck

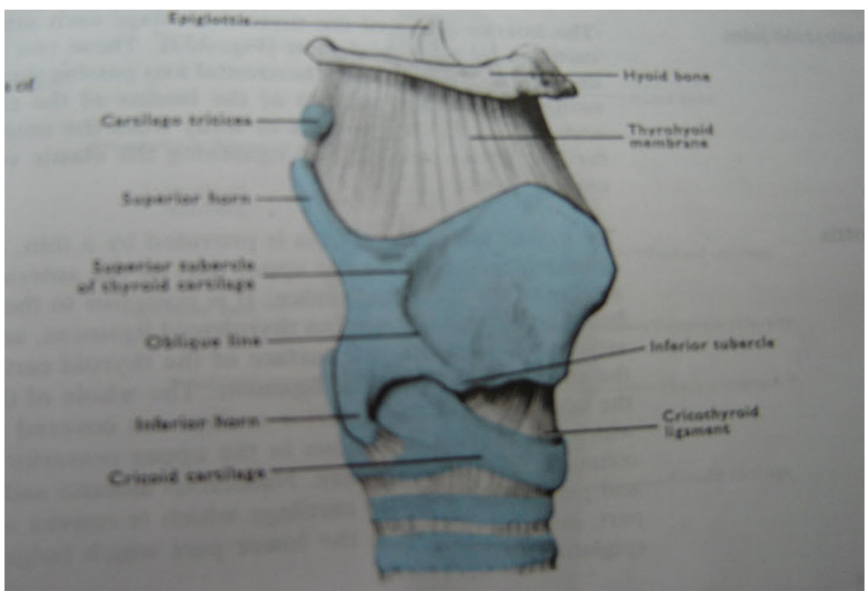
Pic. 3B - Incising the Cricothyroid membrane in Surgical Cricothyroidotomy



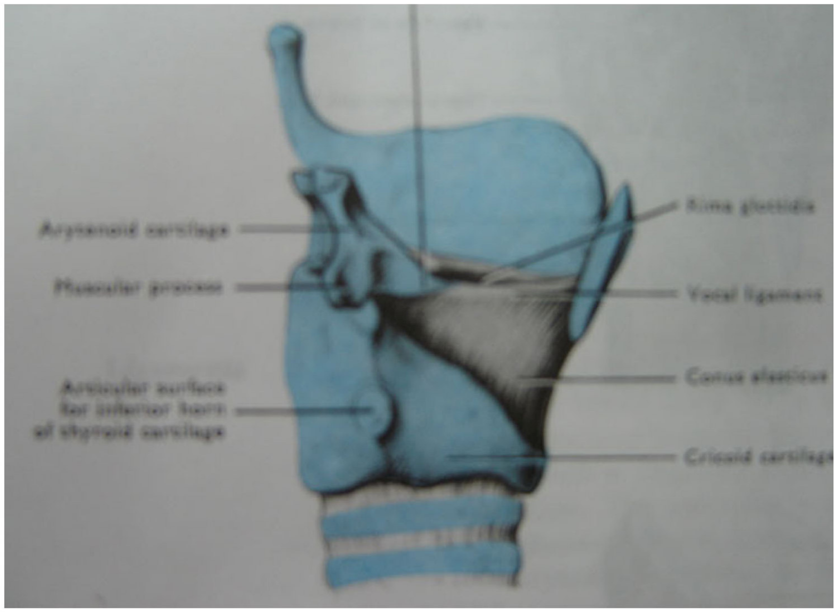
Pic. 3C - Incising the Cricothyroid membrane in Surgical Cricothyroidotomy

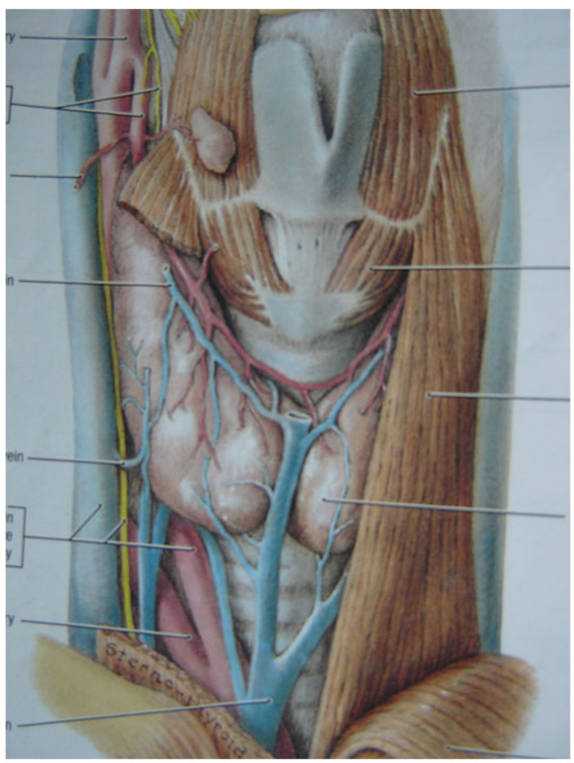
Pic. 3D - Tube being inserted into Cricothyroid space in Surgical Cricothyroidotomy



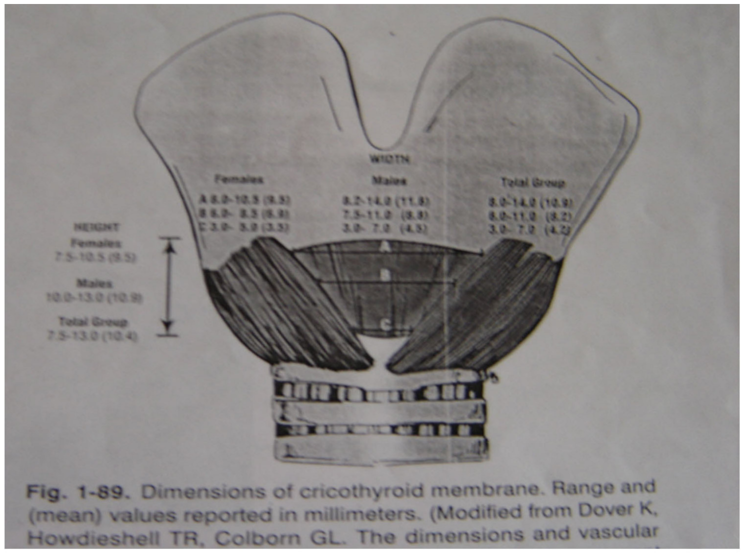


Pic. 4 - Shows Cricothyroid membrane
Anterior and Lateral View





Pic 5 : Shows views of crico thyroid membrane



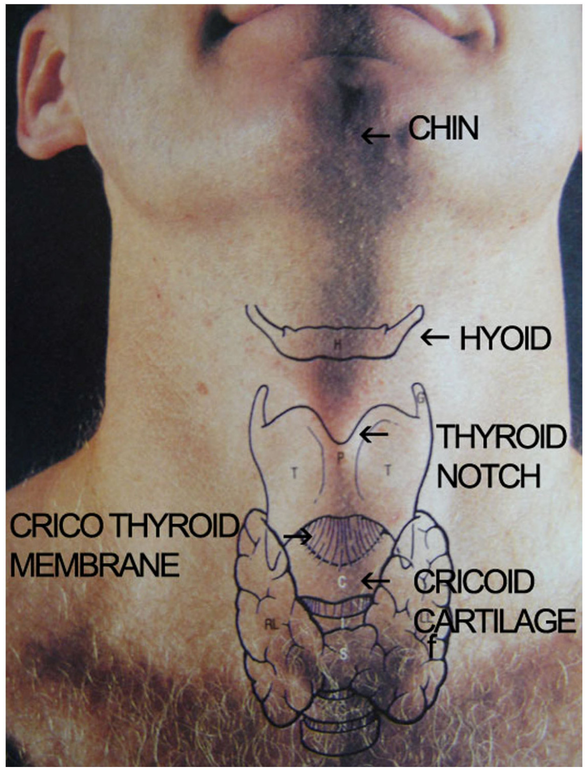
Pic 6 : Shows dimentions of membrane by Dover et al

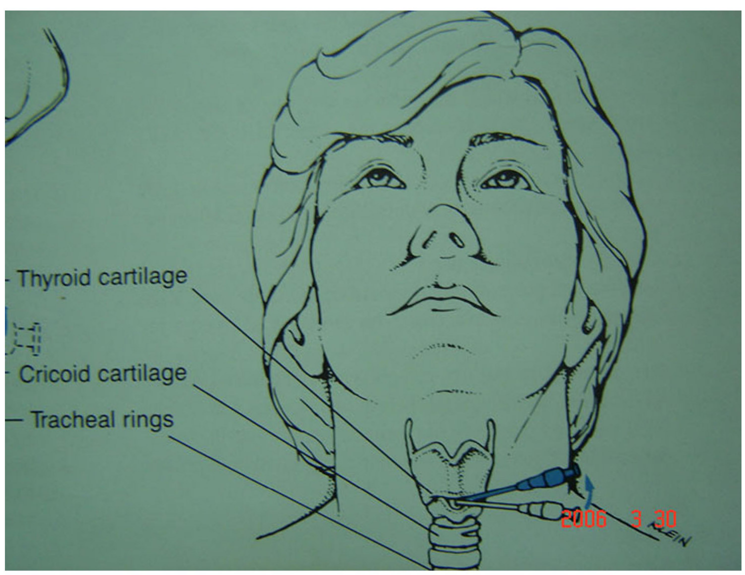
TABLE 1A – shows the transverse widths of the cricothyroid membrane (Dover et al, 1996)

	FEMALES		MALES		IN TOTAL GROUP	
	Range	mean	Range	mean	Range	mean
W1 W2 W3	8.0 – 10.5 6.0 – 8.5 3.0 - 5.0	(9.5) (6.9) (3.5)	8.2 – 14.0 7.5 - 11.0 3.0 - 7.0	(11.6) (8.8) (4.5)	8.0 – 14.0 6.0 – 11.0 3.0 – 7.0	(10.9) (8.2) (4.2)

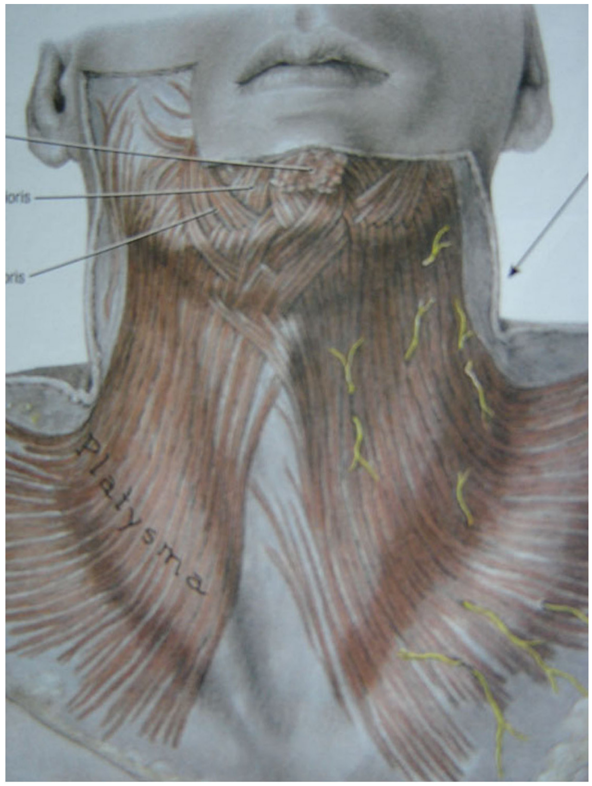
TABLE 1B – shows the range and mean height of the cricothyroid membrane (Dover et al, 1996)

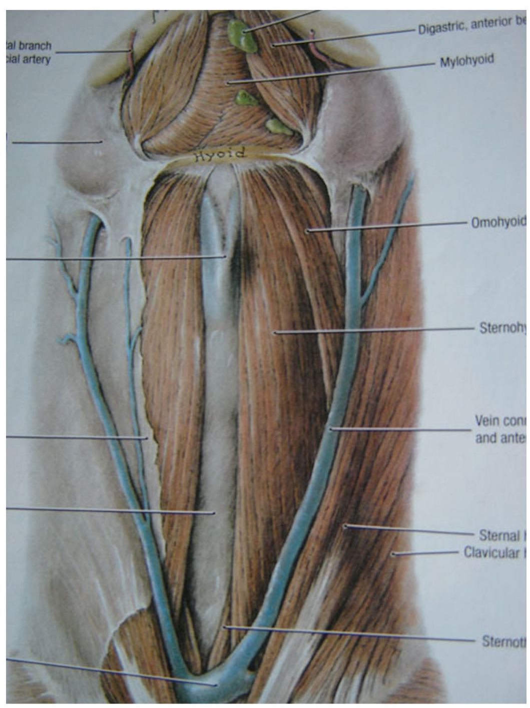
	FEMALES		MALES		TOTAL GROUP	
	Range	Mean	Range	Mean	Range	Mean
HEIGHT	7.5 – 10.5	(9.5)	10.0 – 13.0	(10.9)	7.5 – 13.0	(10.4)



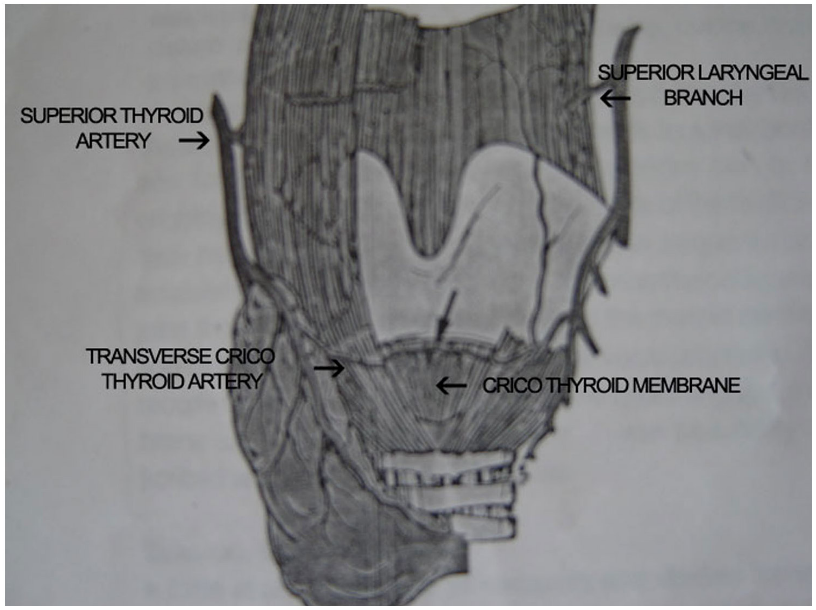


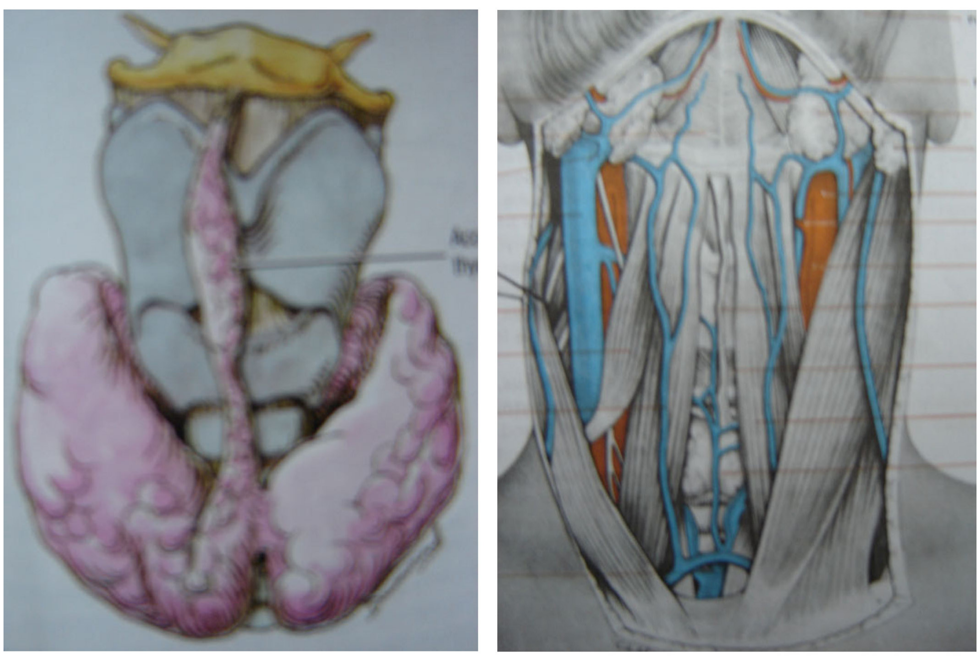
Pic 7 : Shows surface landmarks of anterior neck &
Position of crico thyroid membrane



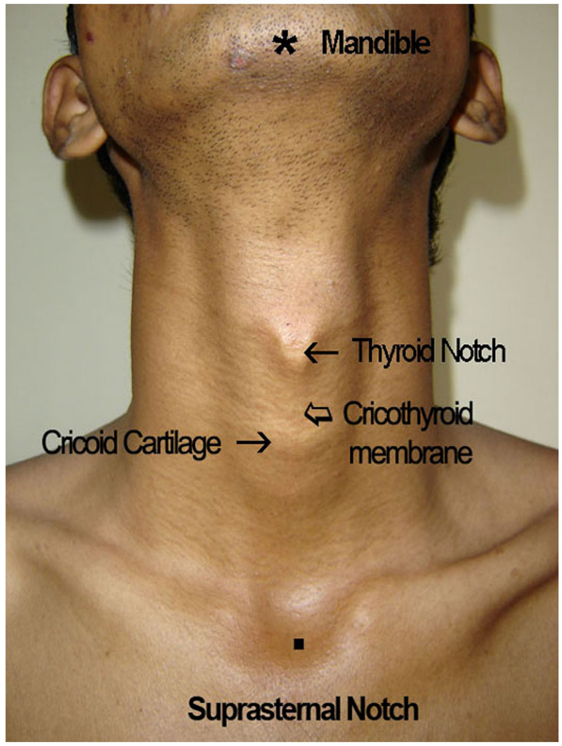


Pic 8 : Structures in front of crico thyroid membrane (Grant's Atlas)

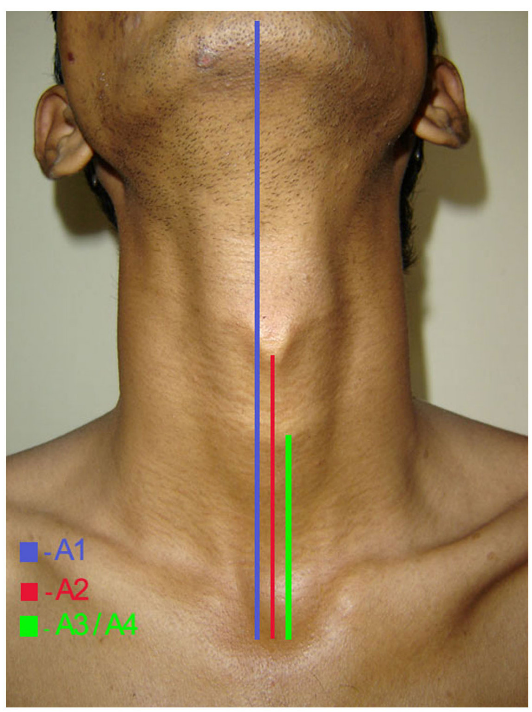




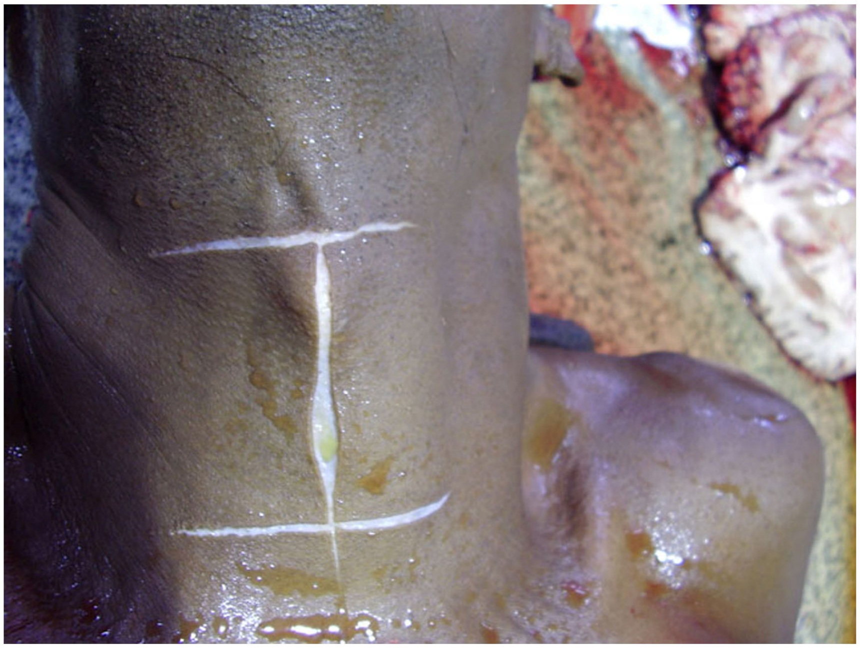
Pic 9 : Structures in front of crico thyroid membrane



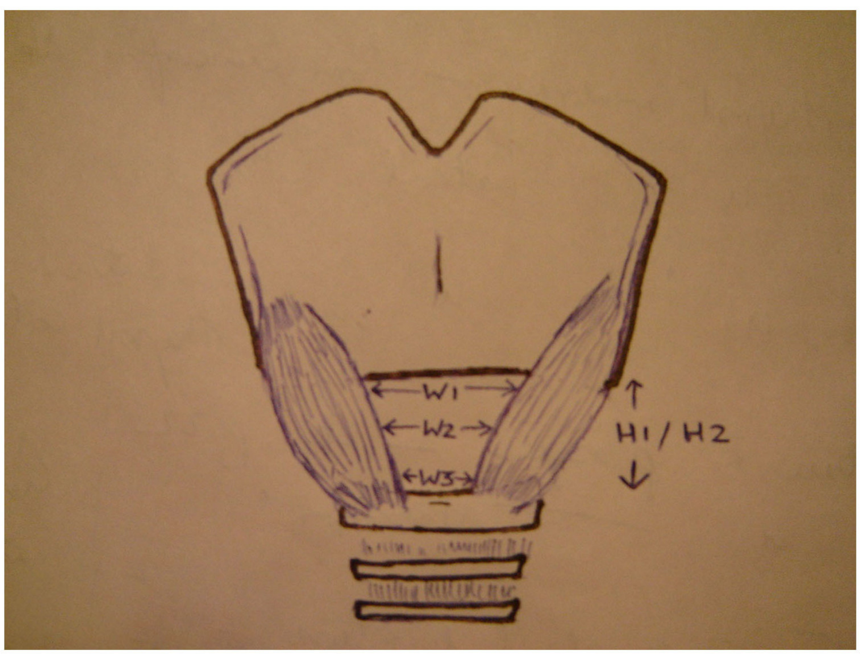
Pic 10 : Shows surface landmarks of neck



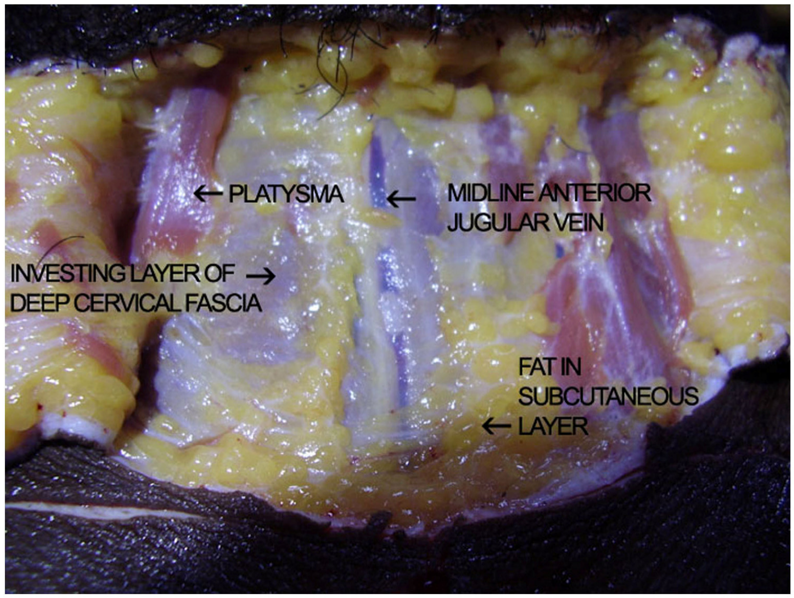
Pic 11 : Shows measurement of anterior neck paramenters

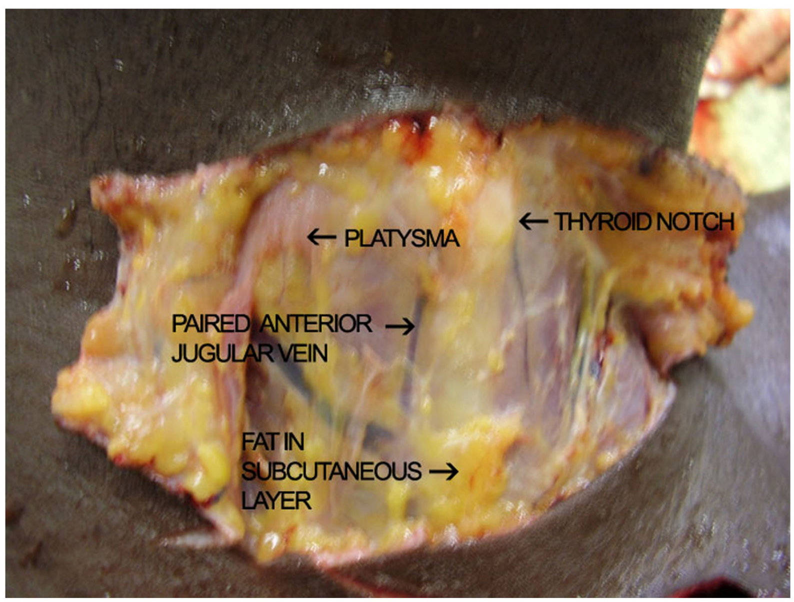


Pic 12 : Shows I shaped skin incision

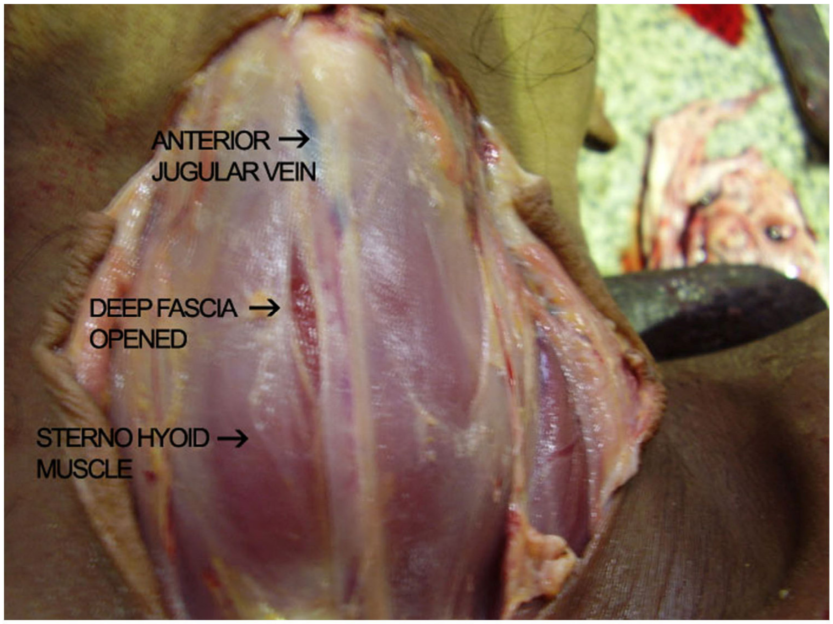


Pic 13 : Dimentions of crico thyroid membrane

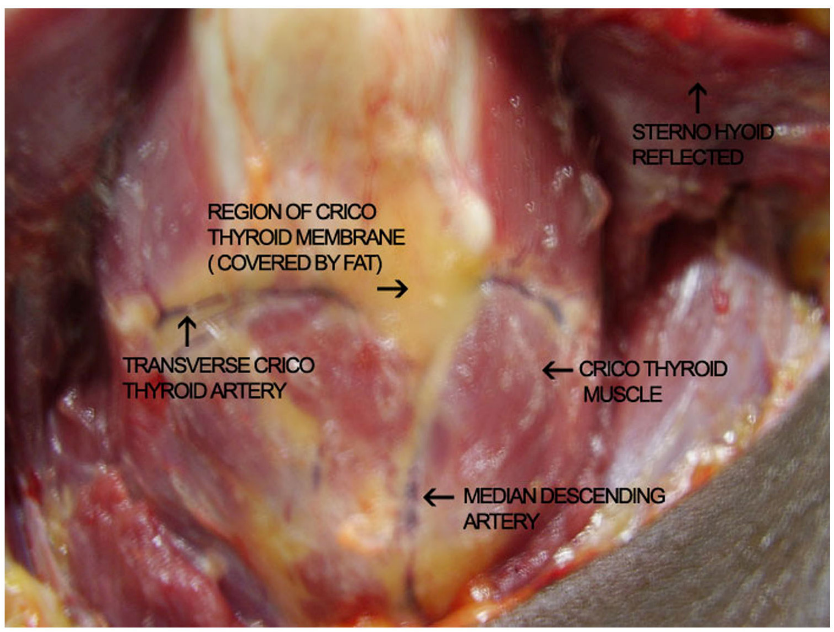




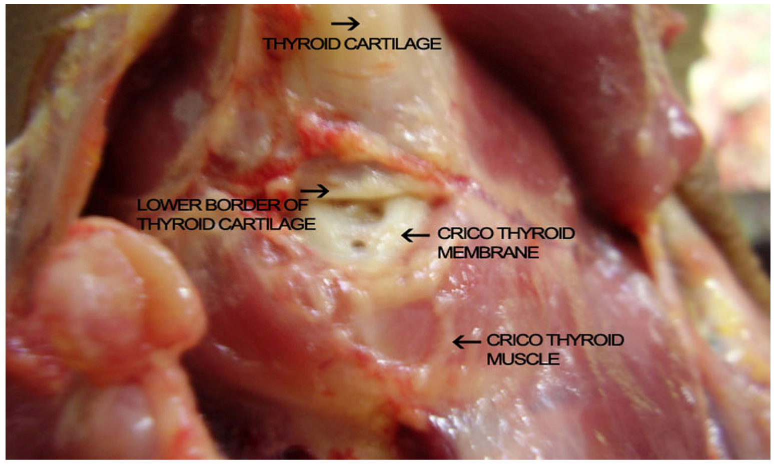
Pic 12 : Shows structures in superficial fascia (taken at dissection)

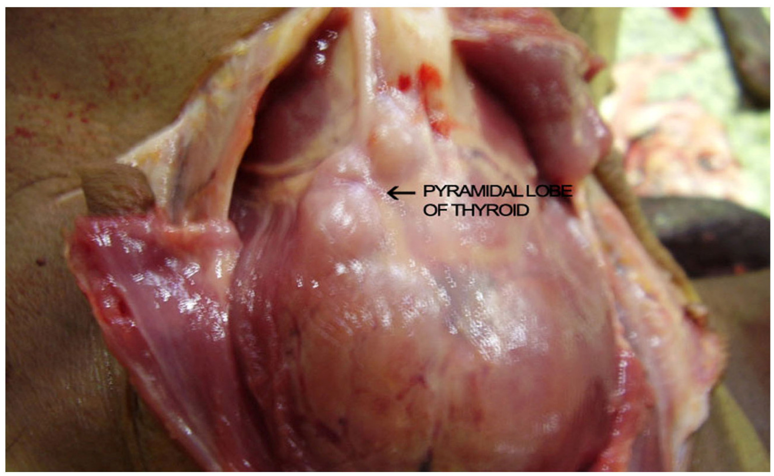


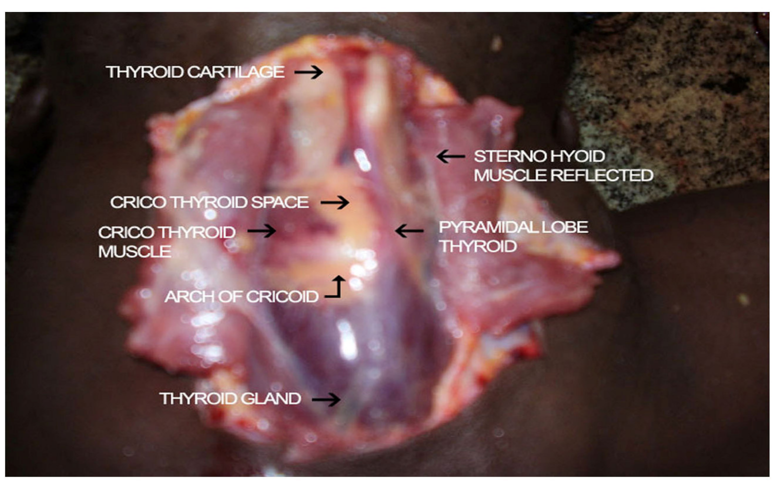
Pic 13 : Shows sterno hyoid strap muscle in the midline



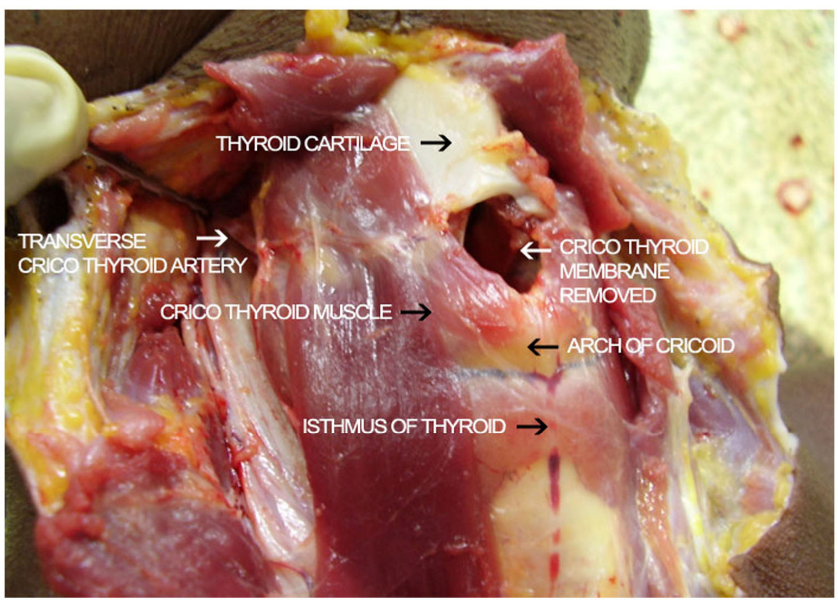
Pic 14 : Shows Transverse crico thyroid artery joining together in the midline



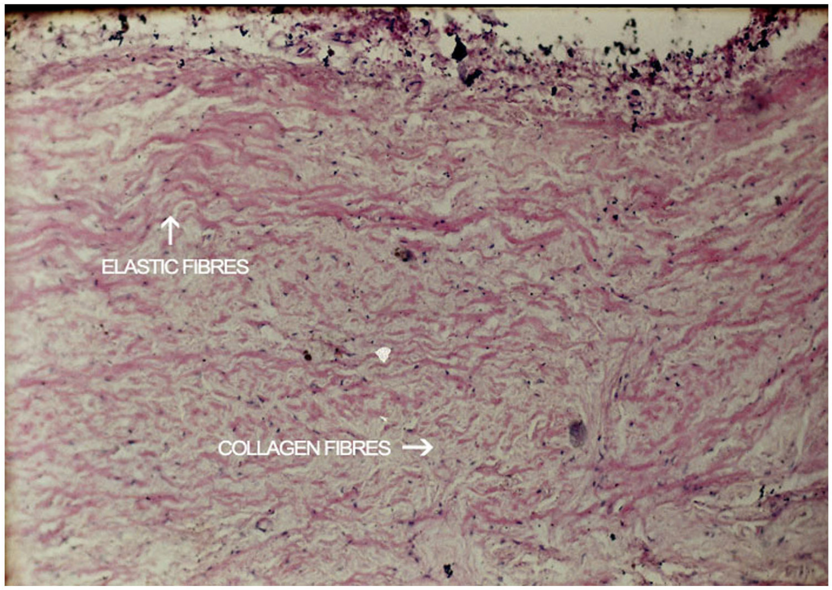


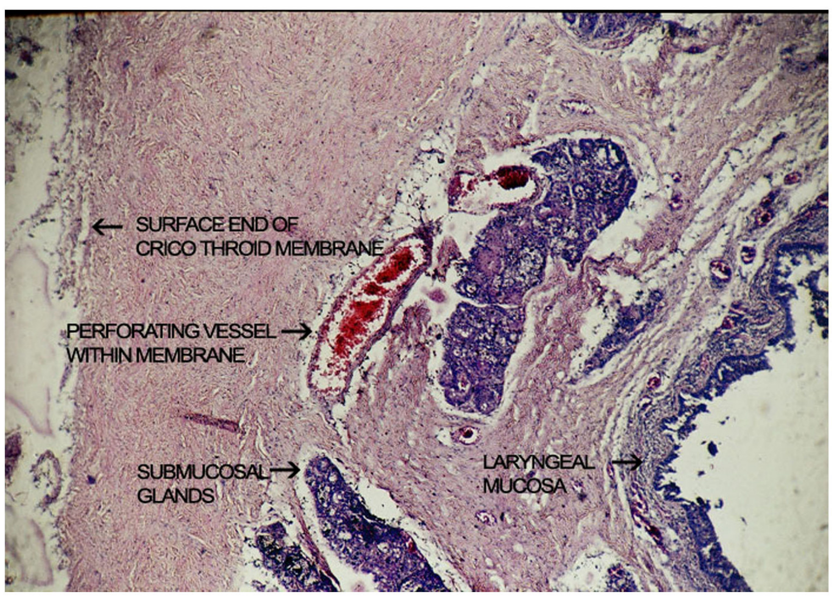


Pic 15 : Shows the crico thyroid membrane
and pyramidal lobe of thyroid gland in front of it

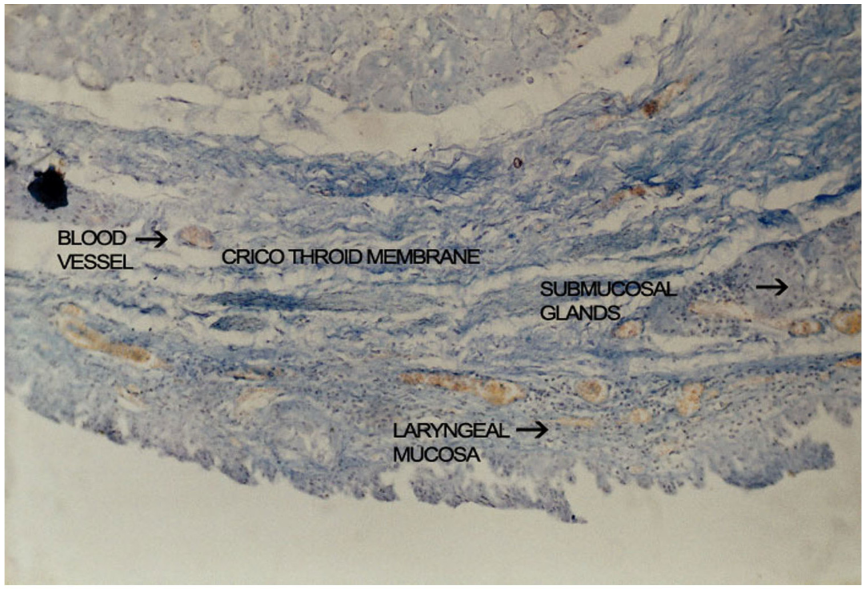


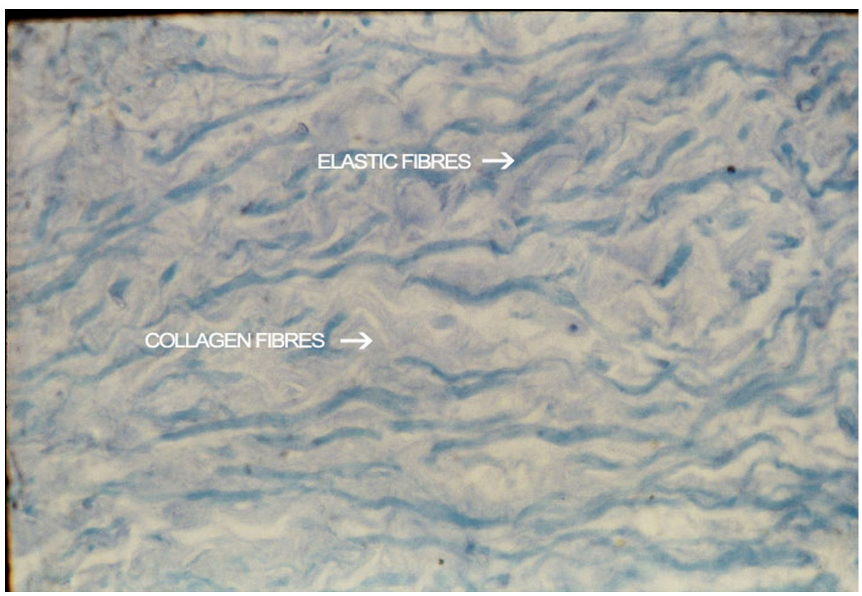
Pic 16 : Shows crico thyroid membrane after removal



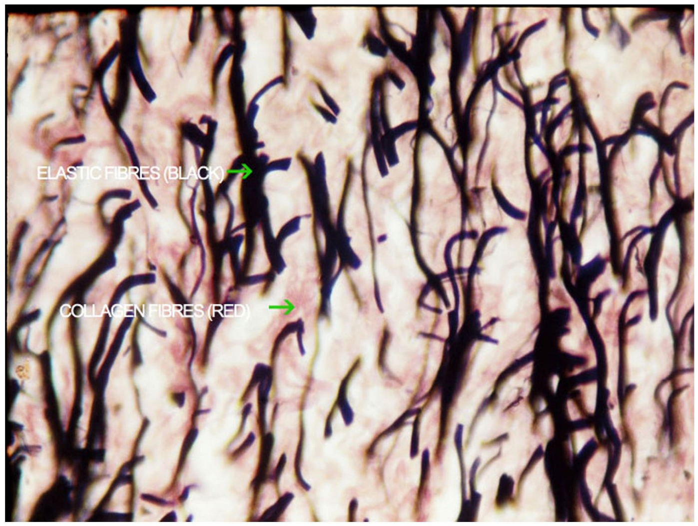


Pic 16 : Haematoxylin & Eosin stain of crico thyroid membrane
at 10X and 4X magnification

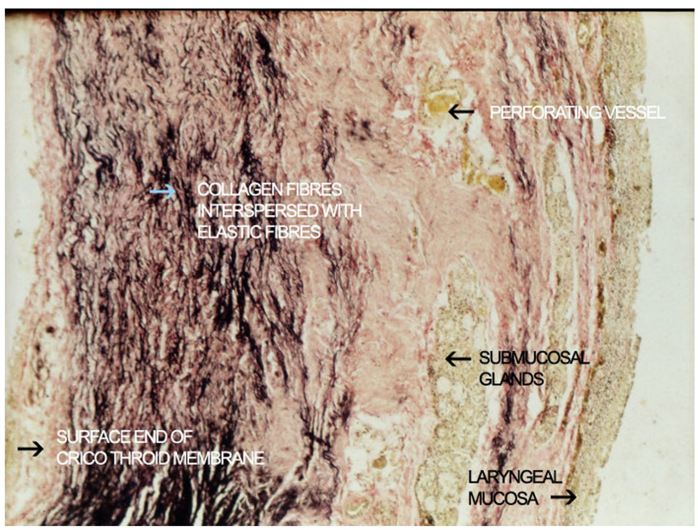




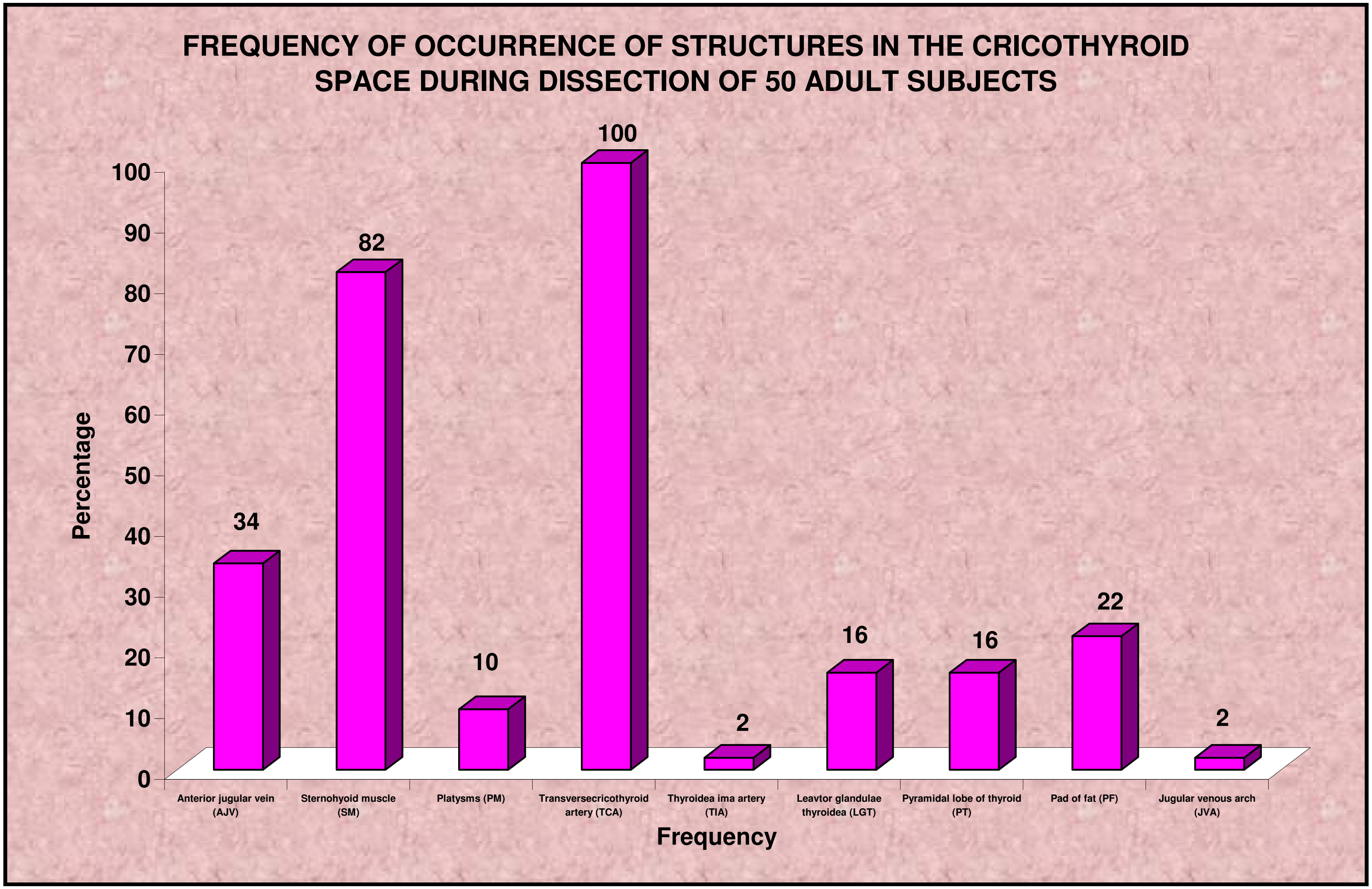
Pic 18 : Trichrome stain at 10X and 40X magnification

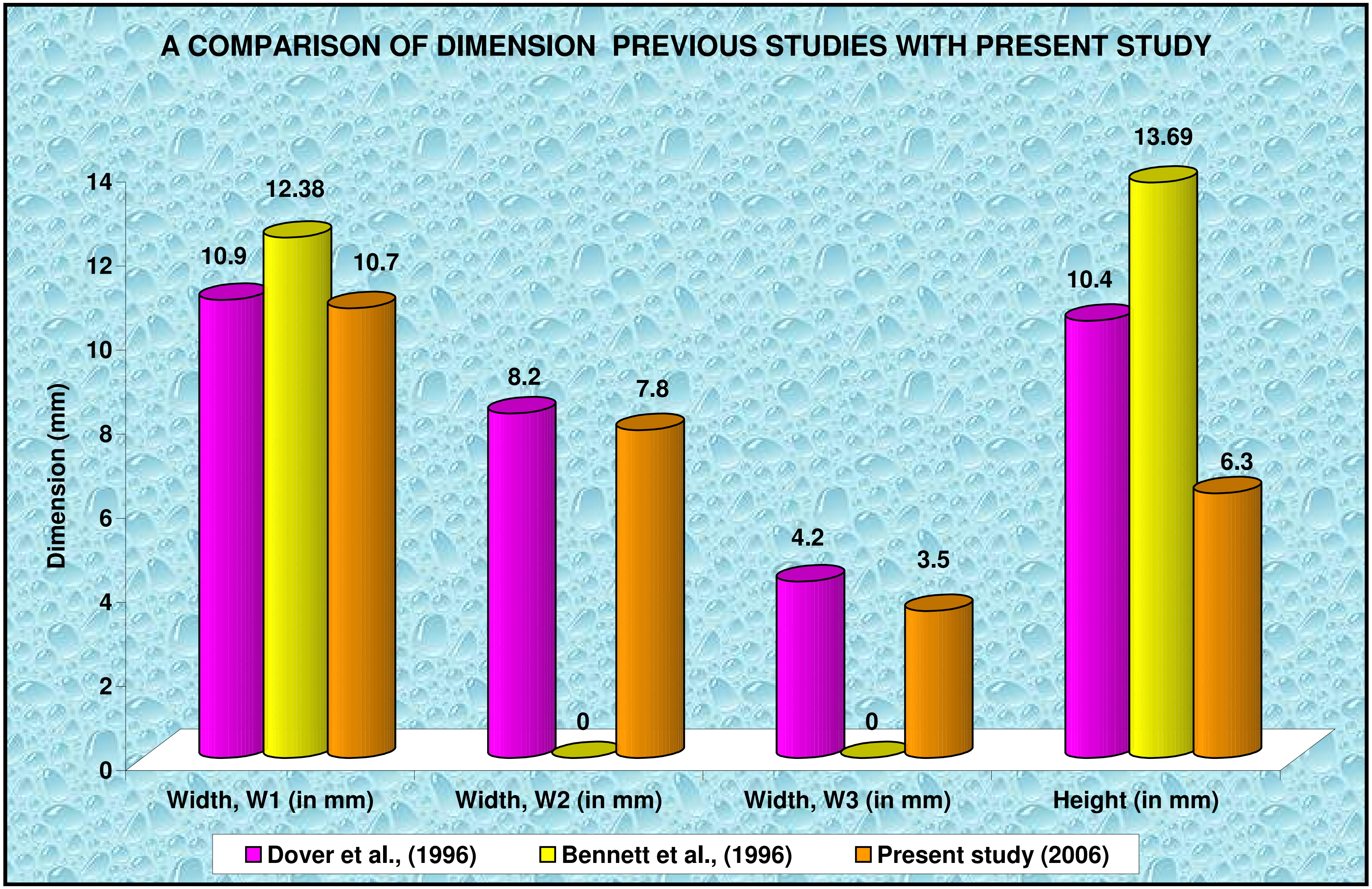


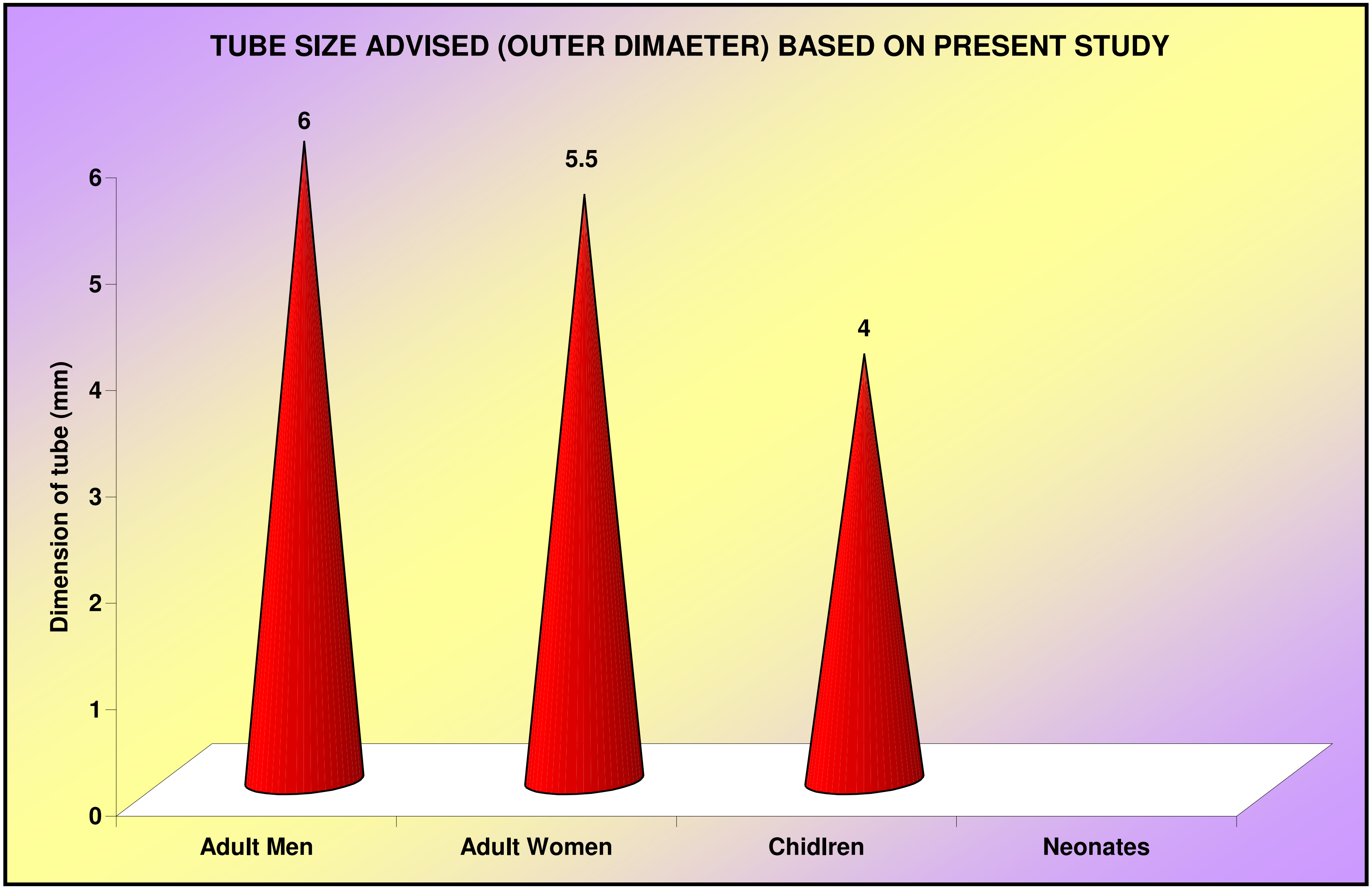
Pic 19 : Voerhoff's special stain crico thyroid membrane at 40X magnification



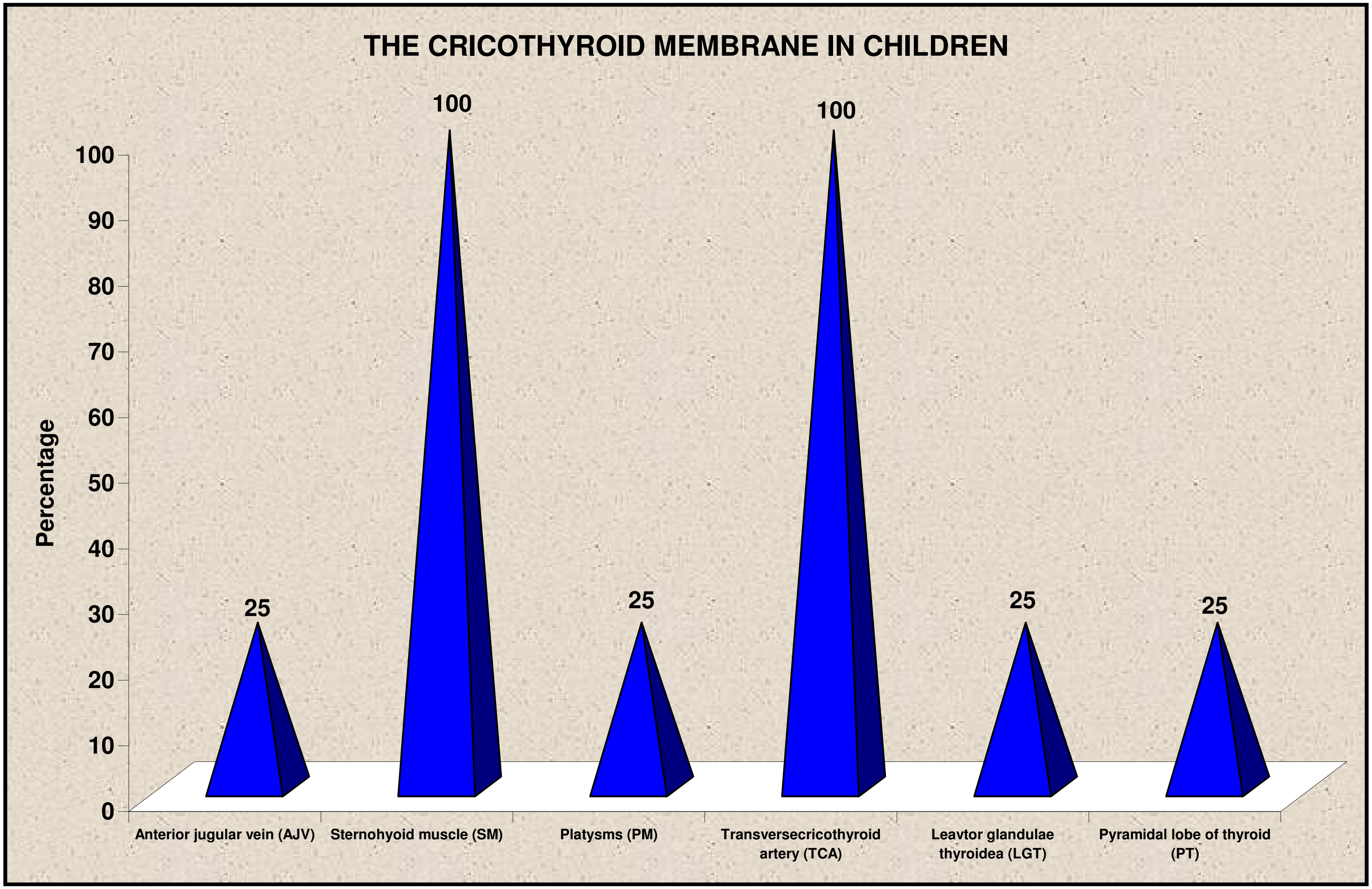
Pic 20 : Voerhoff's special stain crico thyroid membrane at 10X magnification


FREQUENCY OF OCCURRENCE OF STRUCTURES IN THE CRICOTHYROID SPACE DURING DISSECTION OF 50 ADULT SUBJECTS
Percentage
100
90
80
70
60
50
40
30
20
10
0
34
82
10
100
2
16
16
22
2
Anterior jugular vein (AJV)
Sternohyoid muscle (SM)
Platysms (PM)
Transversecricothyroid artery (TCA)
Thyroidea ima artery (TIA)
Leavtor glandulae thyroidea (LGT)
Pyramidal lobe of thyroid (PT)
Pad of fat (PF)
Jugular venous arch (JVA)
Frequency


A COMPARISON OF DIMENSION PREVIOUS STUDIES WITH PRESENT STUDY
Dimension (mm)
0
2
4
6
8
10
12
14
10.9
12.38
10.7
8.2
0
7.8
4.2
0
3.5
10.4
13.69
6.3
Width, W1 (in mm)
Width, W2 (in mm)
Width, W3 (in mm)
Height (in mm)
Dover et al., (1996)
Bennett et al., (1996)
Present study (2006)



TUBE SIZE ADVISED (OUTER DIMAETER) BASED ON PRESENT STUDY
Dimension of tube (mm)
0
1
2
3
4
5
6
6
5.5
4
Adult Men
Adult Women
Chidlren
Neonates


THE CRICOTHYROID MEMBRANE IN CHILDREN
Percentage
0
10
20
30
40
50
60
70
80
90
100
25
100
25
100
25
25
Anterior jugular vein (AJV)
Sternohyoid muscle (SM)
Platysms (PM)
Transversecricothyroid artery (TCA)
Leavtor glandulae thyroidea (LGT)
Pyramidal lobe of thyroid (PT)

Anterior jugular vein (AJV)	34
Sternohyoid muscle (SM)	82
Platysms (PM)	10
Transversecricothyroid artery	100
Thyroidea ima artery (TIA)	2
Leavtor glandulae thyroidea (L	16
Pyramidal lobe of thyroid (PT)	16
Pad of fat (PF)	22
Jugular venous arch (JVA)	2

	Dover et al	Bennett et	Present study (2006)
Width, W1 (in mm)	10.9	12.38	10.7
Width, W2 (in mm)	8.2	0	7.8
Width, W3 (in mm)	4.2	0	3.5
Height (in mm)	10.4	13.69	6.3

Adult Men	6
Adult Women	5.5
Chidlren	4
Neonates	

Anterior jugular vein (AJV)	25
Sternohyoid muscle (SM)	100
Platysms (PM)	25
Transversecricothyroid artery	100
Leavtor glandulae thyroidea (L	25
Pyramidal lobe of thyroid (PT)	25